International Public-Private Strategies in Sustainable Investment and Finance

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International Public-Private Strategies in Sustainable Investment and Finance

Der Fakultät für Wirtschaftswissenschaften der Rheinisch-Westfälischen Technischen
Hochschule Aachen vorgelegte Dissertation zur Erlangung des akademischen Grades einer
Doktorin der Wirtschafts- und Sozialwissenschaften

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Bibliographic Information

This dissertation consists of four articles, presented as Chapters 2 to 5.

Chapter 2:

Schreiner, L.; Madlener, R. (2023) The Impact of Sustainable Innovation Finance on Achieving Global Climate Goals. *FCN Working Paper No. 03/2023*.

Chapter 3:

Schreiner, L.; Beyer, A. (2024) Impacts of ESG Banking Regulation and Supervision on Financing Sustainable Mobility and Energy Technologies. *Forthcoming as ECB Working Paper; FCN Working Paper No. XX/2024*.

Chapter 4:

Schreiner, L.; Beyer, A. (2024) Impacts of ECB Banking Supervision on Climate Risk and Sustainable Finance. *Forthcoming as ECB Working Paper; FCN Working Paper No. XX/2024*.

Chapter 5:

Schreiner, L.; Madlener, R. (2022) New Green Alliances: Requirements to Implement Long-Run Sustainable Energy Partnerships. *FCN Working Paper No. 12/2022*.

UNIVERSITE PARIS I-PANTHEON SORBONNE

IAE Paris-Sorbonne

École Doctorale de Management Panthéon-Sorbonne - ED 559
LAB IAE Paris-Sorbonne - EA 2474

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THESE

présentée et soutenue publiquement le **13 Mai 2024**

en vue de l'obtention du

DOCTORAT EN SCIENCES DE GESTION

par

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JURY

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DOCTORAL THESIS

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April 4, 2024

Acknowledgements

This dissertation has been created in a co-tutelle process under the joint supervision of RWTH Aachen University and Université Paris 1 Panthéon-Sorbonne. Part of my doctorate also included a research exchange to the European Central Bank, during which Chapters 3 and 4 have been developed. Additionally, my work was supported by the Boston Consulting Group and the Konrad Adenauer Stiftung.

My deepest gratitude goes to my doctoral supervisors, Professor Dr. Reinhard Madlener, and Professor Dr. Stéphane Saussier, who have accompanied this work with benevolence and promoted its creation with valuable suggestions. Furthermore, I would like to thank my colleagues at the European Central Bank Andreas Beyer, Ralf Bock, Veerle DeVuyst, Klaus Düllmann, Szabo Kornel, Alexander Popov, and Maria J. Romero Rico for the stimulating discussions.

I am also profoundly grateful to my dear friends and family, who have supported me in various ways and accompanied me through the different stages of my dissertation: Dr. Pablo Antolin, Dr. Biner Bähr, Manuel Cargnel, Dr. Raffaele Dellacroce, Clara Descos, Anna Diews, Eflamm Gueguen, Christina Gudat, Dr. Chris Haarburger, Sandra Hernandez, Marilena Hesse, Jens und Verena Hiegemann, Alex Aung Khant, Dr. Konrad Kollnig, Michel Lachkar, Maria and Clara-Marie Neumann, Dr. Howard Norman, Federico Pasquali, Fabian v. Pfeil, Dr. Nina Pflugfelder, Giesela and Helmut Rischen, Dr. Marten Ritz, Dr. Max Rzepka, Ann-Sophie Saborowski, Amelie Schmidt-Ott, Klaus, Karin, Lucas, Maria and Reinhard Schreiner, Dr. Andreas Schröder, Andrea, Bartho and Frederike Schulte, Dr. Sapna Sinha, Daria Verbeek, Xenia Vogt, and Alfie Walker.

Contents

List of Tables

List of Figures

Résumé en Français

Stratégies Internationales Public-privés des Investissements et des Financements Durables

Liste des Abréviations

BCE	Banque centrale européenne	EUR	Euros
CDN	Contributions déterminées au niveau national	UE	Union européenne
		PIB	Produit intérieur brut
ESG	L'environnement, la société et la gouvernance	SFDR	Règlement de l'UE sur la divulgation d'informations financières durables

Contexte et Problématique Générale

Comment l'interaction des secteurs public et privé à l'échelle mondiale détermine-t-elle la dynamique de l'investissement et de la finance durables à l'échelle internationale ? Le respect de l'objectif de 1,5 °C de l'Accord de Paris, reconfirmé lors de la COP28 de 2023, nécessite la mise en œuvre immédiate d'une économie durable à l'échelle mondiale (UN, 2023a). Cela implique des besoins massifs d'investissements dans des technologies et des infrastructures durables dans tous les secteurs à travers le monde, et cela dans des délais très courts[1]. De nombreuses économies ont fixé des objectifs ambitieux en matière de durabilité dans le cadre de leurs contributions déterminées au niveau national (CDN) et au-delà, comme l'Union européenne (UE) qui s'est engagée à atteindre

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[1] Les estimations du montant exact des investissements supplémentaires nécessaires pour atteindre l'objectif de 1,5 °C couvrent un large éventail de sommes importantes (en Euros, EUR), en fonction des hypothèses sous-jacentes (par exemple, les développements technologiques). Le Groupe d'experts intergouvernemental sur l'évolution du climat, par exemple, estime à environ 2 200 milliards d'euros (tr.) jusqu'en 2035, soit environ 2,5 % du produit intérieur brut (PIB) mondial en 2017 (IPCC, 2019).

la neutralité carbone jusqu'à 2050[2]. Certains pays ont commencé à concrétiser leurs objectifs au moyen de feuilles de route et de plans d'investissement spécifiques, comme le «Plan d'investissement pour une Europe durable» de l'UE, qui est un élément central du «Green Deal européen» (EC, 2020; 2024). Malgré ces efforts, les mesures engagées et leur financement sont jugés insuffisants pour atteindre l'objectif de 1,5 °C, mais devraient conduire à un réchauffement planétaire compris entre 2,5 °C et 2,9 °C, même si toutes les mesures prévues par les CDN sont mises en œuvre (UN, 2023b). Ce déficit entre les niveaux actuels d'investissement dans les technologies et les infrastructures durables et le montant nécessaire pour atteindre les objectifs mondiaux de durabilité (c'est-à-dire l'objectif de 1,5 °C de l'Accord de Paris) est décrit comme le «déficit d'investissement durable»[3] (par exemple, IMF, 2014; APAC/OECD, 2019).

Si les gouvernements veulent honorer pleinement leur engagement à atteindre l'objectif de 1,5°C, il devient impératif de combler le «déficit d'investissement durable» sans pour autant négliger d'autres obligations économiques[4], et c'est là le plus grand défi. Compte tenu des contraintes considérables qui pèsent sur les ménages, la capacité à financer publiquement les investissements

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[2] La CDN de l'Union européenne vise une réduction d'au moins 55 % des émissions de gaz à effet de serre d'ici 2030 par rapport aux niveaux de 1990. L'objectif d'atteindre la neutralité carbone d'ici 2050 va au-delà de l'objectif des CDN et est au cœur du Green Deal européen, défini comme un objectif juridiquement contraignant par la législation européenne sur le climat (EC, 2021).

[3] Tout comme les estimations du montant exact des investissements supplémentaires nécessaires pour atteindre l'objectif de 1,5°C, les estimations du «déficit d'investissement durable» au niveau mondial varient dans leur ampleur. En Allemagne, par exemple, les estimations les plus récentes quantifient les besoins en investissements supplémentaires, nécessaires pour maintenir l'économie nationale allemande sur la voie des 1,5 °C, à au moins 100 milliards d'euros par an, ce qui représente environ 2,5 % du PIB de 2020 et environ 15 % d'investissements bruts supplémentaires par rapport à 2020 (BCG, 2021). Si l'on compare ce montant au financement de 6 milliards d'euros par an (p.a.) actuellement engagé par le gouvernement fédéral allemand dans le cadre des engagements financiers de la COP26/28, on constate qu'il existe un besoin important de financement supplémentaire pour une transition durable conforme aux objectifs de 1,5°C.

[4] D'autres besoins d'investissement, tels que les dépenses sociales (en particulier les aides gouvernementales dans le contexte de la crise COVID-19), les dépenses de défense (par exemple, dans le contexte de la guerre de la Russie contre l'Ukraine) et les investissements généraux dans l'entretien et le renouvellement des infrastructures restent à des niveaux historiquement élevés (Sinn, 2021; BdF, 2023).

durables supplémentaires à l'échelle nécessaire et dans les brefs délais requis est limitée (Sinn, 2021; IMF, 2020; 2021; 2022; 2023). Si la situation est déjà tendue dans les pays les plus riches et les plus développés du monde, souvent appelés le «Nord mondial», elle est encore plus grave dans les pays en développement du «Sud mondial». En effet, les performances économiques étant plus faibles, l'accès aux capitaux est limité et associé à des coûts d'emprunt élevés, tandis que les besoins de développement tels que la réduction de la pauvreté et le développement des infrastructures, qui se disputent les financements disponibles, sont nettement plus importants, ce qui rend difficile l'allocation de ressources significatives à des investissements durables sans soutien international (IMF, 2023). C'est pourquoi le secteur privé est appelé à jouer un rôle important pour combler le «déficit d'investissement durable» (par exemple, UNECE, 2020). Toutefois, compte tenu de la situation économique tendue caractérisée, entre autres, par la hausse des taux d'intérêt à long terme et des coûts d'emprunt, les niveaux élevés d'endettement et d'effet de levier des entreprises ainsi que les pressions sur les liquidités, le potentiel du secteur privé à fournir le financement nécessaire aux besoins d'investissement durable est également limité (IMF, 2021; 2022; 2023). Cela est d'autant plus vrai que les analyses de rentabilité de nombreuses technologies durables doivent encore être élaborées à mesure que l'innovation, la maturation et la diffusion des technologies progressent. Dans ce contexte, certains gouvernements (y compris ceux de l'UE) attribuent un rôle particulier au secteur financier, qui est censé jouer un rôle central dans la fourniture de capitaux à des conditions attrayantes pour financer la transition vers une économie durable sur le plan environnemental, c'est-à-dire pour fournir un financement vert ou, plus spécifiquement, un financement climatique (EC, 2023).

Dans ce contexte, une interaction ciblée entre les secteurs public et privé, ainsi qu'entre les économies développées et en développement, joue un rôle essentiel en contribuant de manière efficace et efficiente à la fourniture de financements pour des investissements durables et, par conséquent, en réduisant le «fossé de l'investissement durable». Cette interaction peut inclure l'introduction d'instruments de politique économique incitant le secteur privé - depuis les entreprises qui installent et produisent du capital à faible teneur en carbone jusqu'aux institutions financières qui investissent dans des entreprises à faible teneur en carbone et leur accordent des prêts - ainsi qu'une coopération renforcée entre les mécanismes financiers publics et privés. Ces éléments soulignent le rôle essentiel de la combinaison des financements pour mobiliser les investissements privés en faveur des objectifs de développement durable (Feyen, 2020; Campiglio et van der Ploeg, 2021). En outre, les complexités des systèmes financiers mondiaux et le besoin urgent de stratégies mondiales d'atténuation et d'adaptation au climat soulignent le besoin indispensable de coopération internationale (par exemple, Nordhaus, 2015). La collaboration internationale vise non seulement à mettre en commun les ressources, mais aussi à partager les connaissances, les technologies et les instruments financiers novateurs pour relever les défis multiformes de la durabilité dans diverses économies.

Contribution et Structure de cette Thèse

Dans le contexte décrit ci-dessus, cette thèse contribue de manière significative à la compréhension du rôle de la coopération internationale public-privé dans l'investissement et le financement durables. En particulier, elle réunit les évaluations macroéconomiques et les évaluations technico-économiques, qui sont souvent utilisées séparément. Cette thèse explore quatre thèmes principaux. Ces thèmes sont présentés dans les chapitres 2, «Impacts du Financement Durable International Public-privé sur la Réalisation des Objectifs Climatiques Mondiaux grâce à l'Innovation et à la Diffusion des Technologies», chapitre 3, «Impacts de la Réglementation et de la Supervision Bancaires ESG sur le Financement des Nouvelles Technologies Durables», chapitre 4, «Impacts de la Supervision Bancaire de la BCE sur le Financement durable et le Risque Climatique» et chapitre 5 «Les Nouvelles Alliances Vertes : Exigences pour la mise en œuvre de Partenariats Internationaux à Long Terme dans le Domaine de l'Energie Durable». Une vue d'ensemble du sujet, y compris le contexte, le champ d'application, la méthodologie et les principales conclusions, est fournie dans ce qui suit.

Impacts du Financement International Durable Public-privé sur la Réalisation des Objectifs Climatiques Mondiaux grâce à l'Innovation et à la Diffusion des Technologies

Le deuxième chapitre conceptualise l'impact de la fourniture (insuffisante) de capital financier - c'est-à-dire la prévalence du "déficit d'investissement durable" - sur l'investissement et la croissance durables au niveau mondial. Ainsi, il (a) démontre l'importance de l'investissement et de la finance durables dans la réalisation des objectifs mondiaux de durabilité au niveau macro, et (b) fournit un cadre général conceptualisant le paysage de l'investissement et de la finance durables, y compris les approches de la politique et de la réglementation en matière de durabilité.

Il propose donc un modèle de croissance macroéconomique du changement technique dirigé avec une décision de financement endogène intégrée. Des modèles de changement technique dirigé ont été mis en place pour évaluer l'adoption de technologies durables par rapport à des technologies non durables au niveau macroéconomique. Ils incluent donc une décision endogène d'innovation durable ou non durable, qui dépend de la taille du marché et des effets de prix (c'est-à-dire des effets de verrouillage) (voir section 2.2.1, par exemple Acemoglu et al., 2012). Cependant, deux dynamiques ne sont pas prises en compte dans les modèles existants, que nous ajoutons à l'approche existante : premièrement, alors que la décision endogène d'innovation durable ou non durable est prise en compte, le processus global de diffusion de la technologie n'est pas modélisé. Ce processus est essentiel en raison du rôle primordial des processus de diffusion technologique (voir section 1.3.3 : 70% à 80% de la transition vers la durabilité peut être réalisée sur la base des technologies existantes, mais leur mise à l'échelle et la maturation associée des technologies sont essentielles) ainsi qu'en raison de la grande pertinence d'une adoption globale des technologies durables (voir section 1.3.4) à la fois dans le «Nord mondial» développé et dans le «Sud mondial» en voie de développement. Par conséquent, sur la base de la dynamique proposée par Barro et Sala-i-Martin

(1997), des processus endogènes de diffusion des technologies entre le "Nord mondial" et le "Sud mondial" sont ajoutés. Deuxièmement, dans les modèles existants, l'investissement et le financement des technologies durables ne sont pas pris en compte. Cependant, les deux jouent un rôle essentiel dans le succès de la transition vers la durabilité au niveau mondial, ce qui a été démontré dans de nombreuses contributions empiriques (voir section 1.3). Afin de conceptualiser et de démontrer cette pertinence dans le contexte macroéconomique, une décision endogène d'investissement et de financement par des financiers publics et privés est ajoutée au modèle. En outre, le modèle est ensuite utilisé pour évaluer les instruments politiques et réglementaires durables qui s'adressent directement aux investisseurs et aux financiers : l'investissement et le financement publics durables ainsi que la réglementation du secteur financier privé. Cela n'est pas possible dans les modèles existants qui ne reflètent pas la décision d'investissement et de financement, où seuls les instruments politiques tels que la tarification du carbone peuvent être pris en compte. Le modèle proposé comprend donc un secteur financier public et privé, ce qui permet une décision de financement endogène en termes de financement interne et externe du changement technique par le biais de différents instruments financiers[5]. Saisissant la dynamique entre le «Nord mondial», c'est-à-dire les économies développées, et le «Sud mondial», c'est-à-dire les économies en développement, il permet au développement technologique de se produire par l'innovation ou l'imitation et, par conséquent, de saisir les processus de diffusion de la technologie dans l'économie mondiale.

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[5] La réduction des gaz à effet de serre nécessite des mesures climatiques dans différents secteurs, y compris des technologies de différentes maturités, dont la majeure partie se trouve à des stades de maturité précoces, par exemple en recherche et développement, en phase pré-commerciale ou en phase d'adaptation précoce, ce qui les affecte à différentes catégories d'actifs. Par exemple, les technologies aux premiers stades de maturité sont souvent financées par des classes d'actifs alternatives telles que le capital-risque, tandis que les investissements dans les technologies plus matures sont principalement réalisés au moyen de fonds propres privés et publics ou de la dette. Dans le contexte des investissements durables, des instruments de financement innovants tels que les obligations vertes sont apparus, voir, par exemple, OECD (2015), Polzin et Sanders (2020), Polzin et al. (2021).

Les conclusions de ce chapitre montrent que la présence de coûts de financement et de frictions sur les marchés financiers - qui sont élevés en ce qui concerne l'innovation durable et dans le monde en développement - fait converger l'économie mondiale vers une trajectoire de croissance non durable en l'absence d'intervention politique. Ainsi, négliger l'évaluation de l'impact de l'investissement et de la finance durables pourrait conduire à une perception trop optimiste des circonstances dans lesquelles la croissance durable mondiale est atteinte. En outre, contrairement aux modèles existants, le modèle proposé permet d'évaluer les instruments politiques et réglementaires ciblés en matière d'investissement et de financement durables. Il démontre ainsi qu'un prix du carbone suffisamment élevé - comme le proposent les modèles existants - peut conduire à des réductions des émissions de carbone. Toutefois, compte tenu du besoin supplémentaire d'incitation réglementaire et politique résultant des coûts et des frictions de financement, ce prix du carbone devrait être irréellement élevé et couvrir une part importante des émissions mondiales. Il est donc essentiel de disposer d'instruments politiques et réglementaires ciblés portant directement sur l'investissement et le financement durables. Pour orienter l'économie vers une croissance pleinement durable, il faut à la fois des investissements et des financements publics durables et une réglementation ou une incitation supplémentaire pour les investisseurs financiers privés.

Les aspects des deux approches ciblées sont évalués plus en détail dans les chapitres 3 et 4 (réglementation ou incitation des investisseurs financiers privés) ainsi que dans le chapitre 5 (investissement et financement publics durables).

Impacts de la Réglementation et de la Supervision Bancaires ESG sur le Financement de la Mobilité Durable et des Technologies Energétiques

En raison du rôle central de la réglementation du secteur financier identifié dans le deuxième chapitre, une plongée en profondeur dans l'évaluation de l'efficacité de la réglementation et de la supervision durables du secteur financier est proposée dans les chapitres 3 et 4.

Dans le troisième chapitre, une étude empirique de l'efficacité de la réglementation financière durable est présentée, évaluant la question de savoir comment la réglementation et la supervision des banques liées à l'environnement, au social et à la gouvernance affectent l'apport de capitaux pour la transition vers la durabilité. Dans le contexte d'objectifs politiques ambitieux en matière de durabilité confrontés à des défis de financement, le secteur financier se voit attribuer un rôle clé pour canaliser davantage de capitaux du secteur privé vers des investissements durables. Toutefois, un compromis apparaît si l'expansion des technologies durables nécessite (en partie) des investissements dans des actifs non-durables, par exemple dans la production d'éoliennes, de panneaux solaires et dans la transition vers la mobilité. En ce qui concerne cette dernière, le passage à des véhicules électriques à batterie nécessite une expansion considérable de l'offre de matières premières pour les batteries, telles que le lithium, le cobalt, le manganèse et le nickel. L'extraction de ces matières a souvent de graves répercussions négatives sur l'environnement, la société et la gouvernance (ESG), telles que les risques pour la santé des mineurs et le travail des enfants, la corruption et le financement de conflits, ainsi que les risques pour la protection des écosystèmes terrestres, notamment la consommation importante d'énergie et d'eau. Une analyse de ce compromis est fournie, répondant à la question de savoir comment la réglementation ESG et la supervision des banques ont un impact sur l'apport de capitaux aux sociétés minières de matières premières en batterie. Concrètement, l'impact du règlement de l'UE sur la divulgation d'informations financières durables (SFDR) et de la taxonomie de l'UE pour les activités durables («la Taxonomie») sur la structure des participations publiques des banques et le coût du capital est évalué, ainsi que l'introduction des efforts de supervision liés au risque climatique de la Banque centrale européenne sur les prêts des banques. Une approche de différence en différence basée sur deux grands ensembles de données inédits est donc présentée. On constate que l'introduction des réglementations ESG a un effet modérateur sur les avoirs des banques concernées dans les sociétés minières de matières premières en batterie, en particulier celles dont les performances ESG sont médiocres.

Dans le même temps, il n'y a pas de changements observables dans les prix des actions des sociétés affectées, ce qui indique une compensation par une demande accrue d'actions de la part d'autres entités. Cet effet implique que le niveau global des participations publiques reste stable, ce qui suggère que, toutes choses égales par ailleurs, le coût du capital ne subit aucun changement. Cet effet implique que le niveau global des participations publiques reste stable, ce qui suggère que, toutes choses égales par ailleurs, le coût du capital ne subit aucun changement. Ces résultats ont plusieurs implications. Tout d'abord, l'observation que les banques, qui sont affectées par la SFDR et la Taxonomie, diminuent leurs participations publiques dans les entreprises de matières premières en batterie, et en particulier dans celles qui n'ont pas de bonnes performances dans les dimensions ESG, implique que les réglementations conduisent aux effets escomptés. Le fait que, dans la configuration actuelle, il n'y ait pas d'augmentation coïncidente du prix des actions des entreprises et, par conséquent, du coût du capital, implique que les réglementations ESG n'aggravent pas actuellement le sous-investissement dans l'approvisionnement en matières premières pour batteries. Toutefois, cela pourrait changer si des réglementations comparables sont introduites de manière plus complète au niveau mondial. En outre, si les banques de l'UE réduisent leurs participations publiques dans des entreprises moins respectueuses des critères ESG, l'effet de levier de l'UE pour inciter les entreprises à améliorer leurs performances ESG diminue. En ce qui concerne l'impact des efforts de supervision de la BCE liés au risque climatique, les analyses révèlent qu'il n'y a pas d'effets significatifs sur les modèles de prêt des banques affectées vers les entreprises impliquées dans l'approvisionnement en matières premières pour les batteries. Ainsi, le deuxième sujet offre une vision nuancée de l'interaction entre les réglementations bancaires ESG et la supervision, les décisions d'allocation de capital et le financement des technologies durables. Il souligne l'efficacité des réglementations ESG pour influencer les stratégies d'allocation de capital des banques vers des pratiques plus durables, tout en soulignant les limites et les conséquences involontaires de ces politiques. L'importance d'une approche réglementaire équilibrée, compte tenu de la nature multidimensionnelle de la finance durable, est soulignée.

Impacts de la Supervision Bancaire de la BCE sur le Risque Climatique et la Finance Durable

En chapitre 4, une analyse empirique de l'impact des efforts de supervision de la BCE liés au risque climatique (i) sur les choix de portefeuille des banques induits en ce qui concerne la finance durable (ii) et sur l'exposition au risque climatique et la gestion des banques. Ces dernières années, le changement climatique et le risque climatique sont devenus deux des principales préoccupations des décideurs politiques des banques centrales et de la supervision bancaire. Cela s'explique notamment par le double rôle que joue le secteur financier en ce qui concerne les risques climatiques et la «transition verte». D'une part, comme indiqué ci-dessus, le secteur financier s'est vu attribuer un rôle clé dans le financement de la transition vers des économies neutres sur le plan climatique, mais d'autre part, les expositions aux risques climatiques représentent un défi croissant pour la stabilité du secteur financier. Dans ce contexte, à partir de 2020, la BCE a introduit diverses mesures pour renforcer les efforts de surveillance liés aux risques climatiques. La première de ces mesures a été le guide 2020 de la BCE sur les risques liés au climat et à l'environnement, qui a servi de base à un contrôle prudentiel ultérieur de la gestion des risques climatiques par les banques. Exploitant le fait que la supervision climatique de la BCE n'a été introduite que pour certaines banques (c'est-à-dire les institutions importantes) au sein de l'UE dans le cadre du mécanisme de surveillance unique, tandis que d'autres banques (c'est-à-dire les institutions moins importantes) n'ont pas été affectées, une configuration de différence dans la différence est présentée sur la base d'un nouvel ensemble de données approfondies fusionnées à partir de Refinitiv Eikon, Capital IQ, Bloomberg, et des données Corep de la BCE. On constate un impact significatif à la fois sur l'augmentation des activités de financement vert des banques et sur l'amélioration de l'exposition au risque climatique et de sa gestion. Toutefois, la disponibilité des données environnementales doit être considérablement améliorée pour mieux comprendre et estimer les effets. Des efforts réglementaires et politiques supplémentaires seront nécessaires pour améliorer l'évaluation de l'exposition des banques au risque climatique et de leur gestion, ainsi que la contribution des banques au financement d'une transition verte.

Nouvelles Alliances Vertes : Exigences pour la mise en œuvre de Partenariats Internationaux à Long Terme dans le Domaine de l'Energie Durable

Le chapitre 5 est consacré aux investissements durables dans le secteur de l'énergie. C'est dans le secteur de l'énergie que les implications de la transition vers la durabilité sont les plus importantes. La production de combustibles fossiles, qui représente environ 35 à 45 % des émissions mondiales de gaz à effet de serre, fait du secteur de l'énergie le principal émetteur de carbone (AIE, 2021). Cela implique également les plus grands besoins d'investissement et de financement durables dans les nouvelles installations de production, de transmission, de distribution et de stockage au cours des prochaines années et décennies.

Comme décrit dans la section 1.3.4.2, les nouveaux partenariats internationaux en matière d'énergie durable basés sur les sources d'énergie renouvelables constituent une approche prometteuse pour réaliser des investissements durables dans le secteur de l'énergie afin de maintenir la sécurité de l'approvisionnement et d'atteindre les objectifs en matière de climat et de développement dans des conditions économiques améliorées. Toutefois, la mise en œuvre réussie de ces partenariats n'est pas triviale, étant donné que les analyses de rentabilité doivent encore être développées et que de nombreux gouvernements et acteurs privés aux intérêts divergents sont impliqués. Une approche théorique des jeux évolutifs est présentée pour évaluer les conditions de la stabilité à long terme des partenariats internationaux en matière d'énergie durable sur l'exemple d'un partenariat Afrique-UE sur l'hydrogène. Ces partenariats peuvent impliquer des entités publiques et privées dans différentes constellations, allant d'investissements purement publics à des investissements purement privés en passant par toute forme de collaboration (par exemple, les PPP) (voir également la section 1.3.2). Bien que toutes les formes de partenariats puissent être modélisées à l'aide de l'approche proposée, l'évaluation se concentre sur les partenariats qui impliquent à la fois des acteurs publics et privés, réalisés sous forme de PPP sous l'égide d'un partenariat énergétique international entre les gouvernements. Cela s'explique par les avantages prometteurs des PPP évoqués à la section 1.3.2. En outre, le modèle proposé décrit les partenariats pour l'énergie durable comme un jeu infini. Les partenariats pour l'énergie durable visent à répondre aux besoins à long terme des parties concernées en matière d'énergies renouvelables. Par conséquent, le modèle ne décrit pas seulement des PPP internationaux autonomes d'une durée limitée, mais des partenariats énergétiques internationaux à long terme, dans le cadre desquels plusieurs PPP peuvent être réalisés, en se chevauchant ou en se succédant. Pour les gouvernements, la coopération implique donc un engagement à long terme envers le partenariat, établissant les conditions institutionnelles de la coopération en matière d'investissement, tandis que la coopération avec le secteur privé décrit l'engagement envers les PPP, qui sont mis en place dans ce contexte.

Il s'avère qu'actuellement, les coûts considérables des sources d'énergie renouvelables et les externalités environnementales incomplètement évaluées empêchent une coopération suffisante du secteur privé, et les améliorations isolées des analyses de rentabilité sont insuffisantes pour encourager une coopération à long terme. Ainsi, la conception des accords de coopération entre les gouvernements ainsi que la conception des contrats de partenariat public-privé sont des facteurs d'influence importants pour le succès à long terme des partenariats en matière d'énergie durable. En particulier, un co-investissement de tous les gouvernements impliqués est crucial, car sinon, les gouvernements peuvent réaliser des bénéfices exceptionnels, ce qui les dissuade de coopérer à long terme. Il est également démontré que les partenariats public-privé fondés sur la disponibilité et impliquant pleinement le secteur privé dans la conception, le financement, la construction, l'exploitation et l'entretien du partenariat constituent la meilleure configuration, car dans ce cas, l'analyse de rentabilité pour les investisseurs privés est améliorée, tandis que les bénéfices inattendus pour les gouvernements sont encore réduits.

Limites et Recherches Futures

Les limites de cette thèse résultent du champ d'application sélectionné, du choix de la méthodologie et de la disponibilité des données. Les limites générales et les possibilités de recherche future résultant de ces trois dimensions sont décrites ci-après, tandis que des limites et des recherches futures plus détaillées et spécifiques sont fournies à la fin de chaque chapitre.

Tout d'abord, bien qu'il existe un nombre croissant de contributions étudiant le rôle de l'investissement et de la finance durables, le domaine est encore relativement nouveau et nécessite des recherches approfondies. Cette thèse contribue à combler cette lacune. Par conséquent, les quatre thèmes ci-dessus traitent de l'impact de l'interaction internationale entre le secteur public et le secteur privé sur l'investissement et la finance durables. Dans le chapitre 2, un modèle de croissance macroéconomique de changement technique dirigé incorporant une décision de financement endogène est présenté, permettant une évaluation de l'impact des frictions financières sur la croissance durable, ainsi qu'une évaluation de différents instruments politiques tels qu'une réglementation durable du secteur financier et des investissements publics et privés durables (y compris des partenariats public-privé). Les chapitres 3 et 4 approfondissent le sujet de la réglementation durable du secteur financier sur l'exemple de l'UE et de la zone euro, et le chapitre 5 fournit une analyse des partenariats publics-privés internationaux dans le domaine de l'énergie durable sur l'exemple d'un partenariat UE-Afrique dans le domaine de l'énergie durable. Par conséquent, cette thèse montre l'espace dans lequel des approches internationales générales public-privé peuvent être mises en place pour accroître la finance durable. Néanmoins, comme le domaine dans son ensemble est encore assez rudimentaire, des recherches substantielles seront nécessaires dans les années à venir pour mieux comprendre la relation entre les secteurs financier et réel dans un environnement de croissance durable souhaitée. Cela peut se faire par des évaluations théoriques supplémentaires et affinées, en affinant encore la conceptualisation de la relation, ainsi que par des évaluations empiriques, complétant celles présentées dans les chapitres 3 et 4. Ces évaluations empiriques supplémentaires peuvent, par exemple, couvrir différents ensembles d'économies et leurs instruments politiques respectifs. En outre, alors que les évaluations empiriques présentées dans les chapitres 3 et 4 sont purement positives (c'est-à-dire qu'elles évaluent si un impact statistiquement significatif de la réglementation bancaire durable est observable, mais elles ne révèlent aucune information sur la question de savoir si cette contribution est suffisante pour se conformer aux objectifs de la politique de durabilité), des évaluations normatives testant également l'adéquation des instruments peuvent être réalisées.

D'autres limites et possibilités de recherche future résultent du choix de la méthodologie dans chacun des chapitres. Dans cette thèse, des approches basées sur des modèles sont présentées, à savoir un modèle de croissance macroéconomique de changement technique dirigé au chapitre 2, des modèles statistiques de différence dans les différences aux chapitres 3 et 4, et un modèle théorique de jeu évolutionnaire au chapitre 5. D'autres méthodologies, qualitatives par exemple, pourraient être choisies, ce qui permettrait de révéler des points de vue distincts ou supplémentaires. D'une manière générale, comme chaque modèle est une abstraction de la réalité basée sur une représentation simplifiée ou généralisée de situations réelles, le choix du modèle présenté dans les chapitres 2 à 5 détermine également quelles interrelations sont analysées, sur la base de quel ensemble d'hypothèses. Par conséquent, à l'avenir, les analyses basées sur différents modèles comprenant différents niveaux d'abstraction et ensembles d'hypothèses et de paramétrages peuvent être intéressantes.

Enfin, la disponibilité des données relatives au climat et à la durabilité constitue une limite à la recherche. Bien que dans toutes les analyses de cette thèse, des analyses de sensibilité soient effectuées pour tenir compte des limites de la disponibilité des données, de la couverture, de la qualité des données (en particulier en ce qui concerne les larges fourchettes d'estimations telles que les prix de l'hydrogène, et dans le contexte de l'écoblanchiment), un manque de normalisation et, par conséquent, de comparabilité, ainsi qu'une granularité insuffisante des données, limitent la signification des analyses. Par conséquent, d'autres recherches futures intéressantes seront possibles, dès que la disponibilité des données se sera améliorée, et il sera utile de refaire la présente analyse et de comparer ces résultats avec les présents, ainsi que d'effectuer des analyses supplémentaires.

Conclusions Générales

A travers les quatre chapitres, cette thèse souligne le rôle central d'une prise en compte adéquate de l'investissement et de la finance durables dans la transition vers la durabilité afin d'atteindre les objectifs de durabilité au niveau mondial.

Les résultats révèlent que les marchés financiers et les frictions financières jouent un rôle substantiel non seulement dans le façonnement de la trajectoire de l'investissement et de la finance durables, mais sont également un déterminant clé pour une réalisation efficace de la croissance durable à l'échelle mondiale. Les dépendances et les effets de verrouillage peuvent détourner l'économie d'une trajectoire de croissance durable si les investissements ne sont pas stratégiquement orientés vers des technologies durables. Le chapitre 2 met en évidence cette dynamique. L'analyse délimite en outre l'espace de solution pour les instruments politiques afin de favoriser le financement durable public-privé, en soulignant les rôles (i) de la tarification du carbone, (ii) de la réglementation et de la supervision du secteur financier, et (iii) des investissements publics et privés durables, y compris les partenariats public-privé.

En ce qui concerne (i) la tarification du carbone, on constate que si un prix du carbone peut généralement servir d'outil pour orienter les investissements vers la durabilité, son efficacité dépend d'un niveau et d'une couverture appropriés. Cela signifie qu'un prix du carbone suffisamment élevé devrait être introduit avec une couverture sectorielle et mondiale élevée, à la fois dans le "Nord mondial" et dans le "Sud mondial", comme indiqué dans les chapitres 2 et 5. Bien qu'il soit évident qu'une tarification du carbone suffisamment élevée et complète serait l'instrument politique le plus efficace, il est très peu probable qu'une mise en œuvre adéquate soit réalisée. D'autant plus que les modèles existants, qui ne tiennent pas compte de la dynamique sous-jacente à l'investissement et au financement durables, sous-estiment systématiquement l'ampleur du prix du carbone, qui est nécessaire pour parvenir à une croissance durable à l'échelle mondiale. Par conséquent, dans cette thèse, l'accent est mis sur des moyens alternatifs d'encourager la transition vers la durabilité, qui peuvent être déployés en plus d'une tarification du carbone, dont la couverture est fragmentée et dont l'ampleur est insuffisante. La réglementation et la supervision du secteur financier (ii) apparaissent comme des leviers essentiels pour promouvoir les investissements durables, avec le potentiel d'influencer de manière significative l'investissement et la finance durables. Cela est démontré en particulier pour les pays de la zone euro dans le chapitre 4.

Cependant, l'incitation du secteur financier nécessite un alignement minutieux avec d'autres instruments politiques et une conscience aiguë des nuances associées aux technologies durables émergentes telles que les véhicules électriques et les nouvelles technologies énergétiques, afin d'éviter des résultats contre-productifs, comme le montre le chapitre 3. Malgré les effets positifs de ces instruments politiques, la recherche présentée au chapitre 2 met également en garde contre le fait qu'une réglementation et une supervision durables du secteur financier ne suffisent pas à elles seules à catalyser le niveau d'investissement nécessaire pour parvenir à une croissance durable à l'échelle mondiale. L'analyse souligne en outre l'importance (iii) des investissements publics et privés durables, y compris des partenariats public-privé. Dans ce contexte, la conception structurelle des partenariats internationaux public-privé pour motiver la coopération entre toutes les parties prenantes est évaluée. Les résultats de l'analyse soulignent que les améliorations isolées des analyses de rentabilité qui sous-tendent les partenariats pour l'énergie durable ne conduisent pas à des partenariats stables à long terme. Cela souligne l'impératif d'intégrer en synergie les évaluations technico-économiques et les évaluations macro-économiques dans la recherche de stratégies de financement et d'investissement durables, puisque la prise en compte isolée de l'une des perspectives conduit à des évaluations incomplètes et à des conclusions potentiellement trompeuses.

Au-delà des considérations purement commerciales, il est essentiel pour le succès à long terme des partenariats pour l'énergie durable que les accords de coopération et les partenariats public-privé soient conçus avec soin. Les investisseurs du secteur privé sont plus susceptibles de coopérer dans le cadre de partenariats d'investissement dans l'énergie durable lorsqu'une analyse de rentabilité doit encore être réalisée, si les partenariats public-privé sont conçus sur la base de la disponibilité. En effet, le risque associé aux projets énergétiques est principalement supporté par les gouvernements. De plus, comme les gouvernements supportent le risque et perçoivent les revenus initiaux des projets énergétiques, leur intérêt à coopérer est plus élevé à long terme, car ils ont intérêt à récupérer leurs investissements initiaux. Pour que tous les gouvernements coopèrent, le co-investissement de toutes les parties concernées est considéré comme un facteur essentiel de réussite.

En résumé, cette thèse plaide en faveur d'une approche à multiples facettes de l'investissement et de la finance durables. Elle souligne la nécessité d'instruments politiques harmonisés et de collaborations stratégiques internationales entre les secteurs public et privé pour réaliser de manière efficace et efficiente l'ambition mondiale d'une croissance durable.

Chapter 1

Introduction

List of Abbreviations

ECB	European Central Bank	PPP	Public-private partnership
EU	European Union	NDC	Nationally Determined Contribution
ESG	Environmental, social, governance	RES	Renewable energy sources
EUR	Euros	SFDR	Sustainable Finance Disclosure Regulation
GDP	Gross domestic product		

1.1 Context and Overarching Problem Statement

How does the interaction of public and private sectors globally determine the dynamics of international sustainable investment and finance and the successful implementation of a sustainable global economy? Adhering to the Paris Agreement's 1.5 °C goal, re-confirmed during the 2023 COP28, requires the immediate implementation of a sustainable economy globally (UN, 2023a). This implies massive requirements for investments into sustainable technology and infrastructure across the sectors worldwide, within a very short time frame[6].

Many economies have set ambitious sustainability targets within their National Determined Contributions (NDCs) and beyond, such as the European Union (EU) with their commitment to

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[6] Estimates of the exact amount of additional investment needed to meet the 1.5 °C goal span a wide range of large investment sums (in Euros, EUR), depending on the underlying assumptions (e.g., technological developments). The Intergovernmental Panel on Climate Change, IPCC, for instance, estimates approx. EUR 2.2 trillion (tr.) until 2035, around 2.5% of the world's gross domestic product (GDP) in 2017 (IPCC, 2019).

reach carbon neutrality until 2050[7]. Some countries have started to operationalize their targets by means of dedicated roadmaps and investment plans, such as the EU's 'Sustainable Europe Investment Plan', which is a central component of the 'European Green Deal' (EC, 2020; 2024). Despite these efforts, committed measures and their funding are stated to be insufficient to adhere to the 1.5°C target but are predicted to lead to a global warming within a range of 2.5°C and 2.9°C, even if all NDCs' measures are realized (UN, 2023b). This shortfall between current levels of investment into sustainable technology and infrastructure and the amount needed to meet the global sustainability goals (i.e., the Paris Agreement's 1.5°C goal) is described as the 'sustainable investment gap'[8] (e.g., IMF, 2014; OECD, 2015a; APAC/OECD, 2019).

Provided that governments want to fully honor their commitment to the 1.5°C goal, closing the 'sustainable investment gap' while not significantly disregarding other economic obligations[9] becomes imperative and biggest challenge. Given considerable constraints in public households, the ability to publicly finance the additional sustainable investments at the necessary scale and within the required short time frame is limited (Sinn, 2021; IMF, 2020; 2021; 2022; 2023). While the situation is already tense in the world's wealthier, more developed countries, often referred to

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[7] The European Union's NDC aims for at least a 55% reduction in greenhouse gas emissions by 2030 compared to 1990 levels. The goal to reach carbon neutrality by 2050 goes beyond the NDCs' goal and is central to the European Green Deal, solified as a legally binding target through European climate law (EC, 2021).

[8] Positive, not normative description. Like the estimates of the exact amount of additional investments needed to meet the 1.5°C goal, estimates of the global 'sustainable investment gap' vary in their magnitude. In Germany, for instance, most recent estimates quantify additional investment requirements, which are necessary to keep the German national economy on the 1.5°C track, to be at least EUR 100 billion (bn.) annually—which is approximately (approx.) 2.5% of the 2020 GDP and approx. 15% additional gross investment compared to 2020 (BCG, 2021). Comparing this amount to the currently committed funding of the German federal government of EUR 6 bn. *per annum* (*p.a.*) laid down in the COP26/28 Finance Commitments reveals a major need for additional funding for a sustainability transition in line with the 1.5°C goals.

[9] Other investment needs, such as social expenditures (e.g., government aids within the context of the COVID-19 crisis), defense expenditures (e.g., within the context of Russia's war against the Ukraine), and general investments into the maintenance and renewal of infrastructure remain at historical highs (Sinn, 2021; BdF, 2023).

as the ‘global North’, it is even aggravated in the developing ‘global South’. This is, since economic performance is weaker, access to capital is limited and associated with high borrowing costs, while development needs such as poverty reduction and infrastructure development, which compete for available funding, are significantly higher. These circumstances make it challenging to allocate significant resources to sustainable investment without international support (IMF, 2023). Due to the insufficient ability of the public sectors of both developed and developing economies to provide capital for the sustainability transition, an important role in closing the ‘sustainable investment gap’ is attributed to the private sector (e.g., UNECE, 2020). However, given the strained economic situation characterized by, *inter alia*, rising long-term interest rates and borrowing costs, high corporate debt levels and leverage as well as liquidity pressures, the private sector’s potential to provide the funding for the sustainable investment needs is also limited (IMF, 2021; 2022; 2023). This is in particular, since business cases for many sustainable technologies are yet to be developed as innovation, maturing, and diffusion of technologies progress. A particular role within this context is assigned by some governments (including the EU governments) to the financial sector, which is supposed to play a central role in providing capital at attractive conditions to finance the transition to an environmentally sustainable economy, i.e., to provide green or, more specifically, climate finance (EC, 2023).

In this context, a target-oriented interaction between the public and private sectors, as well as between developed and developing economies plays a pivotal role in effectively and efficiently contributing to the provision of financing for sustainable investments and, thus, narrowing down the ‘sustainable investment gap’. This interaction can include the introduction of economic policy instruments incentivizing the private sector—ranging from corporate firms, which install and produce low-carbon solutions to financial institutions, which invest in and lend to low-carbon firms—as well as an enhanced cooperation between public and private investors and financiers (Feyen, 2020; Campiglio and van der Ploeg, 2021). Moreover, the intricacies of global economic systems highlight the indispensable need for international cooperation—not only aiming at pooling resources but also at sharing knowledge, technology, and innovative financial instruments to address multifaceted challenges of sustainability across diverse economies (e.g., Nordhaus, 2015).

1.2 Contribution and Structure of this Dissertation

Within the context described above, this dissertation contributes significantly to the understanding of the role of international public-private cooperation in sustainable investment and finance. This is in particular, as it brings together macro-economic assessments with techno-economic evaluations, both of which are often employed separately. This dissertation explores four core topics, presented in the following four Chapters. Chapter 2 overarchingly assesses the 'Impacts of Public-Private International Sustainable Finance on Achieving Global Climate Goals Through Innovation and Technology Diffusion'. Chapters 3 to 5 provide deep dives into select aspects of sustainable investment and finance. Chapter 3 analyzes the 'Impacts of ESG Banking Regulation and Supervision on Financing Sustainable Mobility and Energy Technologies', Chapter 4 the 'Impacts of ECB Banking Supervision on Climate Risk and Sustainable Finance' and Chapter 5 the 'Requirements to Implement Long-Run International Sustainable Energy Partnerships'.

To the end of locating this dissertation within the field of sustainable investment and finance, throughout the following Sections, a more detailed description of the sustainable investment and finance landscape is provided. This is, along four aspects: Firstly, sustainable vs. non-sustainable investments and finance are characterized with regards to their sectoral origin as well as their infrastructure intensity. Secondly, different types of investors and financiers are classified along a scale from public to private, including types of potential policy and regulatory incentivization of their sustainable investments. Furthermore, as mentioned above, innovation and international cooperation play a central role in sustainable investment and finance, both with regards to their necessary contribution to realizing the sustainability transition, and with regards to their impact on sustainable investment and financing properties. Therefore, thirdly, the role of innovation in sustainable investments and finance is discussed; lastly, the role of international cooperation is described. Within these detailed descriptions, the focus of each Chapter is specified, further detailing the contribution of this dissertation. Throughout the characterization, the focus of 'sustainable' investment and finance is laid on 'environmental', and, in particular, on climate-related investment and finance.

1.3 The Sustainable Investment and Finance Landscape

1.3.1 Types of Sustainable Investments and Finance

Within this Section, sustainable investments and finance are characterized in terms of their sectoral origin. Requirements for sustainable investments and finance in general, and climate investments and finance in particular, emerge from decarbonization needs within different economic sectors. To the end of identifying the most relevant sectors within sustainable investment and finance, it is expedient to look into the contribution of the different economic sectors' activities to global carbon emissions. While exact numbers vary, the orders of magnitude in the sectors' shares in global emissions are clear (see, e.g., EEA, 2016; Liu et al., 2022; IEA, 2023)[10]. Emissions from the energy sector account for the largest share of total global emissions, ranging between 35% and 45%, followed by the industrial sector (25% to 30%), the transportation sector (20% to 25%) and the buildings sector and other sectors (10% to 15%). These sectors also require the largest sums of sustainable—i.e., climate—investments and finance (see also BCG (2021) for Germany). Throughout the following, the investment and financing requirements are classified as 'sustainable', if they contribute to the reduction of carbon emissions, and as 'non-sustainable', if they do not

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[10] Numbers represented without emissions from land use, land-use change, and forestry, LULUCF.

contribute to their reduction[11]. When further characterizing the sectors, it becomes evident that the energy and transportation sectors are particularly infrastructure-heavy[12]. This becomes especially relevant when further characterizing the different types of investors and financiers involved (see Section 1.3.2). The types of investments along the different sectors are displayed in Figure 1.

Within this dissertation, the Chapters 2 and 3 assess the interplay of sustainable and non-sustainable investments and finance in general, without focusing on any particular sector. Chapters 4 and 5 provide in-depth analyses of the two largest infrastructure-heavy carbon emitting sectors energy and transportation.

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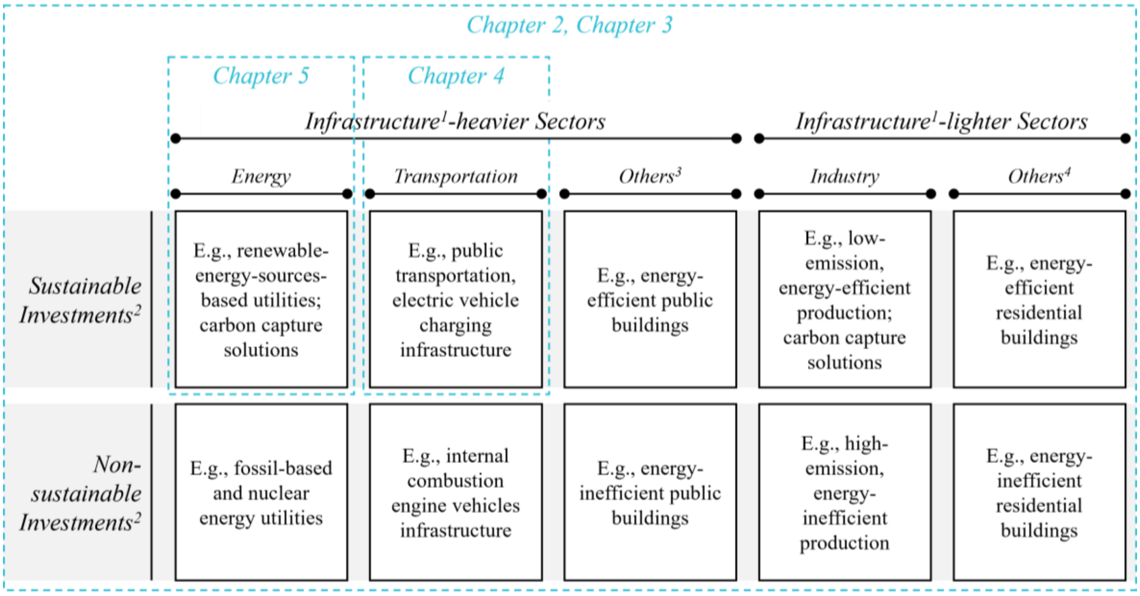
[11] The classification of investments as 'sustainable' and 'non-sustainable' in terms of their carbon emission impact is not always clear. For instance, an investment into a road used by electric vehicles running on electricity generated from renewable energy sources could be classified as 'sustainable', while the same road used by internal combustion engine vehicles could be classified as 'non-sustainable'. The EU Taxonomy for Sustainable Activities ('the Taxonomy') provides the to-date most comprehensive attempt to classify assets and investments in terms of their sustainability (EU, 2020). Classifications throughout this dissertation are, hence, based on the Taxonomy wherever possible.

[12] The share of infrastructure within the sectors is not clearly defined as definitions of infrastructure can vary greatly, and assets and investments are classified based on a broad spectrum of different attributes. Firstly, there is a distinction between institutional and physical infrastructure. While the former includes the structures, such as organizations and governments that make decisions and form the economy and policies (cf. Chappin and van der Lei, 2014), the latter describes physical assets. Within physical infrastructure, a distinction is often made between social and economic infrastructure. Social infrastructure includes, e.g., schools and hospitals. Economic infrastructure includes physical assets such as roads, railways, and energy generation facilities and grids, i.e., the "long-lived, capital intensive, large physical assets that provide essential services or facilities to a country, state, municipality, or region and contributes to its economic development or prosperity" (NAIC, 2020). Other definitions narrow down economic infrastructure to only assets whose provision is affected by market failure (i.e., network effects), and is, thus, provided (partially) by the public sector. Within the following, a definition of infrastructure based on the Nomenclature of Economic Activities NACE (https://nacev2.com/en/) is used, which is also the standard approach of, e.g., the European Investment Bank, EIB (EIB, 2024). According to this definition, infrastructure includes especially assets within the energy and utilities sectors, in transportation and storage, as well as information and communication.



1. According to an infrastructure definition based on the NACE sectors, which is usually used by, e.g., the European Investment Bank. According to this definition, infrastructure includes firms in groups D and E (utilities), group H (transportation and storage) and group J (information and communication). 2. Classification following the EU Taxonomy where available. 3. 'Others' contain mainly the communications and the public buildings sectors. 4. 'Others' contain mainly residential buildings and services.

Figure 1: Types of Sustainable vs. Non-sustainable Investments

1.3.2 Types of Investors and Financiers and the Role of their Incentivization

Within this section, different investors and financiers in sustainable investments are classified, and the role of their policy and regulatory incentivization is laid out.

1.3.2.1 Classification of Investors and Financiers

Within the landscape of sustainable versus non-sustainable investments across the sectors conceptualized in the previous section, different types of investors and financiers are involved.

Within this dissertation, 'investors' refer to actors from the real economy, such as corporates. 'Financiers' subsume all players from the financial sector, including banks and other financial institutions. Actors from the real economy generally take the role of planning and operationalizing the sustainable investments (e.g., transmission system operators in the energy sector carrying out the power grid expansion, which is necessary to integrate RES into the electricity system). Actors from the financial sector generally provide capital to finance or re-finance these investments (e.g., a bank providing a credit to the transmission system operator)[13]. With regards to implementing the sustainability transition, governments often assign the financial sector a key role, using the sustainable regulation of capital provision as a lever to also steer the real economy towards sustainable investment. For instance, limiting the financial sector's capital provision to non-sustainable industries such as fossil power generation also limits down their maintenance and construction. The role of the financial sector in sustainable investment and finance is further discussed in Chapters 3 and 4.

As described in the introduction, the different investors and financiers can be classified into public and private. Public investors and financiers subsume, e.g., all governments, government funds or development banks. Private investors and financiers range from corporates to financial sector players such as banks and asset managers. The public and private actors can either invest by themselves or establish partnerships. These partnerships can be set up amongst private sector investors and other non-government actors such as non-governmental organizations as non-public-private partnerships or as public-private partnerships (PPPs) involving public- and private sector actors[14], see Figure 2.

These four different forms of investment and financing—pure corporate or financial sector investment, non-PPP, PPP, and government investment—are of varying relevance depending on the type of investment (e.g., infrastructure-heavy vs. infrastructure-light investments) and on the considered economy. "Infrastructure stands at the crossroads between public and private investment—i.e., it is usually built and financed by the government and the private sector, but the government maintains a crucial role in planning and regulating its construction and operation"

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[13] The distinction is not always this clearly delimitable. Also, actors from the real economy can act as financial investors. In the case of the German transmission system operator Amprion, for instance, one of the largest German utility companies, RWE, has been one of the main financiers.

[14] PPPs are contractual agreements between public authorities and private entities, where both parties share risks, responsibilities, and rewards in delivering public services or infrastructure projects (World Bank, 2020).

(IMF, 2024). Therefore, especially with regards to infrastructure-heavy investments in the energy and transportation sectors, an analysis of the interplay between the public and the private sectors is pivotal. While there has not been a single global conclusive study of the space, some estimates exist regarding the investment shares of public and private sector investors and financiers across the economies and across the sectors (Bakertilly, 2021). A recent investment report of the IMF quantifies public and private investment shares in infrastructure within the European Union from 2005 to 2022. The study reveals that infrastructure investments have been mainly made by the governments (approx. 40% to 50% of the total infrastructure investments in the EU), and by private investors (approx. 40% to 50%) separately, complemented by non-PPPs (1% to 10%, with an increasing trend over the considered time period), and PPPs (2% to 6%) (IMF, 2024). In the US, the major share of infrastructure investments is made by the private sector (approx. 70%), followed by the governments on the federal, state, and local levels (approx. 30%) (Edwards, 2013). The latter is subject to an increasing trend, with the Biden administration putting more emphasis on public infrastructure investments as a stimulator for economic activities (Boushey, 2023; Van Nostrand, 2023). While stand-alone private and public investments cover almost all US infrastructure investments, "the [PPP] approach to developing major infrastructure is considerably rare in the US at this time" (approx. 1% to 2% in 2021) (Bakertilly, 2023). In developing countries, a World Bank study from 2017 finds that 83% of infrastructure investments are public, made directly by governments or indirectly by state-owned entities such as development banks. The remaining 17% of investments are covered by private investors, however, 55% of these investments were financed by non-private sources, such as public banks (World Bank, 2017). Depending on the definition of PPPs, an approximate share of 10% to 15% of the total infrastructure investments in developing countries can be classified as PPPs (Leigland, 2018). While currently, shares of investments via PPPs are comparably low, their advantages are often pointed out regarding their potential to narrow down the 'sustainable investment gap'—especially for investments in developing economies and into technologies with low maturities (see also Sections 1.3.3 and 1.3.4). Since these investments are usually riskier and less profitable, PPPs have gained prominence due to their potential to overcome financial constraints and bring efficiency, innovation, and cost-effectiveness to (public) projects (Hodge and Greve, 2007; Estache et al., 2014; Romboutsos and Saussier, 2014; World Bank, 2022). Also, in developed economies such as the US, "the confluence of an ever-growing major infrastructure needs backlog at the local, state and national levels, combined with significant funding coming to state and local governments from the [Infrastructure Investment and Jobs Act IIJA passed in November 2021], suggests that there may be a growing appetite for alternative project delivery models [such as PPPs]" (Bakertilly, 2021). In the EU, especially in the energy sector for renewable energy technologies and within internationally set up sustainable energy infrastructure projects, PPPs are discussed as an advantageous investment and financing approach.

1.3.2.2 The Regulatory Incentivization of Investors and Financiers

Sustainable investments internalize both positive and negative environmental externalities[15]. Per definition, internalizing negative environmental externalities leads to additional costs (e.g., for installing systems which reduce pollution). Positive environmental externalities can result in an incomplete capture of profits derived from the sustainable investments, or in free-riding issues, meaning that windfall profits from third party investments can be realized. The prevalence of

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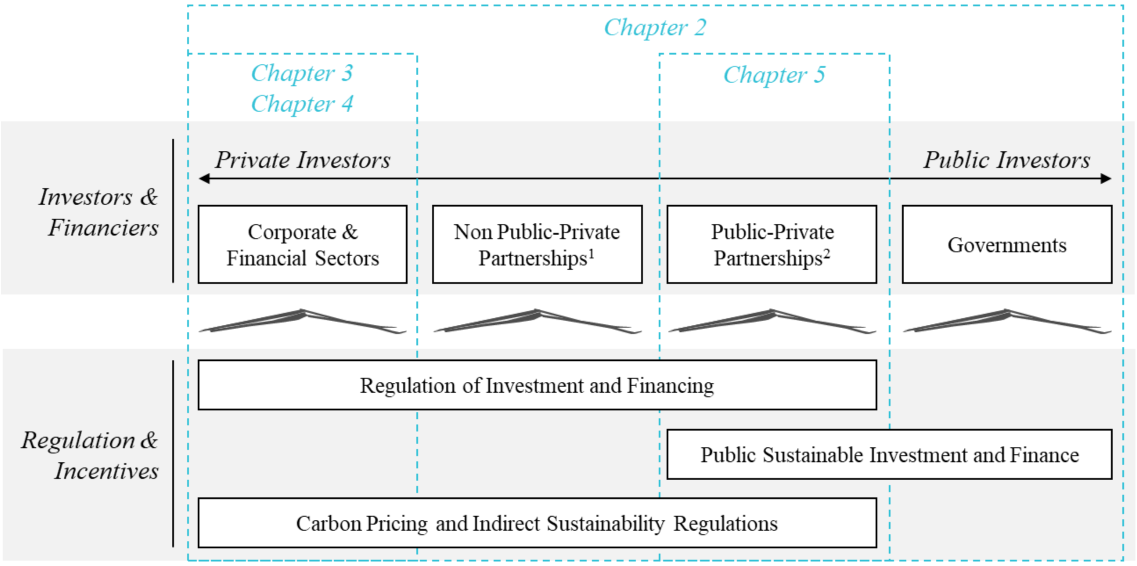
[15] Environmental externalities are costs or benefits arising from economic activities, which are not reflected in market prices, that affect third parties not involved in the decision-making process. These can be either negative (costs) or positive (benefits), such as pollution from industrial activities causing health issues in nearby communities (negative externality) or a company planting trees that improve air quality for the surrounding area (positive externality). Both positive and negative externalities have been classified as 'market failure', justifying policy and regulatory interventions in neoclassical economics. The concept has been foundational in environmental economics, notably discussed in Arthur Pigou's work 'The Economics of Welfare' (1932), where he introduced the idea of using taxes to correct for externalities.

externalities leads to sub-optimal investment levels[16]. To cure the market failures caused by positive and negative environmental externalities, different policy and regulatory instruments can be introduced. In the case of carbon emissions, the instruments, which are often regarded the most efficient, are carbon pricing or carbon taxation (e.g., Nordhaus, 1994; Stern, 2006). Furthermore, a multitude of alternative policy and regulatory instruments incentivizing sustainability exists, ranging from subsidies for specific sustainable technologies to bans of non-sustainable assets (see, e.g., Fraunhofer ISI (2024) for a comprehensive overview of policy and regulatory instruments incentivizing energy efficiency in the EU). Within the context of this dissertation, the focus is, however, on two types of incentives directly addressing private and public investors and financiers. Firstly, sustainable regulation including the associated supervision of the financial sectors is considered. Secondly, public sustainable investment and finance are assessed as a means to increase sustainable investments.



1. Partnerships amongst private sector investors and other non-government actors such as non-governmental organizations. 2. Partnerships between private sector actors and governments.

Figure 2: Types of Investors and Financiers and their Regulatory Incentivization

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[16] This means also, that the market for sustainable products and services depends on the policy and regulatory environment. Especially in the case of investments into technologies with low maturities, this can lead to considerable policy risks, e.g., in the case of policy and regulatory inconsistencies (see also Section 1.3.3).

Considering this investor landscape and its incentivization, Chapter 2 provides an analysis of the investment behavior of investors and financiers on the scale from public to private. The impact of the activities of the different types of investors and financiers on global sustainable growth is assessed. Furthermore, an analysis of three types of policy and regulatory incentivization of sustainable investment is provided: sustainable regulation of private investment and financing; public sustainable investment and financing, as well as carbon pricing (assessed for comparison). Due to the high relevance of private sector investment and finance in the sustainable infrastructure space, as outlined beforehand in the introduction as well as within this section, Chapters 3 and 4 provide deep dives into private sector investments. In particular, they focus on financial sector involvement. This is, since the financial sector is assigned a pivotal role as an accelerator of sustainable investments also in the real sectors by many economies (see also Sections 1.4.2 and 1.4.3). Chapter 5 focuses on sustainable investments within the energy sector, which are realized as partnerships between developed and developing countries, involving the possibility for private sector (co-)investments. While the presented model allows for a reflection of all four types of investments on the scale from public to private, the focus is on international PPPs involving private sector investors from both developed and developing economies.

1.3.3 The Role of Innovation and Technology Diffusion

As mentioned beforehand, innovation and technology diffusion play a dual role with regards to sustainable investment and finance. On the one hand, innovation and diffusion of sustainable technologies plays a key role in realizing the sustainability transition and adhering to sustainability and climate targets. On the other hand, they have a considerable impact with regards to the properties of sustainable investment and financing options.

Regarding the former, technological innovation is an important contributor to an effective and efficient realization of the sustainability transition. Given the currently available technology landscape, realizing a full-fledged sustainability transition of the global economy while avoiding negative impacts on economic performance (e.g., growth) is potentially impossible to realize, and if so, at very high costs (e.g., Stern and Valero, 2021). Therefore, innovation is necessary to create new sustainable technological solutions and to create new business opportunities and decrease costs. While it is challenging to quantify innovation requirements globally, some estimates exist. Estimates of percentages how much of the sustainability transition can be implemented based on existing and mature versus innovative and immature technologies range from 70% to 90% based on existing, the remainder based on innovative technologies (IEA, 2021a,b; BCG, 2021). While these numbers suggest that the amount of required innovation is manageable, the diffusion of sustainable technologies is equally important. Both in developed and developing economies, it is important that existing sustainable technologies are comprehensively adopted. This also implies that existing sustainable technologies, which are often still at low maturity levels, are further developed while being rolled out. During this process, also advantages of scale and scope can be realized, leading to further cost decreases.

Regarding the properties of sustainable investment and finance, three main implications arise. Firstly, as mentioned above, major shares of the investments are needed for research and development activities as well as for further developing and rolling out new technologies of low maturities. For instance, much research is still needed to advance carbon capture, storage, and utilization solutions, which can contribute significantly to the overall achievement of climate targets. The low levels of technological maturity often go hand in hand with the fact that many companies involved in the technology development and implementation are recently founded and often small companies, for instance lacking a longer track record and any substantial collateral. Secondly, since sustainable technologies and infrastructure are often very distinct from the legacy ones, a large share of the investments has greenfield properties. For instance, charging infrastructure for electric vehicles has to be newly built; within the energy sector, renewables-based energy systems are very distinct from the existing systems, including generation facilities at new locations and the according power grid infrastructure, to connect the generation with the load centers. Especially in the case of infrastructure-heavy investments, which constitute a large share of the necessary sustainable investments as described previously, is highly capital-intense and large amounts of upfront investments are required. For instance, the new construction of power grids connecting renewable energy sources to the new energy system requires several billions of investments over the next decade in Germany only, while the associated operational expenses only add an additional 5% to 10% in costs of the total investment volumes (BCG, 2023; 2024). Thirdly, since technologies often do not have a positive business case, yet, and also since internalized environmental externalities cause additional costs, markets often depend on policy and regulatory frameworks and incentives. For instance, many low-carbon technologies, such as the use of green hydrogen in industrial processes, e.g., in the steel industry, only exhibit positive business cases if a sufficiently high carbon price is set. These properties lead to high investment risks, while the potential returns are comparably low, especially in the case of infrastructure-heavy investments[17]. In the case of legacy infrastructure investments, the comparably low returns also used to go hand in hand with low risks and steady returns. Thus, investment profiles have been attractive especially for risk-averse long-term investors such as institutional investors (e.g., pension funds or insurance companies) (OECD, 2015a). For these investors, higher risks are often an exclusion criterion within their investment decisions, often even due to regulatory or legal restrictions (e.g., OECD, 2015b). For other investors, who are willing and able to bear higher risks, the low returns often lead to unfavorable investment decisions.

These characteristics of sustainable investments—i.e., the high innovation and technology diffusion requirements of sustainable investments and the resulting investment properties—

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[17] Infrastructure investments often include considerable shares of basic services, which governments have decided to construct and operate even if not profitable to meet the basic living requirements of their population (e.g., for the energy sector in Germany, this is laid down in the *Energiewirtschaftsgesetz EnWG, §36,* which specifies under which conditions energy companies are legally obliged to provide basic services (‘*Grundversorgung*’)).

underscore the necessity of public-private, but also of international cooperation in their realization. The role of the latter will be described throughout the subsequent section.

1.3.4 The Role of International Cooperation

1.3.4.1 Theoretical Foundations Underlying the Role of International Cooperation

Within this section, the role of international cooperation is discussed. International cooperation in the context of globally implementing the sustainability transition refers to the collaborative efforts amongst countries, international organizations, non-governmental organizations, private sector entities, and other stakeholders to develop, share, and implement policies, technologies, and practices aimed at achieving sustainable development goals. This cooperation is geared towards addressing global environmental challenges such as climate change—which is the focus within this dissertation—but also biodiversity loss, water scarcity, and local pollution, while simultaneously promoting economic growth, social inclusion, and reducing inequalities. Aspects of international cooperation for the sustainability transition can, for instance, include joint research and development initiatives, knowledge and technology transfers, international financial support and investment (i.e., mobilizing resources through international financial institutions, development banks, and climate funds), international agreements and policy coordination (establishing global, regional, and bilateral agreements and frameworks that set common goals, standards, and policies for sustainability), or promoting trade policies and practices that encourage the production and exchange of sustainable goods and services, and the development of green supply chains. Furthermore, international sustainability cooperation can include multi-stakeholder partnerships between governments, the private sector, the civil society, and local communities to leverage the strengths of each sector in driving the sustainability transition.

The central role of international cooperation emerges from two requirements within the context of the sustainability transition: firstly, the fact that the sustainability transition has to be effectively and comprehensively realized on a global scale, including both developed and developing economies; secondly, the above-described imperative of a cost-efficient implementation.

With regards to the fact that the sustainability transition has to be realized on a global scale, the comprehensive adoption of sustainable technologies plays a key role. This includes both the creation of the necessary prerequisites including the necessary know-how to implement sustainable technologies globally, and the actual sustainable investment decision. Within the context of the former, global learning effects, i.e., international knowledge transfers, are relevant. The underlying macro mechanisms have been, for instance, discussed in the seminal work of Barro and Sala-i-Martin (1997), who conceptualizes innovation activities by 'leader' economies, and the global adaption of innovation of 'follower' economies. Other contributions assess macro and micro mechanisms underlying international transfers of know-how and the adaption and diffusion of new technologies in more detail. For instance, Teece (1977) conceptualizes technology transfers through multinational firms, e.g., through merger and acquisition activities and foreign direct investments; Coe and Helpman (1995) analyze international R&D spillovers; and Benhabib et al. (2021) study how "endogenous innovation and technology diffusion interact to determine the shape of the productivity distribution and generate aggregate growth". The thus developed theoretical frameworks have been deployed also to assess the mechanisms underlying sustainable innovation and technology diffusion, such as done by Stern and Valero (2021), who examine "long-term policies and institutions that can enable and foster private sector investments in clean innovation and assets quickly and at scale", thereby discussing the interaction and cooperation of developed and developing economies. The discussion of the actual decision to implement the sustainability transition globally is mostly centered around the international cooperation problem arising from externalities inherent to sustainable action and investments (as discussed in the previous section), and the resulting free-riding problems in combination with the lack of enforcement mechanisms on the global level. In the absence of international cooperation, these properties of sustainable action and investments lead to a non-realization of the sustainability transition, as, for instance, discussed by Nordhaus (1994; 2015; 2021) or Barrett (1994). An important complement to this work in the context of the adoption of sustainable technologies—albeit originally not in an international context—are models of directed technical change (Acemoglu, 2002; Acemoglu et al., 2012). These models also reflect lock-in effects in the decision-making for different technological solutions and support the understanding of the prevalent adaption of sustainable vs. non-sustainable technologies globally, as well as the role of international cooperation in jointly steering the economy towards a sustainable growth path (see also Chapter 2).

Regarding the imperative for cost-efficiency, the well-known advantages of international trade and cooperation suggest that an internationally joint implementation of the sustainability transition can enable a more efficient implementation. For instance, Ricardo's theory of comparative advantage suggests countries specializing in producing goods where they have lower opportunity costs compared to others leads to higher efficiency in production (Ricardo, 1817). Heckscher and Ohlin's trade theory posits that it is efficient if countries export products that utilize their abundant and cheap factors of production and import products that require factors in short supply (Heckscher and Ohlin, 1933). Krugman's new trade theory introduces economies of scale and network effects, explaining the efficiency-increasing effects of trade between similar countries in similar products (Krugman, 1980). Anderson and Wincoop (2003) discusses how border-related trade barriers and the associated transaction costs affect trade flows and how reducing these barriers can significantly improve market efficiency. Further advantages emerge from financial stability considerations, as, for instance, discussed by Obstfeld et al. (2009), as international cooperation in financial markets can promote stability, reduce the risk of crises, and facilitate better crisis management.

1.3.4.2 Green Energy Partnerships: An Example for Sustainable International Cooperation

To the end of making the two sources of requirement for international cooperation in the context of the sustainability transition more tangible, it is expedient to look into their materialization within the energy sector as the main carbon emitter. Within the energy sector, a form of international cooperation, which is currently widely discussed, are sustainable energy partnerships. These partnerships go beyond the simple international trading of energy. International energy trading typically involves the buying and selling of energy commodities across borders, focusing on market dynamics such as supply, demand, and the resulting prices. It is transactional, with short-term to medium-term horizons. In contrast, international energy partnerships often entail long-term collaborations between countries or companies, focusing on shared energy projects, technology transfer, joint ventures, as well as building joint infrastructure. These partnerships aim at the long-term goals of securing energy supply, developing new energy technologies, or achieving sustainability goals, emphasizing cooperation, mutual benefits, and often, strategic interests beyond mere financial transactions. This strategic long-term perspective is particularly important due to the low technological maturity and the requirement for high upfront capital expenses within investments into sustainable energy systems, as described above. Due to their potential advantages, sustainable energy partnerships have been also anchored as a component within many economies' sustainability strategies. For instance, the EU has incorporated sustainable energy partnerships as a key pillar into the European Green Deal (EC, 2020). Germany and Australia have signed an agreement establishing the 'Australian-German Energy Transition Hub' in 2020, and an 'Australia-Germany Hydrogen Accord' in 2021 to strengthen collaboration in RES research, development, and commercialization. Japan and Australia have signed a 'Joint Statement on Enhanced Energy Cooperation' in 2020, outlining their shared commitment to the development of RES with a focus on green hydrogen. Also, multiple other countries have set up energy partnerships with African countries. For instance, the United States have set up the 'US-Africa Clean Energy Finance Initiative' in 2013. India and different African countries have set up several initiatives regarding a cooperation on RES, such as the 'International Solar Alliance', and China has established the 'China-Africa Energy Partnership' as part of the broader 'Forum on China-Africa Cooperation' already in 2000. Furthermore, the EU and African countries have established the ‘Africa-EU Energy Partnership’ in 2007. Key initiatives include the ‘EU-Africa Infrastructure Trust Fund’ and the ‘Africa Renewable Energy Initiative’, as well as an EU-Africa hydrogen partnership.

The physical setup of international energy partnerships usually has the following structure: renewable energy generation facilities are installed in countries with locational advantages in the RES generation, such as high solar densities, high and constant wind speeds, and the availability of sufficient space to install large-scale RES facilities. Countries with these properties are often located in the ‘global South’, i.e., in developing economies in Africa, the Middle East, or South America. RES generation facilities usually include solar power plants such as concentrated solar power plants[18] or wind turbines. The renewable energy is transmitted to the countries, where it is consumed, which are, generally, highly industrialized countries in the ‘global North’ such as the EU or Japan, where RES generation is much more difficult. The transmission of energy can be realized by means of different technological and infrastructure solutions, such as power transmission lines, or, as discussed more recently, the use of hydrogen as an energy carrier, which can be transmitted through pipelines or by means of shipping.

In this context, as mentioned above, potential partnerships, which have been widely discussed, are RES partnerships between the EU and African countries (see, e.g., African Union, 2007). These partnerships are described in the following as tangible examples of how sustainable energy

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[18] Concentrated solar power plants generate electricity by using mirrors to concentrate sunlight onto a receiver, where it heats a fluid to produce steam. This steam drives a turbine connected to a generator, producing electricity. Concentrated solar power plants are often equipped with storage systems, allowing them to store thermal energy for periods when sunlight is not available, thus providing a consistent power supply. The setup includes a field of mirrors (heliostats), a central receiver or tower, a heat storage system, and a steam turbine. To install and run a concentrated solar power plant, several key requirements must be met: a location with high solar irradiance, typically in desert or arid regions where sunlight is abundant and cloud cover is minimal; extensive land to accommodate the solar mirrors or collectors (usually between two and five hectare per megawatt installed capacity); water supply for the cooling process and steam generation, although dry cooling techniques can reduce this requirement.

partnerships can be designed in terms of their physical and institutional setup, and how cost-efficiency and a global adoption of sustainable technologies can be enabled. Also, barriers to the setup of these partnerships are laid out.

The first attempt to set up a sustainable energy partnership between EU and African countries has been the DESERTEC project, an ambitious initiative aimed at harnessing the vast potential of solar and wind energy in the deserts of the Sahara, to meet a significant portion of the global energy demand, including Europe, the Middle East, and North Africa region[19]. The project has been set up as a private sector cooperation, brought to life in 2009 with the foundation of the DESERTEC Foundation and Industrial Initiative (Dii GmbH). The consortium consists of large technology corporates such as Siemens and ABB, as well as financial and insurance players such as Deutsche Bank and MunichRe. Over time, it has included various European energy companies and financial institutions. The DESERTEC concept envisions a network of solar thermal power plants and wind farms across the Middle Eastern and Northern African region. Key RES generation technologies include concentrated solar power plants using mirrors to concentrate sunlight to heat a fluid and produce steam for electricity generation, photovoltaic solar panels, and wind turbines. As transmission infrastructure, high voltage direct current transmission lines have been proposed to efficiently transport electricity over long distances from the Middle Eastern and Northern African region to Europe. Since its introduction, however, the DESERTEC project has significantly scaled back from its initial grand vision. The Dii GmbH has shifted focus from the original broad scope to promoting renewable energy projects within the Middle Eastern and Northern African region itself, rather than the extensive power export to Europe. This is, since the DESERTEC project faced several challenges that prevented it from achieving its initial ambitions (see, e.g., Schmitt, 2018). Among these, political instability loomed large. The Arab Spring and the ensuing turmoil in many

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[19] See https://desertec.org/. The idea was inspired by the notion that desert regions of the world could produce about 700 times more electricity than the entire European Union was consuming in 2007.

North African countries cast a long shadow over the project’s feasibility and the security of investments, making stakeholders hesitant. Compounding this issue were the high costs and financing challenges associated with the project. Initial cost estimates were staggering, largely due to the massive upfront capital required for the necessary infrastructure, including the high voltage direct current lines and renewable energy plants. This financial risk proved too great a barrier for securing the needed investment. Further complicating the project’s path was a web of regulatory and market barriers. The lack of a cohesive European energy policy towards the Middle Eastern and North African region, combined with diverse regulatory environments and market uncertainties, added layers of complexity that were difficult to navigate. On the technological front, while the capabilities for concentrated solar power, photovoltaic solar panels, and wind turbines existed, scaling these technologies up to the project's ambitious capacity and efficiency targets posed significant challenges. Moreover, stakeholder concerns played a critical role in the project's struggles. Issues such as the potential for significant water usage in concentrated solar power cooling processes, disputes over land rights, and doubts about whether the benefits of the project would truly extend to local populations in the Middle Eastern and Northern African region raised questions about the project's sustainability and equity. Together, these factors created a daunting array of hurdles that the DESERTEC project struggled to overcome, leading to a reevaluation of its scope and aims. Despite these challenges, the DESERTEC concept has influenced ongoing discussions and projects related to RES deployment in desert regions and the potential for cross-border energy cooperations. The vision of using deserts as renewable energy powerhouses continues to inspire new initiatives, albeit on smaller scales or within different frameworks. Also, many lessons can be learned from the DESERTEC initiative when setting up future sustainable energy partnerships, in particular with regards to success factors and barriers to be considered. Thus, the findings also inform the model setup and discussion in Chapter 5.

One of these newer initiatives is an EU-Africa Hydrogen Partnership. This partnership is currently discussed under the aegis of the Africa-EU Energy Partnership established in 2007, with the goal to leverage the vast renewable energy resources of Africa to produce green hydrogen, which could be used both locally and exported to the EU. The partnership would focus on building infrastructure and technology development for renewable energy generation; and instead of the transmission of the energy through a power transmission line, hydrogen would be used as an energy carrier. With regards to its physical setup, solar and wind resources would be used to produce green hydrogen through electrolysis. This includes the development of the necessary infrastructure including electrolyzers, storage facilities, and pipelines or shipping solutions for hydrogen transport. Regarding the latter, hydrogen transport via pipelines cannot only be realized by the greenfield construction of new pipelines, but also by retrofitting existing gas pipelines. Regarding its institutional setup, the partnership would include EU governmental bodies, energy agencies, and potentially private sector partners, as well as African governments and regional cooperation bodies. International Organizations such as the International Renewable Energy Agency IRENA might also play a role in facilitating and supporting the partnership. Since the EU-Africa Hydrogen Partnership is currently in a concept stage, the concrete design of such a partnership would depend on the actual agreements made, projects initiated, and investments secured. The partnership’s progress would be marked by the successful completion of pilot projects, scaling of hydrogen production, and establishment of export mechanisms to the EU. While the potential advantages are considerable, ensuring the economic competitiveness of green hydrogen in the global energy market is still challenging. Considerable investments into the further development and scale-up of the technology are needed, as well as massive investment into infrastructure for hydrogen production, storage, and export. Also, navigating the complex political and regulatory environments across multiple EU and African countries and setting up successful cooperations is not a trivial task. Success factors of an EU-Africa Hydrogen Partnership are assessed in Chapter 5 of this dissertation.

1.4 Approach: Scope and Methodology

As described throughout the previous sections, sustainable investment and finance play a key role in successfully realizing the sustainability transition globally. As described above, the four following Chapters provide approaches to better understand key aspects of international public-private sustainable investment and finance. Chapter 2 conceptualizes the impact of sustainable investment and finance on the achievement of global sustainability goals, with a focus on the decision-making of public and private investors and financiers and their policy and regulatory incentivization. Chapters 3 to 5 deep dive into aspects of the sustainable investment and finance landscape characterized in Chapter 2, providing assessments of private sustainable capital allocation decisions (Chapters 3 and 4) as well as of sustainable energy partnerships (Chapter 5). The selected approaches and methodologies are distinct across the Chapters. Therefore, in the following, an overview of the topics is provided separately, including background, scope, methodology and key findings.

1.4.1 Impacts of Public-Private International Sustainable Finance on Achieving Global Climate Goals Through Innovation and Technology Diffusion

The second Chapter conceptualizes the impact of the (insufficient) provision of financial capital—i.e., the prevalence of the ‘sustainable investment gap’—on global sustainable investment and growth. Thereby, it (a) demonstrates the relevance of sustainable investment and finance in achieving global sustainability goals on a macro level, and (b) provides an overarching framework conceptualizing the sustainable investment and finance landscape including approaches to sustainability policy and regulation.

Therefore, it proposes a macroeconomic growth model of directed technical change with an integrated endogenous financing decision. Models of directed technical change have been set up to assess the adoption of sustainable vs. non-sustainable technologies on a macroeconomic level.

Thereby, they include an endogenous decision for sustainable versus non-sustainable innovation, dependent on market size and price effects (i.e., lock-in effects) (see Section 2.2.1, e.g., Acemoglu et al., 2012). However, two dynamics are not reflected in the existing models, which we add to the existing approach: firstly, while the endogenous sustainable versus non-sustainable innovation decision is reflected, the global technology diffusion process is not modeled. This process is essential due to the essential role of technology diffusion processes (see Section 1.3.3: 70% to 80% of the sustainability transition can be realized based on existing technologies, however, their scale-up and the associated maturing of the technologies is essential) as well as due to the high relevance of a comprehensive global adoption of sustainable technologies (see Section 1.3.4) in both the developed 'global North' and the developing 'global South'. Therefore, based on the dynamics proposed in Barro and Sala-i-Martin (1997), endogenous technology diffusion processes between the 'global North' and the 'global South' are added. Secondly, in the existing models, investment and financing of sustainable technologies is not reflected. However, both play an essential role in the success of the global sustainability transition, which has been shown in multiple empirical contributions (see Section 1.3). To the end of conceptualizing and demonstrating this relevance within the macroeconomic context, an endogenous investment and financing decision by public and private financiers is added to the model. Furthermore, the model is then used to assess sustainable policy and regulatory instruments addressing investors and financiers directly: public sustainable investment and finance as well as private financial sector regulation. This is not possible in existing models not reflecting the investment and financing decision, where only policy instruments such as carbon pricing can be reflected. The proposed model, hence, includes a public and private financial sector, allowing for an endogenous financing decision in terms of internal and different external financing of technical change through different financial instruments[20]. Capturing the dynamics between the 'global North', i.e., the developed economies, and the 'global South', i.e., the developing economies, it allows for technological development to occur through innovation or imitation and, hence, capturing technology diffusion processes in the global economy.

The Chapter's findings substantiate the way in which the presence of financing costs and frictions in the financial markets—which are elevated with regards to sustainable innovation and in the developing world—cause the global economy to converge towards a non-sustainable growth path in the absence of policy intervention. Thus, neglecting an assessment of the impact of sustainable investment and finance might lead to an overly optimistic perception of the circumstances, under which global sustainable growth is achieved. Furthermore, other than existing models, the proposed model allows to assess targeted policy and regulatory instruments addressing sustainable investment and finance. It thereby demonstrates that a sufficiently high carbon price—as proposed in the existing models—can lead to carbon emission reductions. However, given the additional need for regulatory and policy incentivization resulting from financing costs and frictions, this carbon price would have to be unrealistically high and cover an extensive share of global emissions. Therefore, targeted policy and regulatory instruments addressing sustainable investment and finance directly are essential. To steer the economy to a fully sustainable growth path, both sustainable public investment and finance, and an additional regulation or incentivization of private financial investors is necessary.

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[20] Abating greenhouse gases requires climate measures across different sectors and including technologies of different maturities, with major shares being in early maturity stages, e.g., in research and development, pre-commercial or early adaption stages (see Section 1.3.3), assigning them to different asset classes. For instance, technologies in the earlier maturity stages often financed by means of alternative asset classes such as venture capital, while investments into more mature technologies are predominantly realized by means of private and public equity or debt. In the context of sustainable investments, innovative financing instruments such as green bonds have emerged, see, e.g., OECD (2015), Polzin and Sanders (2020), Polzin et al. (2021).

Aspects of the two targeted approaches are further assessed in detail in Chapters 3 and 4 (regulation or incentivization of private financial investors) as well as in Chapter 5 (sustainable public investment and finance).

1.4.2 Impacts of ESG Banking Regulation and Supervision on Financing Sustainable Mobility and Energy Technologies

Due to the pivotal role of the regulation of the financial sector identified throughout the second Chapter, a deep dive into the assessment of the effectiveness of sustainable regulation and supervision of the financial sector is provided with Chapters 3 and 4.

In Chapter 3, an empirical investigation of the effectiveness of sustainable financial regulation is presented, assessing the question of how environmental, social and governance related regulation and supervision of banks affects capital provision to the sustainability transition. Within the context of ambitious sustainability policy targets facing funding challenges, the financial sector is assigned a key role in channeling more private-sector capital into sustainable investments. However, a trade-off arises if the scale-up of sustainable technologies (partially) requires investments into non-sustainable assets, e.g., in the production of windmills, solar panels, and the mobility transition. Regarding the latter, an extensive shift to battery electric vehicles requires a considerable expansion of the supply of battery raw materials, such as Lithium, Cobalt, Manganese, and Nickel. The sourcing of such materials often exhibits severe adverse environmental, social and governance (ESG) impacts, such as health risk of miners and child labor, corruption, and the financing of conflicts, as well as risks for the protection of land-based ecosystems including extensive energy and water consumption.

While these trade-offs might have severe impacts regarding the effectiveness and efficiency of sustainable financial sector regulation, to the best knowledge of the author no assessment raising and analyzing this concern exists, yet. Hence, an analysis of this trade-off is provided, answering the question of how ESG regulation and supervision of banks impacts the capital provision to battery raw material mining companies. Concretely, the impact of the EU’s Sustainable Finance Disclosure Regulation (SFDR) and of the EU Taxonomy for Sustainable Activities (‘the Taxonomy’) on banks’ public holdings structure and cost of capital is assessed, as well as the introduction of the European Central Bank’s climate-risk-related supervisory efforts on banks’ lending. A difference-in-difference approach based on two large, novel data sets is therefore presented. It is found that the introduction of the ESG regulations has a dampening effect on the affected banks’ holdings in battery raw material mining companies, in particular those with poor ESG performance. Meanwhile, there are no observable changes in the affected companies’ share prices, pointing to a compensation by an increased demand for shares from other entities. This effect entails that the overall level of public holdings remains stable, suggesting that, *ceteris paribus*, the cost of capital does not experience any changes. These findings have several implications. First and foremost, the observation that banks, which are affected by the SFDR and the Taxonomy decrease their public holdings in battery raw material companies, and especially in those, which do not perform well across the ESG dimensions, implies that the regulations lead to the intended effects. The fact that, in the current setup, there is no coinciding increase in the companies’ share prices and, thus, cost of capital implies that the ESG regulations currently do not aggravate the underinvestment in battery raw materials sourcing. However, this might change if comparable regulations are introduced more comprehensively on a global level. Furthermore, if EU banks reduce their public holdings in less ESG compliant companies, the EU’s lever to incentivize companies to increase their ESG performance diminishes. Regarding the impact of the ECB’s climate-risk-related supervisory efforts, the analyses reveal that there are no significant effects on the affected banks’ lending patterns towards companies involved in battery raw material sourcing. Thus, the second topic provides a nuanced view of the interplay between ESG banking regulations and supervision, capital allocation decisions, and the funding of sustainable technologies. It underscores the effectiveness of ESG regulations in influencing banks’ capital allocation strategies towards more sustainable practices, while also pointing out the limitations and unintended consequences of these policies. The importance of a balanced regulatory approach, considering the multifaceted nature of sustainable finance, is highlighted.

1.4.3 Impacts of ECB Banking Supervision on Climate Risk and Sustainable Finance

In Chapter 4, an empirical analysis of the impact of the ECB’s climate-risk-related supervisory efforts on the induced banks’ portfolio choices with regard to sustainable finance and on climate risk exposure and management of banks. In the recent years, climate change and climate risk have become two of the key concerns for policy makers at central banks and in banking supervision. One reason for that is rooted in a dual role the financial sector plays with respect to climate risks and the ‘green transition’. While on the one hand, as mentioned above, the financial sector has been assigned a key role in financing the transition to climate-neutral economies, on the other hand, exposures due to climate risks impose an increasing challenge to the stability of the financial sector. Against this background, from 2020 onwards, the ECB has introduced various measures to enhance climate-risk-related supervisory efforts. The first one of those has been the 2020 ‘ECB Guide on Climate-related and Environmental Risks’ that has provided the basis for a subsequent supervisory review of banks’ climate risk management. Exploiting the fact that the ECB’s climate supervision has only been introduced for select banks (i.e., the Significant Institutions) within the EU under the Single Supervisory Mechanism, while other banks (i.e., the Less Significant Institutions) have remained unaffected, a difference-in-difference setup is presented based on a new extensive data set merged from Refinitiv Eikon, Capital IQ, Bloomberg, and ECB Corep data. A significant impact on both an increase in banks’ green finance activities and on improvements in climate risk exposure and management is found. However, environmental data availability needs to be significantly improved to better understand and estimate the effects. Additional regulatory and policy efforts will be necessary to improve the assessment and evaluation of banks’ climate risk exposure and management and banks’ contribution towards financing a green transition.

1.4.4 New Green Alliances: Requirements to Implement Long-Run International Sustainable Energy Partnerships

Chapter 5 focuses on sustainable investments in the energy sector. Within the energy industry, implications of the sustainability transition are the most significant. Fossil fuel generation, with a share of approx. 35% to 45% in global greenhouse gas emissions, makes the energy sector the largest carbon emitter (IEA, 2021). This also entails the largest requirements for sustainable investment and finance into the new generation, transmission, distribution, and storage facilities within the next years and decades.

As described in Section 1.3.4.2, new international sustainable energy partnerships based on renewable energy sources are a promising approach to realize sustainable investments in the energy sector to sustain security of supply and achieve climate and development goals at improved economic conditions. However, a successful implementation of such partnerships is not trivial, as business cases have yet to be developed, and multiple governments and private stakeholders with diverging interests are involved. An evolutionary game theoretical approach is presented to assess conditions for the long-term stability of international sustainable energy partnerships on the example of an Africa-EU hydrogen partnership. Such partnerships can involve public and private entities in different constellations, ranging from purely public investments to purely private investments via any collaboration form (e.g., PPPs) in between (see also Section 1.3.2). While all forms of partnerships can be modeled with the proposed approach, the focus of the assessment is laid on partnerships, which involve both public and private players, realized as PPPs under the aegis of international energy partnerships between governments. This is due to the promising advantages of PPPs—especially in cases in which developing economies are involved—discussed in Section 1.3.2. The proposed model describes sustainable energy partnerships as an infinite game. Sustainable energy partnerships are aimed at meeting the long-term RES requirements of the parties involved. Therefore, the model not only describes stand-alone international PPPs with finite durations, but long-term international energy partnerships, under whose cooperation multiple PPPs can be realized, in overlapping or subsequent order. For governments, hence, cooperation implies a long-term commitment to the partnership, setting the institutional framework conditions for the investment cooperation, while private sector cooperation describes the commitment to PPPs, which are set up within this context.

It is found that currently, the considerable costs of renewable energy sources and incompletely priced environmental externalities inhibit a sufficient cooperation of the private sector, and stand-alone improvements in the business cases are insufficient to incentivize a long-term cooperation. Thus, the design of the cooperation agreements between the governments as well as the design of the public-private partnership contracts are important influencing factors regarding the long-term success of sustainable energy partnerships. In particular, a co-investment of all involved governments is crucial, as otherwise, governments can realize windfall profits, which disincentivize them to cooperate in the long run. Also, it is shown that availability-based public-private partnerships with a full-fledged private sector involvement in designing, financing, building, operating, and maintaining the partnership are the preferrable setup, as under this design, the business case for private investors is improved, while windfall benefits for governments are further reduced.

1.5 Limitations and Future Research

Limitations of this dissertation result from the selected scope, the methodology choice and from data availability. The overarching limitations and possibilities for future research resulting from these three dimensions are described in the following, while more detailed and specific limitations and future research are provided at the end of each Chapter.

First and foremost, while an increasing number of contributions exist investigating the role of sustainable investment and finance, the field is still relatively new and requires extensive research.

This dissertation contributes to addressing this lacuna. Therefore, the four themes above address the impact of international public-private interaction in sustainable investment and finance. In Chapter 2, a macroeconomic growth model of directed technical change incorporating an endogenous financing decision is presented, allowing for an assessment of the impact of financial frictions in sustainable growth, as well as an assessment of different policy instruments such as a sustainable regulation of the financial sector and sustainable public and private investment (including public-private partnerships). Chapters 3 and 4 deep dive into the subject of sustainable regulation of the financial sector on the example of the EU and eurozone, and Chapter 5 provides an analysis of international sustainable energy public-private partnerships on the example of an EU-Africa sustainable energy partnership. Hence, this dissertation shows the space through which general international public-private approaches increased sustainable finance can be achieved. Nevertheless, as the field as a whole is still rather rudimentarily investigated, substantial research will be necessary in the coming years to better understand the relationship of the financial and the real sectors in an environment of desired sustainable growth. This can be done by additional and refined theoretical assessments, further refining the conceptualization of the relationship, as well as empirical assessments, complementing the ones presented in the Chapters 3 and 4. These further empirical assessments can, for instance, cover different sets of economies and their respective policy instruments. Also, while the empirical assessments presented in the Chapters 3 and 4 are purely positive (meaning that they do assess, if a statistically significant impact of sustainable banking regulation is observable, while they do not reveal any information on if this contribution is sufficient to comply with sustainability policy targets), normative assessments also testing for the sufficiency of the instruments can be performed.

Further limitations and possibilities for future research result from the methodology choice within each of the Chapters. Within this dissertation, model-based approaches are presented, i.e., a macroeconomic growth model of directed technical change in Chapter 2, statistical difference-in-difference models in the Chapters 3 and 4, and an evolutionary game theoretical model in Chapter 5. Alternative, e.g., qualitative, methodologies could be selected, potentially revealing distinct or additional insights. Generally, as each model is an abstraction from reality based on the simplified or generalized representation of real-world situations, also the model selection presented in the Chapters 2 to 5 determines, which interrelations are analyzed, based on which set of assumptions. Therefore, going forward, analyses based on different models including different levels of abstraction and sets of assumptions and parametrizations can be insightful.

Finally, the availability of data related to climate and sustainability constitutes limitations to the research. While within all analyses throughout this dissertation, sensitivity analyses are performed to address limitations in data availability, coverage, data quality (especially related to broad ranges in estimates such as hydrogen prices, and in the context of greenwashing) a lack of standardization, and, hence, comparability, as well as insufficient data granularity impose limitations to the meaningfulness of the analyses. Therefore, further interesting future research will be possible, as soon as data availability has improved, and it will be worthwhile to re-run the present analysis and compare those results with the present ones and to perform additional analyses.

1.6 Overarching Conclusions

Along the four Chapters, this dissertation underscores the pivotal role of adequately considering sustainable investment and finance in the sustainability transition to the end of achieving sustainability targets globally.

The findings reveal that financial markets and financial frictions play a substantial role not only in shaping the trajectory of sustainable investment and finance, but are also a key determinant for an effective realization of sustainable growth globally. Path dependencies and lock-in effects may divert the economy from a sustainable growth path if investments are not strategically directed towards sustainable technologies. Chapter 2 highlights these dynamics. The analysis further delineates the solution space for policy instruments in fostering public-private sustainable finance, emphasizing the roles of (i) carbon pricing, (ii) financial sector regulation and supervision, and (iii) sustainable public and private investments, including public-private partnerships.

With regards to (i) carbon pricing, it is found that while a carbon price can generally serve as a tool for steering investments towards sustainability, its effectiveness is contingent upon being set at an appropriate level and coverage. This means that an adequately high carbon price would have to be introduced with a high sector and global coverage, both in the 'global North' and the 'global South', as discussed in Chapters 2 and 5. While it is a common sense that a sufficiently high and comprehensive carbon pricing would be the most efficient policy instrument, an adequate implementation is very unlikely to be realized. This is especially, since existing models, which do not account for the dynamics underlying sustainable investment and finance, systematically underestimate the magnitude of the carbon price, which is necessary to achieve sustainable growth globally. Therefore, within this dissertation, the focus is laid on alternative ways to incentivize the sustainability transition, which can be deployed in addition to a carbon pricing, whose coverage is fragmented and whose magnitude insufficient. Regulation and supervision of the financial sector (ii) emerge as critical levers for promoting sustainable investments, with the potential to significantly influence sustainable investment and finance. This is shown in particular for the Eurozone countries in Chapter 4. However, incentivizing the financial sector requires careful alignment with other policy instruments and an acute awareness of the nuances associated with emerging sustainable technologies like electric vehicles and new energy technologies, to avoid counterproductive outcomes, as shown in Chapter 3. Despite the positive impacts of these policy instruments, the research in Chapter 2 also cautions that sustainable regulation and supervision of the financial sector are not alone sufficient to catalyze the level of investment needed to achieve sustainable growth on a global scale. The analysis further elucidates the importance of (iii) sustainable public and private investments, including public-private partnerships. Within this context, the structural design of international public-private partnerships in motivating cooperation among all stakeholders is assessed. The analysis results highlight that stand-alone improvements in the business cases underlying the sustainable energy partnerships do not lead to long-term stable partnerships. This underlines the imperative to synergistically integrate techno-economic evaluations with macro-economic assessments in the pursuit of sustainable finance and investment strategies, since the stand-alone consideration of one of the perspectives leads to incomplete assessments and potentially misleading conclusions. Beyond pure business case considerations, it is crucial for the long-term success of sustainable energy partnerships that both cooperation agreements and public-private partnerships are carefully designed. Private sector investors are more likely to cooperate within sustainable energy investment partnerships where a business case has yet to be developed if the public-private partnerships are designed as availability-based. This is, as the risk associated with the energy projects is mainly borne by the governments. Also, as governments bear the risk and collect the initial revenues from the energy projects, their interest to cooperate is higher in the long run, as they have an interest in recovering their initial investments. For all governments to cooperate, co-investment of all involved parties is identified as a critical factor for success.

In conclusion, this dissertation advocates for a multi-faceted approach to sustainable investment and finance. It emphasizes the need for harmonized policy instruments and strategic international public-private collaborations to realize the global ambition of sustainable growth effectively and efficiently.

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Chapter 2

Impacts of Public-Private International Sustainable Finance on Achieving Global Climate Goals Through Innovation and Technology Diffusion

List of Abbreviations

CES	Constant elasticity of substitution	G7	Group of Seven
		HH	Household
ESG	Environmental, social and governance	OPEX	Operational expenditures
		ODE	Ordinary differential equation
E1	Economies 1 (‘global North’)	PF	Production function
E2	Economies 2 (‘global South’)	PPP	Public-private partnership
FI	Financial intermediaries	RES	Renewable energy sources
FOC	First-order condition	ROW	Rest of the World
GDP	Gross domestic product	TFP	Total factor productivity

2.1 Introduction

For the achievement of climate policy goals, the development and diffusion of low-carbon technologies plays a key role[21] (e.g., IEA, 2021, for the energy sector). The achievement of climate policy goals is a global effort, and technological developments and diffusion must take place across both developed and developing economies[22]. The innovation and diffusion of cutting-edge technologies require considerable investment volumes (cf. e.g., Pollitt & Mercure, 2018; BCG, 2021). However, in both developed and developing economies, financial constraints such as limitations in cash availability and constrained access to external financing options such as private

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[21] This is especially the case, as the transition to a sustainable economy is supposed to not take place at the expense of economic performance, currently measured in growth targets. A discussion of an adjustment of growth targets by alternative metrics exists, see literature related to zero-growth economics, e.g., Daley (1973; 1991), Raworth (2017).

[22] This generally holds true if all climate targets are supposed to be reached. The question of the distribution of effort and costs, in particular between the industrialized, developed economies (often referred to as the ‘global North’) and the less industrialized, developing economies (often referred to as the ‘global South’) is controversial (e.g., Shue, 1993; Caney, 2010).

and public equity and debt impose severe challenges to raising sufficient capital for investments. The current macroeconomic environment characterized by increasing inflation and rising interest rates further aggravates the constraints (IMF, 2014; 2020 to 2023; Sinn, 2021). While this holds true for the financing of any kind of investment, the financing of innovation and technologies with low maturities face additional challenges. Outcomes of research and development are uncertain by nature, and information asymmetries often markedly increase the uncertainty for potential financial investors (Kerr and Nanda, 2015; Hahn et al., 2019). Also, innovators are often young, small, and technology-intensive firms with, hence, unfavorable risk profiles, for instance lacking a longer track record and any substantial collateral (cf., Hall and Lerner, 2010; Ascani et al., 2020).

These challenges are aggravated in the sustainable innovation space. To underpin this, it is worthwhile to illuminate more closely the nature of the required technology to be subject to innovation, the actors involved in the innovation processes, as well as the potentially available financing vehicles and financiers behind them. The most GHG-intensive sectors are the energy industry, the buildings sector, the transport sector, as well as the aggregate remaining industry, followed by other emitting sectors such as agriculture[23] (e.g., BCG, 2021). All these sectors are infrastructure-heavy[24], and within all these sectors, a reduction of greenhouse gas (GHG) emissions requires a replacement or improvement of the legacy infrastructure. For instance, in the energy industry, fossil energy power plants need to be replaced by power plants based on renewable energy sources (RES), and the electricity grid needs to be modified in a way that it serves the RES-based system (cf. Schreiner and Madlener, 2021; 2022). In the transport sector, alternative drive

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[23] Depending on the economic structure of different countries, the size and the emission intensities of these emitting sectors can vary. For instance, in developing economies, where agriculture represents a large part of economic output, the shares of total GHG emissions emitted by this sector are generally higher than in developed economies, where agriculture represents a smaller part of economic output.

[24] Often including critical infrastructure. We deploy a broad definition of infrastructure, involving not only infrastructure facilities, which are subject to market failures such as network externalities (e.g., related to the electricity grid), but also any form of capital-expenditure-heavy facilities, such as power plants.

technologies such as battery-electric vehicles can reduce GHG emissions, entailing the need for an according charging infrastructure, and production and recycling facilities for batteries. In the manufacturing industry, for instance, more energy-efficient machine parks, or carbon capture, utilization, and storage facilities can be installed. All these examples highlight that investments in innovation in sustainable technologies are characterized by high capital expenditure requirements. Furthermore, investments related to infrastructure are usually characterized by comparably small expected returns. In the case of infrastructure investments based on mature technologies, these small expected returns often come along with low-risk profiles of the investments, which make them attractive investment options for investors looking for low-risk-low-return profiles such as institutional investors (cf., e.g., Della Croce and Yermo, 2013; OECD, 2021). When considering investments into innovative sustainable infrastructure, however, both the expected returns and the risk profiles tend to be less attractive. Unless environmental externalities are fully internalized[25], investment decisions into sustainable innovation can be motivated by non-monetary goals and thus, investment decisions are not necessarily based on a return-on-investment approach in monetary terms. Hence, revenues tend to be smaller, while risk is elevated, especially given policy uncertainty regarding green premia, and increasing merchandising risk. Besides, path dependencies and lock-in effects can make innovation in the sustainable space the less attractive investment option (cf., Awerbuch, 2000; Mazzucato, 2013, 2018; Yu et al., 2021). Due to the nature of sustainable innovation being infrastructure-heavy, as well as due to the global nature of the sustainability transition, actors involved in the sustainable innovation process stem from both the public and the private sectors, and they involve economies across the globe. Sustainable innovation is, therefore, an effort requiring both public-private and transnational cooperation (cf., e.g., Dechezleprêtre and Sato, 2017; He and Tian, 2018; Owen et al., 2018; D'Orazio and Valente, 2019). These

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[25] Either by pricing environmental externalities adequately, for instance by setting a carbon price, or caused by buying decisions which reflect a positive willingness to pay a sustainability premium.

characteristics impact the attractiveness of the sustainable investment options to different financiers in different ways[26]. In general, however, the outlined financing challenges of sustainable innovation can be expected to lead to considerable underinvestment and a constrained development of sustainable technologies (cf., e.g., Mercure et al., 2019). Improving financing conditions for sustainable innovation is, hence, an indispensable lever to successfully achieve climate policy and sustainable development goals.

Despite its vital role, not much research exists so far on how the financing of sustainable innovation and technology diffusion impacts the achievement of global climate policy and sustainable development goals, which inefficiencies regarding sustainable innovation arise from financing constraints, and which measures can be taken to address these inefficiencies. This Chapter attempts to contribute to filling this lacuna by incorporating financing decisions in an environment of imperfect financial markets into a model of directed technical change that is based on innovation and imitation (i.e., technology diffusion) activities in developed and developing countries.

The Chapter's findings substantiate the way in which the presence of financing costs and frictions in the financial markets—which are elevated with regards to sustainable innovation and in the developing world—cause the global economy to converge towards a non-sustainable growth path in the absence of policy intervention. Thus, neglecting an assessment of the impact of sustainable investment and finance might lead to an overly optimistic perception of the circumstances, under which global sustainable growth can be achieved. Furthermore, other than existing models, the proposed model allows to assess targeted policy and regulatory instruments

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[26] External financing can, for instance, be provided by private actors such as private banks, equity funds including venture capital funds, and corporates, or public intermediaries such central banks, development banks or governments. Different groups of investors have different preferences, depending on the characteristics of sustainable innovation itself or the characteristics of the innovator. Different forms of financing are, due to their distinct characteristics, better or less well suited for financing, given the distinct characteristics in the green and non-sustainable spaces and the different investment environments in developed and developing economies.

addressing sustainable investment and finance. It thereby demonstrates that a sufficiently high carbon price—as proposed in the existing models—can lead to carbon emission reductions. However, given the additional need for regulatory and policy incentivization resulting from financing costs and frictions, this carbon price would have to be unrealistically high and cover an extensive share of global emissions. Therefore, targeted policy and regulatory instruments addressing sustainable investment and finance directly are essential. To steer the economy to a fully sustainable growth path, both sustainable public investment and finance, and an additional regulation or incentivization of private financial investors is necessary.

2.2 Current State of the Art and our Contribution

This Chapter proposes a macroeconomic growth model of directed technical change with an integrated endogenous financing decision. Models of directed technical change have been set up to assess the development and adoption of sustainable vs. non-sustainable technologies on a macroeconomic level. Thereby, they include an endogenous decision for sustainable versus non-sustainable innovation, dependent on market size and price effects (i.e., lock-in effects) (see, e.g., Acemoglu et al., 2012). However, two dynamics are not reflected in the existing models, which we add to the existing approach: firstly, while the endogenous sustainable versus non-sustainable innovation decision is reflected, the global technology diffusion process is not modeled. This process is essential due to the key role of technology diffusion processes[27] as well as due to the high

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[27] While it is challenging to quantify innovation requirements globally, some estimates exist. Estimates of percentages how much of the sustainability transition can be implemented based on existing and mature versus innovative and immature technologies range from 70% to 90% based on existing, the remainder based on innovative technologies (IEA, 2021a,b; BCG, 2021). While these numbers suggest that the amount of required innovation is manageable, the diffusion of sustainable technologies is equally important. Both in developed and developing economies, it is important that existing sustainable technologies are comprehensively adopted. This also implies that existing sustainable technologies, which are often still at low maturity levels, are further developed while being rolled out. During this process, also advantages of scale and scope can be realized, leading to further cost decreases.

relevance of a comprehensive global adoption of sustainable technologies (see Section 1.3.4) in both the developed 'global North' and the developing 'global South'. Therefore, based on the dynamics proposed in Barro and Sala-i-Martin (1997), endogenous technology diffusion processes between the 'global North' and the 'global South' are added. Secondly, in the existing models, investment and financing of sustainable technologies is not reflected. However, both play an essential role in the success of the global sustainability transition, which has been shown in multiple empirical contributions (see Section 1.3). To the end of conceptualizing and demonstrating this relevance within the macroeconomic context, an endogenous investment and financing decision by public and private financiers is added to the model. Furthermore, the model is then used to assess sustainable policy and regulatory instruments addressing investors and financiers directly: public sustainable investment and finance as well as private financial sector regulation. This is not possible in existing models not reflecting the investment and financing decision, where only policy instruments such as carbon pricing can be reflected. The proposed model, hence, includes a public and private financial sector, allowing for an endogenous financing decision in terms of internal and different external financing options of technical change through different financial instruments[28]. Capturing the dynamics between the 'global North', i.e., the developed economies, and the 'global South', i.e., the developing economies, it allows for technological development to occur through innovation or imitation and, hence, capturing technology diffusion processes in the global economy.

This Chapter, thus, builds upon and contributes to different strands of literature related to (A) endogenous growth and innovation, (B) innovation finance and capital structure decisions, and (C)

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[28] Abating greenhouse gases requires climate measures across different sectors and including technologies of different maturities, with major shares being in early maturity stages, e.g., in research and development, pre-commercial or early adaption stages (see Section 1.3.3), assigning them to different asset classes. For instance, technologies in the earlier maturity stages often financed by means of alternative asset classes such as venture capital, while investments into more mature technologies are predominantly realized by means of private and public equity or debt. In the context of sustainable investments, innovative financing instruments such as green bonds have emerged, see, e.g., OECD (2015), Polzin and Sanders (2020), Polzin et al. (2021).

literature assessing how the decision-making and dynamics in the financial economy assessed in the latter literature strand impact the dynamics of the real economy assessed in the former literature strand. Contributions in all three fields have often emerged unrelatedly to sustainability considerations, but with the increasing relevance of sustainable and green developments, many contributions have enhanced the fields by adding a sustainability perspective. In relation to the analyses presented in this Chapter, hence, sustainability-irrelated contributions often provide the theoretical foundations, which then have been further adjusted and developed, while the fundamental insights are still relevant as a basis for our research. Table 1 provides an overview of the three related literature strands and sub-strands, as well as a brief description in the spaces unrelated and related to sustainability (columns three and four). The highlighted field points to the field of our contribution. In the following, we provide a description of seminal contributions in the field. A summary of the contributions is provided in Table 1.

Table 1: Strands of Related Literature

Literature Strand	Sub-strand	(I) Sustainability-unrelated	(II) Sustainability-related
(A) Real economy: Endogenous growth and innovation	(A.1) Growth, innovation, and technological diffusion	Endogenous innovation and technology diffusion as explanation for growth	Green growth models, incorporating environmental externalities
	(A.2) Directed technical change	Direction of technological change based on path dependencies and lock-in effects	Models of directed technical change including ‘clean’ and ‘dirty’ sectors
	(A.3) Climate policy models & sector-specific models	N/A, as rooted in the sustainability-related space	Climate models to assess the impact of environmental policies or sector-specific models to assess, e.g., aspects of the energy transition
(B) Financial economy: Innovation finance and optimal capital structure	(B.1) Optimal capital structure decisions and private innovation financing	Explanations for the capital structure decisions of corporations, i.e., the choice between debt, equity, and other financing options	Considerations regarding adequate financing of sustainable innovation, often in the context of the energy transition
	(B.2) Public-private innovation finance	The role of the public sector (i.e., governments and agencies) in innovation and innovation finance	Financing innovation with non-profit goals, e.g., ‘Mission-oriented’ research and development, public-private partnerships, innovative financing instruments
(C) Real and financial economy: Impact of financing on real economy	(C.1) Finance in innovation and technological diffusion & in the energy transition	The impact of dynamics in the financial sector on real economy outcomes, e.g., regarding innovation volumes and direction	• The impact of dynamics in the financial sector on green growth & the achievement of climate goals • Sector-specific models incorporating the financial economy, e.g., E3 models incorporating a financial sector

Note: Our original contribution is located in the field highlighted in grey color.

2.2.1 Real Economy: Endogenous Growth and Innovation (A)

Endogenous growth theories emerged in the late 20th century as an alternative to the neoclassical growth models, emphasizing the role of innovation and technology in long-term economic growth (key literature see below). Other than in the neoclassical growth models, in which growth is exogenous and driven by factors like population growth or capital accumulation, growth is driven by endogenous factors, such as human capital accumulation, knowledge spillovers, or research and development activities (cf., Novales et al., 2022). Within the field of endogenous growth theories, growth models focusing on the role of knowledge and innovation provide the background for our considerations. While their origin is not related to sustainability considerations, endogenous growth theories based on innovation have been adjusted and developed to reflect sustainability considerations.

2.2.1.1 Growth, Innovation, and Technological Diffusion (A.1)

Amongst the growth models focusing on innovation, our research builds upon the class of models in which innovation is reflected as an increasing number of producer products, i.e., product variants, and growth is caused by spillover effects. The approach roots back to the Romer model (Romer, 1986; 1987; 1990), which explains growth within a one-country, one-sector economy, in which a representative producer of a final good deploys an increasing number of intermediate input varieties. The increase in varieties—which can also be interpreted as knowledge accumulation[29]—has the effect of an increase in the overall economic efficiency, which is comparable to the effect

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[29] As compared to other growth models based on product variants such as the one established by Aghion and Howitt (1992), which is based on creative destruction, meaning that, other than in the Romer model, with the emergence of a new product variant, the established variant becomes obsolete. Other contributions such as Acemoglu and Cao (2015) have merged the two approaches, and included different aspects, such as the role of institutions and policy interventions, the role of technology markets (Peretto, 1998; Akcigit et al., 2016; 2018) or the role of patents (Grossman and Lai, 2004; Zeira, 2011; Aghion et al., 2015).

of an increase in total factor productivity (TFP). Subsequent approaches have refined the theory. A seminal contribution stems from Barro and Sala-i-Martin (1997), which adds a technology diffusion process to the model. The model establishes the concept of a leader country, in which—as in the Romer model—new product variants emerge through innovation, and a follower country, which copies existing product varieties from the leader country. By doing so, the model allows to capture dynamics between developed and developing economies.

Building upon the insights from the endogenous growth models, multiple approaches have been suggested to reflect sustainability considerations in endogenous growth models. Seminal contributions in the field stems from Nordhaus (1994, 2013). The DICE (Dynamic Integrated Climate-Economy) model developed by William Nordhaus is an integrated assessment model that combines economic growth and climate change dynamics. It focuses on the interplay between economic activity, greenhouse gases emissions, and the resulting impacts of climate change and is designed to estimate the optimal path of carbon emissions and climate policy by considering the costs and benefits of reducing emissions. While the original DICE model did not include endogenous growth, further developments of the model do (cf. e.g., Goulder and Mathai, 2000). Other approaches exist as well. Popp (2002; 2004; 2006) explores the relationship between energy use and energy prices, technological change, and economic growth. Brock and Taylor (2010) integrate environmental factors into the traditional Solow growth model, examining the impact of natural resource constraints and environmental quality on long-term economic growth. Van der Ploeg and Withagen (2012) investigate the role of natural resources in economic growth in a growth model that is based on learning-by-doing, where productivity improvements occur as a result of accumulated experience in the extraction and use of natural resources.

2.2.1.2 Directed Technical Change (A.2)

A particular type of endogenous growth model develops the concept of directed technical change, which emphasizes that "innovation does not only have a size, but also a direction"

(Acemoglu et al., 2012). The idea of directed technical change has been introduced in endogenous growth modeling by Acemoglu (1998, 2002), who studies how the direction of technological progress—shown for the example of a two-sector model—can be influenced by relative factor prices and by market sizes. Doing so, this Chapter conceptualized path dependencies and lock-in effects affecting the type of innovation occurring in an economy.

The idea of directed technical change has been applied to questions around optimal policy intervention regarding the achievement of climate goals, which had been previously treated, *inter alia*, by means of the sustainability-related growth models introduced above. Acemoglu et al. (2012) apply the concept of directed technical change towards one of two sectors to the case of a 'clean' and a 'dirty' sector, the direction of the change following the same mechanisms as in their previous, sustainability-unrelated work. Other than in Acemoglu (2002), however, the endogenous growth mechanism is not based on the emergence of product variants, but on an increasing factor productivity in the intermediate goods production function (PF). The model of 'Directed Technological Change and the Environment' is complemented by the accumulation of GHG emissions, which impose disutility on private households (HH), and which eventually lead to an environmental collapse once accumulated emissions exceed a 'tipping point'. The conclusion of the work is that immediate and decisive intervention is necessary to break path dependencies and set the world economy on a path of 'clean' innovation.

2.2.1.3 Climate Policy Models and Sector-specific Models (A.3)

Apart from the originally sustainability-unrelated macroeconomic growth models incorporating sustainability, various other approaches investigating the role of sustainability in economic developments exist. One type of approach are energy and environmental models, in which some form of endogenous technical change has been incorporated, such as, for instance, in Grubb et al. (2002), Gillingham et al. (2008) and Goulder et al. (2016). These approaches take different economic models, such as equilibrium models or sector-specific partial equilibrium models and incorporate some form of endogenous technical change.

2.2.2 Financial Economy: Innovation Finance and Optimal Capital Structure (B)

Shedding light on the financing of sustainable innovation builds upon two broad strands of literature, which deal with innovation financing of private actors such as corporations or entrepreneurs, as well as the decision-making regarding optimizing the capital structure on the one hand, and innovation finance involving public-private partnerships (PPP) on the other.

2.2.2.1 Optimal Capital Structure Decisions and Private Innovation Financing

Contributions regarding optimal capital structure decisions seek to find explanations for the capital structure decision of private companies, i.e., their selection and composition of different internal and external financing instruments such as cash, debt, or equity. Thus, contributions in the field are not solely related to innovation financing, but rather cover capital structure decisions for all kinds of investments including the financing of innovation (Straebulaev and Whited, 2012).

With their seminal work 'The Cost of Capital, Corporation Finance, and the Theory of Investment', Modigliani and Miller (1958) established the Modigliani-Miller Theorem which postulates that under the assumption of perfect capital markets, the firm value is unaffected by its capital structure, and the financing decision is irrelevant. However, empirical evidence suggests that many capital market imperfections in the form of financial frictions incl. financing frictions[30] exist. Hence, manifold approaches have been developed since, adducing different forms of capital

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[30] Financial frictions usually refer to a broader range of imperfections of financial markets incl. financial intermediaries. They include financing frictions, referring to the barriers or difficulties that companies face in obtaining external financing arising from factors such as asymmetric information between lenders and borrowers, transaction costs, or legal and regulatory restrictions. Beyond this, financial frictions also encompass a broader set of issues related to financial market imperfections, such as market incompleteness, agency problems, and externalities (Gertler and Kiyotaki, 2010).

market imperfections as an explanation for firms' capital structure decisions. These approaches include the trade-off theory, the pecking order theory, and the market timing theory, which have been applied specifically to innovation financing. The trade-off theory posits that firms choose a mix of debt and equity that balances the tax advantages of debt with the costs of financial distress, which may arise if a firm cannot meet its debt obligations and is forced to default or restructure its debt. This theory suggests that firms with stable cash flows and tangible assets, such as property and equipment, are more likely to use debt financing to fund innovation, while firms with less stable cash flows and intangible assets, such as intellectual property, are more likely to use equity financing (Kraus and Litzenberger, 1973; Scott, 1976; Miller, 1977; Fama and French, 2002). The pecking order theory proposes that firms prefer internal financing, such as retained earnings, to external financing, such as debt and equity, to fund innovation; and equity over debt financing[31] (Brown et al., 2009; 2015). This is because internal financing does not require firms to give up control or incur transaction costs, mainly caused by information asymmetries and moral hazard (Donaldson, 1961; Myers and Maljuf, 1984). The market timing theory suggests that firms may time their issuance of debt and equity to take advantage of market conditions. It proposes that firms will issue equity when their stock prices are high, and choose debt when their stock prices are low, to maximize their financing flexibility and minimize their cost of capital. In the context of financing innovation, the market timing theory suggests that firms may be more likely to issue equity to fund high-risk, high-reward projects, and use debt to fund lower-risk projects with more predictable cash flows (Baker and Wurgler, 2002; Lynadres, 2007; Baker and Martin, 2011). These theoretical approaches have been widely reflected in approaches to financial modeling (for an overview see Streabulaev and Whited, 2012). Furthermore, other determinants of the optimal capital structure

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[31] This hypothesis is also controversially discussed: depending on the nature of the investment, equity financing can be preferrable, since, firstly, it does not require a collateral and, secondly, unlike providers of debt, equity investors share in the upside of the investment. This can make external equity cheaper and more favorable than external debt (Brown, et al., 2009; 2015).

choice such as different macroeconomic conditions, e.g., in developed vs. developing economies have been analyzed for instance by Korajczyk and Levy (2002), and Booth et al. (2001). Kerr and Nanda (2015) provide a literature review regarding the latter aspect.

In the context of sustainable finance and sustainable innovation finance, apart from these general factors, there are other, more particular factors impacting the capital structure decision one the one hand, and the financing availability and costs on the other hand (Haqiqi and Mirian, 2015). Helms et al. (2015), for instance, emphasize the difference in both the investment characteristics and the investor base of RES vs. fossil energy infrastructure, as well as frictions arising from a limited access to knowledge and human resources and information asymmetries. Noally and Smeets (2016) particularly shed light on the effects of the usually smaller firms investing in the sustainable innovation space. Egli et al. (2022) emphasize the relatively higher impact of the cost of capital—which can change over time, e.g., due to changing interest rates (Schmitt et al., 2019)—on RES-related investments, compared to rather high operational expenditures (OPEX) technologies in the fossil space (see also Steffen, 2020; Polzin et al., 2021; Steffen and Waidelich, 2022) and Ameli et al. (2021) for a perspective involving developing economies. BCG (2023) provide a more applied approach and outline different risk-related financial frictions of sustainable technologies, such as elevated technology and merchandising risk accompanied by information asymmetries and leading to prohibitively high risk premia, making many sustainable technology projects unbankable.

2.2.2.2 Public-private Innovation Finance (B.2)

Financing involving private actors such as private corporates and public stakeholders such as governments and development banks is another area of interest in capital structure decisions. In this context, firms may seek financing from both private and public sources, each of which may have different objectives and expectations for the use of funds. Several theories have emerged to explain how firms choose to finance their operations and growth initiatives in this complex environment, including the agency theory, the stakeholder theory, and the signaling theories (cf. e.g., Jensen and Meckling, 1976; Freeman, 1984).

Regarding sustainable innovation finance, public-private approaches are often seen as a means to close investment gaps, as well as to allocate risks in a more efficient manner (cf. e.g., OECD, 2017; 2020). In this context, *inter alia* OECD (2019) investigate the role of alternative financing vehicles in sustainable finance, including, for instance, PPPs. Regarding more specific characteristics and criteria for an efficient setup and design of such alternative vehicles, different streams of specialized in-depth research exist. For instance, regarding PPPs, Roumboutsos and Saussier (2014) investigate which type of PPP contract most efficiently incentivizes public-private innovation. Aghion et al. (2013) more generally investigate the effects of institutional ownership on innovation.

2.2.3 Real and Financial Economy: Impact of Financing on the Real Economy (C)

2.2.3.1 Finance in Endogenous Growth and Innovation (C.1)

In the recent years, the incorporation of financial frictions in macroeconomic growth models has emerged as a crucial area of research in the field of macroeconomics. The seminal works of Bernanke and Gertler (1989) and Kiyotaki and Moore (1997) laid the foundation for the study of credit market imperfections and their impact on macroeconomic outcomes. To explore the importance of financial frictions in business cycle dynamics, Christiano et al. (2003) and Bernanke et al. (1999) developed dynamic stochastic general equilibrium (DSGE) models that incorporate financial frictions and demonstrated their significance in explaining economic fluctuations. Gertler and Kiyotaki (2010) provide further insights into the role of financial intermediaries (FI) in transmitting shocks to the real economy. Another line of research has focused on the role of financial frictions in shaping long-term economic growth. Aghion et al. (2005) and Levine (2005) have shown how financial frictions can hinder the efficient allocation of resources and impede technological progress, ultimately affecting growth prospects. More recently, Midrigan and Xu (2014), Mendoza and Quadrini (2018) and Elenev et al. (2020) have explored the implications of financial frictions for international trade and capital flows, highlighting the interdependence between financial markets and macroeconomic growth across countries. On the development economics side, for instance, Brunnschweiler (2010) explores the relation between financial development and real economic development.

Regarding the impact of financing sustainable innovation, the role of finance has been considerably underestimated (Mercure et al., 2019). De Haas and Popov (2022)—providing some empirical insights regarding the relationship between finance and green growth—point to the limited understanding of the relation between regular finance and the environment and emphasize that to date, no rigorous evidence exists on how finance affects industrial pollution when economies grow and its relevance for a large scale decarbonization transition and its impact on the macroeconomy. For instance, only few of the current E3 models have representations of a stylized financial sector, (e.g., as in GEA, 2012; IPCC, 2014b; Kriegler et al., 2014; Pollitt & Mercure, 2018). Besides these energy-specific approaches, some empirical evidence exists regarding the way in which sustainable innovation finance and the type of financiers impact the type of innovation. Ghisetti et al. (2015) and Noally and Smeets (2016) qualitatively describe the role of financing constraints for directed technical change from fossil fuel to renewable innovation. Mazzucato (2013, 2018) and Mazzucato and Semieniuk (2018) describe the impact of the type of finance on the direction of innovation, mainly making a distinction between public and private finance. They provide recommendations regarding how to regulate the financial sector to better serve public goals based on an empirical study of the preferences and investment patterns of different public and private financiers regarding sustainable vs. non-sustainable investments. Furthermore, and referring to the impact of the European Central Bank as a financier for sustainable innovation, Papoutsi et al. (2022) present an assessment of the impact of quantitative easing on sustainable developments in the economy. The analyses provided in the following contribute to this strand of literature, providing an approach to conceptualize the way in which dynamics in the financial sector impact sustainable vs. non-sustainable innovation.

2.3 The Model

2.3.1 The Private Households

We consider an infinite-horizon continuous-time economy, admitting Ramsey-type private HH with the standard constant relative risk aversion (CRRA) preference,

$$U_i = \int_0^\infty e^{-\rho t} \frac{C_i^{1-\theta} - 1}{1 - \theta} dt \, , \tag{1}$$

with HH utility U_i, a constant rate of time preference $\rho > 0$, a constant elasticity of the marginal utility of consumption[32] $\theta > 0$, and consumption C_t. The HH supply is labor-inelastic, which yields competitive wages denoted by w_k with $k = r, f$. We assume the number of HH members to be constant over time but allow them to differ between the leader and the follower economies.

2.3.2 Summarizing Model Description

We present a continuous-time model of endogenous directed technical change in a RES-based and a fossil-based sector, with endogenous decisions for innovation finance in both sectors.

The model considers two types of global economies, the leader countries, representing the global North, and the follower countries, representing the global South, denoted with the subscripts $i = 1{,}2$. In both economies, growth is achieved through the emergence of new varieties of intermediate goods, N_i, which can be created through either innovation, if the product variety has not existed in either of the economies previously, or through imitation, if the product variety has already existed

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[32] The inter-temporal elasticity of substitution is then the reciprocal value $1/\theta$.

within the respectively other economy. These dynamics are comparable to the growth model based on endogenous innovation presented by Barro and Sala-i-Martin (1997). Within each economy, a RES-based and a fossil-based type of intermediate goods exist, denoted with the subscripts $k = r, f$. RES-based intermediate goods represent all those intermediate goods, which are produced by means of ‘clean’ energies and technologies, and which we assume to be carbon-neutral. Fossil-based intermediate goods represent all intermediate goods, which are produced by means of ‘dirty’, GHG-emitting energies and technologies. This conceptualization is comparable to the model of the environment and directed technical change presented by Acemoglu et al. (2012).

Intermediate goods producers in both economies and in both sectors cannot finance costly innovation and imitation activities fully internally[33] but are also dependent on external financing options. Based on insights from theories of the optimal capital structure of investments, intermediate goods producers can decide between different debt- and equity-financing options, as they seek to maximize their firm value and minimize their innovation and imitation costs including their financing costs. Financing options are provided by two types of financial intermediaries. Private financial intermediaries—such as lender banks, credit funds or equity funds including venture capital funds—offer private debt and equity, seeking to maximize their shareholders’ revenues. Public financial intermediaries subsume public institutions such as governments and development banks and offer public debt and public financing options with equity characteristics, such as project participations or availability-based PPPs. Other than private financial intermediaries, public financial intermediaries do not seek to maximize shareholder revenues, but to maximize stakeholder benefits by efficiently—i.e., at the optimal cost-benefit ratio—supporting non-financial goals such as GHG reductions.

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[33] With reference to the pecking order theory, and resonating that innovation has intrinsic properties that make it difficult to finance externally, we assume that the preference of intermediate goods producers is to finance innovation internally to the largest extent possible (cf., Noally and Smeets, 2016).

2.3.3 The Final Goods Sector

There is one consumption good in each economy, consisting of two types of final goods. $Y_{r,i}$ denotes the final good which is produced from RES-based intermediate inputs, $Y_{f,i}$ the final good produced from fossil-based intermediate inputs. $Y_{r,i}$ and $Y_{f,i}$ are imperfect substitutes with a constant elasticity of substitution (CES), defined by

$$Y_i = \left[\gamma Y_{r,i}^{\frac{\varepsilon-1}{\varepsilon}} + (1-\gamma) Y_{f,i}^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{2}$$

with ε being the elasticity of substitution and γ being a distribution parameter determining the importance of the RES-based and fossil-based final goods in the aggregate production of the consumption good. The RES-based and fossil-based types of final goods are produced competitively according to the Cobb-Douglas-type production functions

$$Y_{r,i} = A_{r,i} \frac{1}{1-\beta} \int_0^{N_{r,i}} \left(x_{r,ij} \right)^{1-\beta} dj \, {L_{r,i}}^{\beta} \tag{3}$$

and

$$Y_{f,i} = A_{f,i} \frac{1}{1-\beta} \int_0^{N_{f,i}} \left(x_{f,ij} \right)^{1-\beta} dj \, {L_{f,i}}^{\beta}, \tag{4}$$

with $A_{k,i}$ being the overall total factor productivity (TFP) of the RES-based and the fossil-based final goods sectors in the economy, $L_{k,i}$ being the labor dedicated to the production of the two types of final goods, and $N_{k,i}$ being the intermediate goods variants. Final goods producers in both sectors take factor prices as given and maximize their profits according to

$$\max_{x_{r,i}, L_{r,i}} (1-\tau_i) p_{r,i} Y_{r,i} - w_{r,i} L_{r,i} - \int_0^{N_{r,i}} \psi_{r,ij} x_{r,ij} dj, \tag{5}$$

and

$$\max_{x_{f,i}, L_{f,i}} \left(1 - \tau_{ij} - \tau_i^{CO2} \right) p_{f,t} Y_{f,t} - w_{f,t} L_{f,t} - \int_0^{N_{f,i}} \psi_{f,ij} x_{r,ij} dj \,, \tag{6}$$

with τ_i being the economy's tax rate and $\psi_{r,ij}$ and $\psi_{f,ij}$ being the prices for the intermediate goods[34]. From the profit maximization problem[35], we obtain the iso-elastic demand curves for the intermediate goods

$$x_{r,ij} = \left(\frac{(1-\tau_i)p_{r,i}A_{r,i}}{\psi_{r,i}}\right)^{\frac{1}{\beta}} L_{r,i}, \tag{7}$$

and

$$x_{f,ij} = \left(\frac{\vartheta_i\left(1-\tau_i-\tau_i^{CO2}\right)p_{f,i}A_{f,i}}{\psi_{f,i}}\right)^{\frac{1}{\beta}} L_{f,i}. \tag{8}$$

The wages in the production of the two outputs are

$$w_{k,i} = \left(1-\tau_i-\tau_{k,i}^{CO2}\right)A_{k,i}\frac{\beta}{1-\beta}p_{k,i}\left(\int_0^{N_{k,i}}\left(x_{k,ij}\right)^{1-\beta}dj\right)L_{k,i}{}^{\beta-1}, \tag{9}$$

with $\tau_{r,i}^{CO2} = 0$. Following Aghion and Howitt (1992), Acemoglu (2002) and Acemoglu et al. (2012), in equilibrium, the relative prices of the RES-based final goods and the fossil-based final goods, $p_{r,i}/p_{f,i}$, must equal the marginal rate of substitution in demand between the two goods, depending on the relative quantity $Y_{r,i}/Y_{f,i}$ according to

$$p_i \equiv \frac{p_{f,i}}{p_{r,i}} = \frac{1-\gamma}{\gamma}\left(\frac{Y_{f,i}}{Y_{r,i}}\right)^{-\frac{1}{\varepsilon}}, \tag{10}$$

with $\varepsilon > 0$. Choosing the ideal price index of the final good as the numéraire implies that

$$\left[\gamma^{\varepsilon}p_{r,i}^{1-\varepsilon} + (1-\gamma)^{\varepsilon}p_{f,i}^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} = 1, \tag{11}$$

And, thus, reveals the relation of the prices of the RES-based and fossil-based final goods,

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[34] We assume that each RES-based intermediate good is produced at the same amount, i.e., $x_{k,ij} = X_{k,i}/N_{k,i}$ and is sold to the final goods sector for the same price, i.e., $\psi_{k,ij} = \Psi_{k,i}/N_{k,i}$, with $X_{k,i}$ being the total amount of intermediate goods, and $\Psi_{k,i}$ being the price for the total number of variants.

[35] For the derivation, see the supplementary material (available upon request).

$$p_{r,i} = \left(\frac{1-(1-\gamma)^{\varepsilon}}{\gamma^{\varepsilon}}\right)^{\frac{1}{1-\varepsilon}} p_{f,i}. \tag{12}$$

2.3.4 The Intermediate Goods Sectors

2.3.4.1 Overall Description of the Intermediate Goods Sectors

As described above, in both economies, intermediate goods producers can either imitate or innovate to the end of developing new varieties of intermediate goods, with the total number of varieties $N_{k,i}$ in each economy being

$$N_i = N_{r,i} + N_{f,i} = N_{r,i}^{I} + N_{r,i}^{C} + N_{f,i}^{I} + N_{f,i}^{C}, \tag{13}$$

with $N_{k,i}^{I}$ being the number of innovated goods, and $N_{k,i}^{C}$ being the number of imitated ('copied') goods. We define the shares of innovated variants in the total variants, $\lambda_{k,i}$, as

$$\lambda_{k,1} \equiv \frac{N_{k,1}^{I}}{N_{k,1}} = \left(\frac{N_{k,2}}{N_{k,1}}\right)^{\frac{b}{2}} \tag{14}$$

and

$$\lambda_{k,2} \equiv \frac{N_{k,2}^{I}}{N_{k,2}} = \left(\frac{N_{k,2}}{N_{k,1}}\right)^{b}, \tag{15}$$

to ensure that $\lambda_{r,2} \leq \lambda_{r,1}$, meaning that the leader countries have a higher proportion of innovated goods as compared to imitated goods. As in Barro and Sala-i-Martin (1997), we assume that the intermediate goods producers act as monopolists supplying their variants of the intermediate good. The profits of an intermediate goods producer can, hence, be written as

$$\pi_{r,ij} = (1-\tau_i)\left(\psi_{r,ij} - \varphi_{r,ij}\right)x_{r,ij} \tag{16}$$

and

$$\pi_{f,ij} = \left(1-\tau_i-\tau_i^{CO2}\right)\left[\psi_{f,ij} - \varphi_{f,ij}\right]x_{f,ij}. \tag{17}$$

Since the demand curves in eqs. (8) and (9) are iso-elastic, the profit-maximizing price of the intermediate goods is a constant markup over marginal cost, $\psi_{r,ij} = \varphi_{r,ij}/(1-\beta)$ and $\psi_{f,ij} =$

$\varphi_{f,ij}/(1-\beta)$. To simplify, we normalize the marginal cost to $\varphi_{r,ij} = 1-\beta$ and $\varphi_{f,ij} = 1-\beta$, resulting in equilibrium prices of intermediate inputs $\psi_{r,ij} = \psi_{f,ij} = 1$.

We, hence, obtain in the equilibrium

$$x_{r,ij} = \left((1-\tau_i)p_{r,i}A_{r,i}\right)^{\frac{1}{\beta}} \ L_{r,i} \tag{18}$$

and

$$x_{f,ij} = \left((1-\tau_i-\tau_i^{CO2})p_{f,i}A_{f,i}\right)^{\frac{1}{\beta}} \ L_{f,i}, \tag{19}$$

as well as

$$x_{r,i} = \int_0^{N_{r,i}} \left(x_{r,ij}\right)^{1-\beta} dj = \left((1-\tau_i)p_{r,i}A_{r,i}\right)^{\frac{1-\beta}{\beta}} \ L_{r,i}{}^{1-\beta} N_{r,i} \tag{20}$$

and

$$x_{f,i} = \int_0^{N_{f,i}} \left(x_{f,ij}\right)^{1-\beta} dj = \left((1-\tau_i-\tau_i^{CO2})p_{f,i}A_{f,i}\right)^{\frac{1-\beta}{\beta}} \ L_{f,i}{}^{1-\beta} N_{f,i}. \tag{21}$$

Furthermore, it is

$$Y_{r,i} = \frac{1}{1-\beta} A_{r,i}{}^{\frac{1}{\beta}} \left((1-\tau_i)p_{r,i}\right)^{\frac{1-\beta}{\beta}} \ L_{r,i}N_{r,i} \tag{22}$$

and

$$Y_{f,i} = \frac{1}{1-\beta} A_{f,i}{}^{\frac{1}{\beta}} \left((1-\tau_i-\tau_i^{CO2})p_{f,i}\right)^{\frac{1-\beta}{\beta}} \ L_{f,i}N_{f,i}. \tag{23}$$

The profits of the intermediate goods producers from the two sectors are[36]

$$\pi_{r,ij} = \pi_{r,i} = (1-\tau_i)^{\frac{\beta+1}{\beta}} \beta \left(p_{r,i}A_{r,i}\right)^{\frac{1}{\beta}} L_{r,i} \tag{24}$$

and

$$\pi_{f,ij} = \pi_{f,i} = \left(1-\tau_i-\tau_i^{CO2}\right)^{\frac{\beta+1}{\beta}} \beta \left(p_{f,i}A_{f,i}\right)^{\frac{1}{\beta}} L_{f,i}. \tag{25}$$

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[36] It is $\pi_{r,ij} = \pi_{r,i}$, as the growth in $N_{k,i}$ expresses itself as an increase in TFP (cf. eqs. (20) and (21)).

Furthermore, with eqs. (20) and (21), the wages from eq. (9) become

$$w_{k,i} = \frac{\beta}{1-\beta}\left(\left(1-\tau_i-\tau_{k,i}^{CO2}\right)p_{r,i}A_{r,i}\right)^{\frac{1}{\beta}}\ N_{r,i}, \tag{26}$$

again with $\tau_{r,i}^{CO2} = 0$.

2.3.4.2 Innovation Costs of the Intermediate Goods Sectors

Costs for new variants are the weighted average cost of economy i's costs for innovation and imitation activities to create new variants in the RES- and fossil-based intermediate goods sectors,

$$e_i = e_{r,i} + e_{f,i} = \left(1-\lambda_{r,i}\right)\upsilon_{r,i} + \lambda_{r,i}\eta_{r,i} + \left(1-\lambda_{f,i}\right)\upsilon_{f,i} + \lambda_{f,i}\eta_{f,i}, \tag{27}$$

with $\eta_{k,i}$ being the costs of innovation activities, and $\upsilon_{k,i}$ being the costs of imitation, which we define as

$$\upsilon_{k,i} = \eta_{r,i}\left(\frac{N_{r,i}}{N_{r,l}}\right)^{\sigma} \qquad i = 1,2; l = 1,2 \neq i. \tag{28}$$

To cover their aggregate costs of innovation and imitation, intermediate goods producers can deploy the cash flows resulting from their profits—i.e., deploy internal finance—and issue different types of securities, with $a_{k,i}^{s}$ being one security of type $s \in S$, as described in more detail in section 2.3.4.3. The costs of innovation activities consist, hence, of the costs of research and development activities themselves, which are related to any research and development activities, $\eta_{k,i}^{R\&D}$, and financing costs, which arise from the acquisition of external capital to finance the innovation activities, $\varphi_{k,i}^{fin}$,

$$\eta_{k,i} = \eta_{k,i}^{R\&D} + \varphi_{k,i}^{fin}, \tag{29}$$

which, with eqs. (15), (27) and (28) is

$$e_{k,1} = \left[\left(\frac{N_{k,2}}{N_{k,1}}\right)^{-\sigma} - \left(\frac{N_{k,2}}{N_{k,1}}\right)^{\frac{b}{2}-\sigma} + \left(\frac{N_{k,2}}{N_{k,1}}\right)^{\frac{b}{2}}\right]\left(\eta_{k,1}^{R\&D} + \varphi_{k,1}^{fin}\right) \tag{30}$$

and

$$e_{k,2} = \left[\left(\frac{N_{k,2}}{N_{k,1}}\right)^{\sigma} - \left(\frac{N_{k,2}}{N_{k,1}}\right)^{\sigma+b} + \left(\frac{N_{k,2}}{N_{k,1}}\right)^{b}\right]\left(\eta_{k,2}^{R\&D} + \varphi_{k,2}^{fin}\right). \tag{31}$$

Under the assumption of perfect capital markets, the Modigliani-Miller theorem holds, and financing costs equal the economy-wide interest rate, making any financing decision trivial (Modigliani and Miller, 1958). Then, the present value of the intermediate goods firms' profits can be expressed as

$$V_{k,i}^{I} = V_{k,i}^{C} = V_i = \left(V_{r,i} + V_{f,i}\right) = \left(\pi_{r,i} + \pi_{f,i}\right)\int_t^{\infty} e^{-\int_t^s M_i(v)dv} ds, \tag{32}$$

where M_i is the real interest rate in economy i at time v, which is also the cost of a one-period risk-free asset. Assuming free entry into the research and development business, in equilibrium,

$$V_i = e_i\left(\frac{N_2}{N_1}\right) \tag{33}$$

must hold. Substituting eqs. (32) in (33) and taking the derivatives of both sides with regards to t reveals

$$M_i(t) = \frac{\pi_{r,i} + \pi_{f,i}}{e_{r,i} + e_{f,i}} + \frac{\dot{e}_{r,i} + \dot{e}_{f,i}}{e_{r,i} + e_{f,i}} \tag{34}$$

under the assumption of perfect capital markets and, hence, a common interest rate $M_i(t)$ for the RES-based and the fossil-based sector in each economy; with

$$\frac{\dot{e}_{k,1}}{e_{k,1}} = \frac{\dot{\eta}_{k,1}}{\eta_{k,1}} + \frac{\left(\dot{\frac{N_{k,2}}{N_{k,1}}}\right)}{\left(\frac{N_{k,2}}{N_{k,1}}\right)} \frac{\left[-\sigma\left(\frac{N_{k,2}}{N_{k,1}}\right)^{-\sigma} - \left(\frac{b}{2} - \sigma\right)\left(\frac{N_{k,2}}{N_{k,1}}\right)^{\frac{b}{2}-\sigma} + b\left(\frac{N_{k,2}}{N_{k,1}}\right)^{\frac{b}{2}}\right]}{\left(\frac{N_{k,2}}{N_{k,1}}\right)^{-\sigma} - \left(\frac{N_{k,2}}{N_{k,1}}\right)^{\frac{b}{2}-\sigma} + \left(\frac{N_{k,2}}{N_{k,1}}\right)^{\frac{b}{2}}} \tag{35}$$

and

$$\frac{\dot{e}_{k,2}}{e_{k,2}} = \frac{\dot{\eta}_{k,2}}{\eta_{k,2}} + \frac{\left(\dot{\frac{N_{k,2}}{N_{k,1}}}\right)}{\left(\frac{N_{k,2}}{N_{k,1}}\right)} \frac{\left[\sigma\left(\frac{N_{k,2}}{N_{k,1}}\right)^{\sigma} - (\sigma + b)\left(\frac{N_{k,2}}{N_{k,1}}\right)^{\sigma+b} + b\left(\frac{N_{k,2}}{N_{k,1}}\right)^{b}\right]}{\left(\frac{N_{k,2}}{N_{k,1}}\right)^{\sigma} - \left(\frac{N_{k,2}}{N_{k,1}}\right)^{\sigma+b} + \left(\frac{N_{k,2}}{N_{k,1}}\right)^{b}} \tag{36}$$

being the growth rates of the costs for innovation and imitation.

2.3.4.3 The Financing Decision of the Intermediate Goods Sectors under Financial Frictions

Intermediate goods producers seek to minimize their costs of innovation and imitation activities by choosing their optimal capital structure, taking $\eta_{k,i}^{R\&D}$ as given. As mentioned above, we allow for four different types of financing options facing the intermediate goods sectors: private debt, d, and private equity, e, which is provided by aggregate private financial intermediaries subsuming, *inter alia*, lender banks, credit funds or equity funds, as well as public debt, pd, and public financing options with equity characteristics, pe, defining $S = \{d, e, pd, pe\}$. The total overall financing costs consist, hence, of the financing costs for the four different types of capital,

$$\varphi_{k,i}^{fin} = \varphi_{k,i}^{d} + \varphi_{k,i}^{e} + \varphi_{k,i}^{pd} + \varphi_{k,i}^{pe}, \tag{37}$$

with $\varphi_{k,i}^{d}$ being the total costs of private debt, $\varphi_{k,i}^{e}$ being the total costs of private equity, $\varphi_{k,i}^{pd}$ being the total costs of public debt and $\varphi_{k,i}^{pe}$ being the total costs of public financing options with equity characteristics.

Following, e.g., Kraus and Litzenberger (1973) and Van Binsbergen et al. (2010), we describe the total costs of debt as

$$\varphi_{k,i}^{d} = a_{k,i}^{d}\left[\frac{1}{\iota_{k,i}^{d}}\left(1-\tau_{r,i}^{d}\right)R_{k,i}^{d}\left(a_{k,i}^{d}, a_{k,i}^{pd}\right) - v_{k,i}^{d}\right], \tag{38}$$

with $R_{k,i}^{d}\left(a_{k,i}^{d}, a_{k,i}^{pd}\right)$ being the unit costs—i.e., interest rates—per debt security issued, $\iota_{k,i}^{d} \in [0, 1)$ being a parameter describing the efficiency of lending[37] and $v_{k,i}^{d}$ being the market value of debt. Following standard assumptions, and based on the rationale that the higher a firm's debt ratio is, the higher the risk of bankruptcy, we model the costs per debt security issued to be linearly

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[37] Cost of debt is also dependent on firm size, which we assume here to equal out since we consider a model of one representative firm per sector and without capital accumulation. When comparing the RES-based and the fossil-based intermediate goods sectors, firm size is often smaller in the RES-based sector, as new players enter the market. This case can be accounted for by setting $m_{r,ij}^{d}$ accordingly. Furthermore, at this point, we do not explicitly account for any costs of financial distress, such as bankruptcy costs (cf. e.g., Scott, 1976; Baker and Martin, 2011), but limit these considerations to the costs for debt increasing in leverage.

increasing in the intermediate goods producer's leverage $\lambda_{k,ij}^{d}$, for which we use the definition of the debt-to-EBITDA ratio[38],

$$\lambda_{k,i}^{d} = m_{k,i}^{d} \frac{a_{k,i}^{d} + a_{k,i}^{pd}}{Y_{k,i} p_{k,i}}, \tag{39}$$

with $m_{r,ij}^{d}$ being the proportionality factor. We, hence, obtain

$$R_{k,i}^{d}\left(a_{k,i}^{d}, a_{k,i}^{pd}\right) = m_{k,i}^{d} \frac{a_{k,i}^{d} + a_{k,i}^{pd}}{Y_{k,i} p_{k,i}}, \tag{40}$$

with $R_{k,i}^{Md}$ being the model-endogenous market price for debt. Further, $\tau_{r,i}^{d}$ represents the rate at which interest rates for debt are deducible from corporate taxes (cf., e.g., Modigliani and Miller, 1958; Cordes and Sheffrin, 1983; Kane et al., 1984; Graham, 2002), capturing the tax benefit of debt, with

$$0 \leq \tau_{k,i}^{d} \leq \tau_{k,i} \leq 1. \tag{41}$$

Further, based on, e.g., Kraus and Litzenberger (1973), Scott (1976), Altinkilic and Hansen (2000), and Gomes (2001), we describe the costs of private equity as

$$\varphi_{k,i}^{e} = \varphi_{k,i}^{e,fix} + a_{k,i}^{e} \left[\frac{1}{\iota_{k,i}^{e}} R_{k,i}^{e}\left(a_{k,i}^{d}, a_{k,i}^{pd}\right) - v_{k,i}^{e} \right], \tag{42}$$

with $\varphi_{k,i}^{e,fix}$ being flotation costs, $v_{k,i}^{e}$ being the market value of equity, and $R_{k,i}^{e}\left(a_{k,i}^{d}, a_{k,i}^{pd}\right)$ being the costs per equity security issued, which can be described as

$$R_{k,i}^{e}\left(a_{k,i}^{d}, a_{k,i}^{pd}\right) = d_{k,i}\left(Y_{k,i} p_{k,i} - \varphi_{k,i}^{d} - \varphi_{k,i}^{pd}\right), \tag{43}$$

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[38] EBITDA describes earnings before interest, taxes, depreciation, and amortization. We use the debt-to-EBITDA ratio for two reasons. Firstly, our model does not include capital accumulation, so any definition based on a firm's assets or capital would be inappropriate. Secondly, the chosen notation allows for the option to include revenue risks into the model, by making the profit development stochastic, e.g., by means of a Brownian motion.

with $d_{k,i}^{e} \in \left(0{,}1 - d_{k,i}^{pe}\right)$ being the agreed dividend payments expressed as a share of the firm's net profits, i.e., less its costs for issuing other types of securities, and $\iota_{k,ij}^{e} \in (0{,}1)$ being a market efficiency parameter.

Costs for public debt have the same structure as costs for private debt, and differences are expressed only through the magnitude of the parameters. It is

$$\begin{aligned}\varphi_{k,i}^{pd} &= a_{k,i}^{pd}\left[\left(1-\tau_{k,i}^{pd}\right)\frac{1}{\iota_{k,i}^{pd}}R_{k,i}^{pd}\left(a_{k,i}^{d},a_{k,i}^{pd}\right)-v_{k,i}^{pd}\right]\\ &= a_{k,i}^{pd}\left[\left(1-\tau_{k,i}^{pd}\right)\frac{1}{\iota_{k,i}^{pd}}\left(m_{k,i}^{pd}\frac{a_{k,i}^{d}+a_{k,i}^{pd}}{Y_{k,i}p_{k,i}}\right)-v_{k,i}^{pd}\right],\end{aligned} \tag{44}$$

with the parameter definitions being analogous to the parameter definitions regarding the costs of private debt.

The cost structure of public equity is

$$\varphi_{k,i}^{pe} = a_{k,i}^{pe}\left[\frac{1}{\iota_{k,i}^{pe}}R_{k,i}^{pe}\left(a_{k,i}^{d},a_{k,i}^{pd}\right)-v_{k,i}^{pe}\right] = a_{k,i}^{pe}\left[\frac{1}{\iota_{k,i}^{pe}}d_{k,i}^{pe}\left(Y_{k,i}p_{k,i}-\varphi_{k,i}^{d}-\varphi_{k,i}^{pd}\right)-v_{k,i}^{pe}\right], \tag{45}$$

with the parameter definitions being analogous to the parameter definitions regarding the costs of private equity. Compared with the cost structure of private equity, firms do not face any flotation costs related to the issuance of public equity securities.

Given the cost structures of issuing different types of securities as described above, the intermediate goods producers minimize their aggregate innovation and imitation costs at each point in time according to

$$\min_{a_{k,ij}^{d},a_{k,ij}^{e},a_{k,ij}^{pd},a_{k,ij}^{pe}} \varphi_{k,i}^{fin}. \tag{46}$$

The first constraint of the maximization problem describes that at each moment in time, the aggregate intermediate goods producers in each sector need to cover their innovation and imitation costs (eqs. (30) and (31)) by means of the cash inflows from their profits and the issuance of securities of the types s, which can be expressed as

$$\left[\left(\frac{N_{k,2}}{N_{k,1}}\right)^{-\sigma}-\left(\frac{N_{k,2}}{N_{k,1}}\right)^{\frac{b}{2}-\sigma}+\left(\frac{N_{k,2}}{N_{k,1}}\right)^{\frac{b}{2}}\right]\left(\eta_{k,i}^{R\&D}+\varphi_{k,ij}^{fin}\right)=Y_{k,i}p_{k,i}+\sum_{s\in S}a_{k,i}^{s}v_{k,i}^{s}, \tag{47}$$

with $v_{k,i}^{s}$ being the market-determined value of one security issued. We assume non-negative interest rates. Furthermore, intermediate goods producers can only issue securities and do not act as financiers on the financial markets. Hence, the second constraint is that the financing costs must be non-negative, i.e.,

$$\varphi_{k,i}^{fin}\geq 0. \tag{48}$$

2.3.5 The Financial Sector

As described above, the financial sector consists of private and public financial intermediaries. They both provide their specific financing options competitively to the intermediary goods producers of both sectors under their sector-specific conditions.

2.3.5.1 Private Financial Intermediaries

Private intermediaries choose holding a mix of private debt and equity to both intermediate sectors within one economy to maximize their shareholders' value by maximizing the returns of their portfolio Υ_i according to

$$\begin{aligned}\max_{a_{r,i}^{d},a_{r,i}^{e},a_{f,i}^{d},a_{f,i}^{e}}\Upsilon_i=\max_{a_{r,i}^{d},a_{r,i}^{e},a_{f,i}^{d},a_{f,i}^{e}}&\left[R_{f,i}^{d}\left(a_{f,i}^{d},a_{f,i}^{pd}\right)-v_{f,i}^{d}\right]a_{f,i}^{d}\\&+\left[R_{f,i}^{e}\left(a_{f,i}^{d},a_{f,i}^{pe},a_{f,i}^{pd}\right)-v_{f,i}^{e}\right]a_{f,i}^{e}+\left[R_{r,i}^{d}\left(a_{r,i}^{d},a_{r,i}^{pd}\right)-v_{r,i}^{d}\right]a_{r,i}^{d}\\&+\left[R_{r,i}^{e}\left(a_{r,i}^{d},a_{r,i}^{pe},a_{r,i}^{pd}\right)-v_{r,i}^{e}\right]a_{r,i}^{e}-h_i\left(a_{f,i}^{d},a_{f,i}^{e},a_{r,i}^{d},a_{r,i}^{e}\right),\end{aligned} \tag{49}$$

with h_i being the per-period holding costs, which we define as being dependent on the quantity of securities held,

$$h_i\left(a_{f,i}^{d},a_{f,i}^{e},a_{r,i}^{d},a_{r,i}^{e}\right)=h_i^{fix}+h_i^{var}\left(a_{f,i}^{d}+a_{f,i}^{e}+a_{r,i}^{d}+a_{r,i}^{e}\right)^{\omega} \tag{50}$$

With h_i^{fix} being the fixed, and h_i^{var} being the variable holding costs, and ω, expressing the type of returns to scale. The private financial intermediaries receive their investable resources from the HH savings S_i. Hence, private financial intermediaries face the constraint

$$a_{f,i}^{d} v_{f,i}^{d} + a_{f,i}^{e} v_{f,i}^{e} + a_{r,i}^{d} v_{r,i}^{d} + a_{r,i}^{e} v_{r,i}^{e} + h_i\left(a_{f,i}^{d}, a_{f,i}^{e}, a_{r,i}^{d}, a_{r,i}^{e}\right) \leq S_i \tag{51}$$

to their shareholder value maximization problem. The magnitude of S_i can be obtained from the HH intertemporal utility maximization based on eq. (1), assuming a standard HH budget constraint. As we assume that due to information asymmetries, HH cannot differentiate between the different investment options, they make their savings decision based on the real interest rate in economy i, M_i. Given this, savings are in each point in time

$$S_i = L_{r,i} w_{r,i} + L_{f,i} w_{f,i} - C_i. \tag{52}$$

2.3.5.2 Public Financial Intermediaries

Other than private financial intermediaries, public financial intermediaries do not maximize shareholder value, but are interested in pursuing specific goals. This can—generally and in an ideal world—be broken down to the principle of maximizing stakeholder value, for instance, an achievement of environmental, social and governance (ESG) goals including a reduction of GHG emissions. However, when considering the overall economy, public financial intermediaries are still bound to market mechanisms. Furthermore, a maximization of stakeholder value still implies a maximization of returns on investment, Υ_i^p, as one criterion for public financial intermediaries, and hence, investments into fossil-based intermediate goods are not excluded from the public intermediaries' portfolio[39]. To account for a generally stronger preference of public financial

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[39] This can be illustrated by the following two examples. The first example refers to the limitations, which public investors face with regards to their investment allocation according to stakeholder maximization criteria. Public health insurances and pension funds, which are highly relevant institutional investors in terms of public investment volumes, pursue the primary goal of investing their funds efficiently and profitably, to the end of adequately ensuring their

intermediaries to invest into securities issued by the RES-based sector, we introduce a valuation parameter, p_i^{CO2}, which can be interpreted as an internal carbon price, the magnitude of which is determined by the individual sustainability goals of an economic actor. These considerations lead to the maximization problem of the public financial intermediaries,

$$\begin{aligned}&\max_{a_{r,i}^{pd},a_{r,i}^{pe}a_{f,i}^{pd},a_{f,i}^{pe}} Y_i^p\\ &= \max_{a_{r,i}^{pd},a_{r,i}^{pe}a_{f,i}^{pd},a_{f,i}^{pe}} \left[R_{f,i}^{pd}\left(a_{f,i}^{d},a_{f,i}^{pd}\right)-v_{f,i}^{pd}-p_i^{CO2}\right]a_{f,i}^{pd}\\ &+\left[R_{f,i}^{pe}\left(a_{f,i}^{d},a_{f,i}^{e},a_{f,i}^{pd}\right)-v_{f,i}^{pe}-p_i^{CO2}\right]a_{f,i}^{pe}+\left[R_{r,i}^{pd}\left(a_{r,i}^{d},a_{r,i}^{pd}\right)-v_{r,i}^{pd}\right]a_{r,i}^{pd}\\ &+\left[R_{r,i}^{pe}\left(a_{r,i}^{d},a_{r,i}^{e},a_{r,i}^{pd}\right)-v_{r,i}^{pe}\right]a_{r,i}^{pe}-h_i^p\left(a_{f,i}^{pd},a_{f,i}^{pe},a_{r,i}^{pd},a_{r,i}^{pe}\right).\end{aligned} \tag{53}$$

Investible funds arise from taxes and social security contributions, T_i, which leads to the constraint to the maximization problem of public financial intermediaries

$$\begin{aligned}&a_{r,i}^{pd}v_{r,i}^{pd}+a_{r,i}^{pe}v_{r,i}^{pe}+a_{f,i}^{pd}v_{f,i}^{pd}+a_{f,i}^{pe}v_{f,i}^{pe}+h_i^p\left(a_{f,i}^{pd},a_{f,i}^{pe},a_{r,i}^{pd},a_{r,i}^{pe}\right)\\ &=\tau_i\left(Y_{r,i}p_{r,i}+Y_{f,i}p_{f,i}\right).\end{aligned} \tag{54}$$

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members' benefits, i.e., the funding of medical services and the payout of pension payments. This is also subject to corresponding regulations in the form of constraints regarding the assets institutional investors are allowed to hold. These regulations vary dependent on the country's legislation; however, all inhibit institutional investors from holding high-risk assets (e.g., OECD, 2011). In a secondary instance—and given the limitations that their primary goal imposes—they can also pursue other goals with their investments, such as a promotion of clean energy or technologies. The second example illustrates that even if the only goal that public investors pursue is stakeholder value maximization, this does not necessarily mean a total exclusion of investments in the fossil sector. Firstly, fossil-based intermediate goods often serve as system-relevant transitional technologies, such as gas power plants in the energy system. Secondly, pursuing different ESG goals can lead to trade-offs. Investing in a fossil-based power plant in a developing country can increase energy access and, thus, contribute to the social ESG dimension, while, coincidingly, increase carbon emissions and, thus, negatively contribute to the environmental ESG dimension.

2.3.6 The Relationship Between Innovation in the RES-based and the Fossil Sectors

To determine the relation between innovation in the RES- and the fossil-based intermediate goods sectors, we revisit the relation between $p_{r,i}$ and $p_{f,i}$. Substituting eqs. (22) and (23) into eq. (10) reveals

$$\frac{p_{f,i}}{p_{r,i}} = \left(\frac{1-\gamma}{\gamma}\right)^{\frac{\beta\varepsilon}{\kappa}} \left(\frac{A_{f,i}}{A_{r,i}}\right)^{-\frac{1}{\kappa}} \left(\frac{\left(1-\tau_i-\tau_i^{CO2}\right)}{(1-\tau_i)}\right)^{-\frac{1-\beta}{\kappa}} \left(\frac{L_{f,i}N_{f,i}}{L_{r,i}N_{r,i}}\right)^{-\frac{\beta}{\kappa}}, \qquad (55)$$

with $\kappa \equiv 1-\beta+\varepsilon\beta$.

2.3.6.1 The Innovation Possibilities Frontier

The production function for new machine varieties is

$$\dot{N}_{k,i} = \varsigma_{k,i} e_{k,i}, \qquad (56)$$

where $\varsigma_{k,i}$ is an efficiency parameter, which allows the cost of innovation to differ. In this specification, $\varsigma_{r,i}/\varsigma_{f,i}$ is constant. In the balanced growth path, the prices $p_{r,i}$ and $p_{f,i}$ are constant, and $N_{r,i}$ and $N_{f,i}$ grow at the same rate. The technology market clearing condition is then

$$\frac{V_{r,i}}{V_{f,i}} = \frac{\varsigma_{f,i}}{\varsigma_{r,i}}, \qquad (57)$$

which, given that the interest rate $M_{r,i} = M_{f,i} = M_i$, simplifies to

$$\varsigma_{r,i}\pi_{r,i} = \varsigma_{f,i}\pi_{f,i}. \qquad (58)$$

With eqs. (16), (17) and (52), it is then

$$N_{f,i} = \left(\frac{1-\gamma}{\gamma}\right)^{\varepsilon} \left(\frac{1-\tau_i-\tau_i^{CO2}}{1-\tau_i}\right)^{\frac{\kappa(\beta+1)-1+\beta}{\beta}} \left(\frac{A_{f,i}}{A_{r,i}}\right)^{\frac{\kappa-1}{\beta}} \left(\frac{L_{f,i}}{L_{r,i}}\right)^{1-\kappa} \left(\frac{\varsigma_{f,i}}{\varsigma_{r,i}}\right)^{\kappa} N_{r,i}, \qquad (59)$$

and we define

$$N_{f,i} \equiv \xi_i N_{r,i}. \qquad (60)$$

Further, in the balanced growth path , $N_{r,i}$ and $N_{f,i}$ grow at the same rate, i.e., $\dot{N}_{r,i}/N_{r,i} = \dot{N}_{f,i}/N_{f,i}$, and $\xi_i = N_{f,i}/N_{r,i}$ (see Acemoglu, 2002), which leads to the relationship $\dot{N}_{f,i} = \xi_i \dot{N}_{r,i}$.

Allowing for changing carbon taxes and a changing difference between fossil and RES cumulated financing costs, $\Delta\dot{\varphi}_i^{fin,a} = \dot{\varphi}_{f,i}^{fin,a} - \dot{\varphi}_{r,i}^{fin,a}$, with $\varphi_{k,i}^{fin,a} = \frac{\varphi_{k,i}^{d}}{a_{k,i}^{d}} + \frac{\varphi_{k,i}^{e}}{a_{k,i}^{e}} + \frac{\varphi_{k,i}^{pd}}{a_{k,i}^{pd}} + \frac{\varphi_{k,i}^{pe}}{a_{k,i}^{pe}}$, taking the derivatives of both sides of eq. (59) leads to the approximated relation

$$\dot{N}_{f,i} = \dot{N}_{r,i}\xi_i - \left(\dot{\tau}_i^{CO2} + \Delta\dot{\varphi}_i^{fin}\right) N_{r,i}\xi_i, \tag{61}$$

2.3.7 Aggregation

Given eq. (2), the economies' overall budget constraints are

$$Y_i = \left[\gamma Y_{r,i}^{\frac{\varepsilon-1}{\varepsilon}} + (1-\gamma) Y_{f,i}^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}} = C_i + x_{r,i}N_{r,i} + x_{f,i}N_{f,i} + e_{r,i}\dot{N}_{r,i} + e_{f,i}\dot{N}_{f,i}, \tag{62}$$

with $e_{r,i}\dot{N}_{r,i}$ and $e_{f,i}\dot{N}_{f,i}$ being the expenditures for the innovation and imitation of new variants, respectively (see below). As in Barro and Sala-i-Martin (1997), trade is assumed to be balanced between the two economies, which means that the total output Y_i in both economies equals the total respective domestic expenditures. These expenditures are for consumption, $C_i = C_{r,i} + C_{f,i}$, production of the variants of intermediate goods, $x_{r,i}N_{r,i}$ and $x_{f,i}N_{f,i}$, and for innovation and imitation activities leading to the emergence of new variants, $e_{r,i}\dot{N}_{r,i}$ and $e_{f,i}\dot{N}_{f,i}$. With eqs. (22), and (23), it is

$$\left[\gamma\left(\tilde{Y}_{r,i}N_{r,i}\right)^{\frac{\varepsilon-1}{\varepsilon}} + (1-\gamma)\left(\tilde{Y}_{f,i}N_{f,i}\right)^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}} = C_i + x_{r,i}N_{r,i} + x_{f,i}N_{f,i} + e_{r,i}\dot{N}_{r,i} + e_{f,i}\dot{N}_{f,i}, \tag{63}$$

with $\tilde{Y}_{k,i} = Y_{k,i}/N_{k,i}$, and with eqs. (60) and (61) we can write the growth rates of $N_{k,i}$ as

$$\frac{\dot{N}_{r,i}}{N_{r,i}} = \frac{1}{e_{r,i} + e_{f,i}\xi_i}\left\{\left[\gamma\left(\tilde{Y}_{r,i}\right)^{\frac{\varepsilon-1}{\varepsilon}} + (1-\gamma)\left(\tilde{Y}_{f,i}\xi_i\right)^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}} - x_{r,i} - x_{f,i}\xi_i - \frac{C_i}{N_{r,i}} + \dot{\tau}_i^{CO2} \right.$$
$$\left. + \Delta\dot{\varphi}_i^{fin}\right\} \tag{64}$$

and

$$\frac{\dot{N}_{f,i}}{N_{f,i}} = \frac{1}{e_{r,i}{\xi_i}^{-1} + e_{f,i}} \left\{ \left[\gamma\left(\tilde{Y}_{r,i}{\xi_i}^{-1}\right)^{\frac{\varepsilon-1}{\varepsilon}} + (1-\gamma)\left(\tilde{Y}_{f,i}\right)^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}} - x_{r,i}{\xi_i}^{-1} - x_{f,i} - \frac{C_i}{N_{f,i}} \right. \tag{65}$$

$$\left. - \dot{\tau_\iota^{CO2}} - \Delta\dot{\varphi_\iota^{f\iota n}} \right\}.$$

We define further

$$\frac{\dot{\left(\widehat{N_k}\right)}}{\widehat{N_k}} \equiv \frac{\dot{\left(\frac{N_{k,2}}{N_{k,1}}\right)}}{\frac{N_{k,2}}{N_{k,1}}} = \frac{\dot{N}_{k,2}}{N_{k,2}} - \frac{\dot{N}_{k,1}}{N_{k,1}} \tag{66}$$

as the growth rate of the number of variants in economies 2 as compared to economies 1, and thus the ratio of the growth rates of the two economies.

A Maximization of HH utility (eq. (1)) subject to a standard inter-temporal budget constraint reveals the Euler equation for HH consumption

$$\frac{\dot{C}_i}{C_i} = \frac{1}{\theta}[M_i - \rho], \tag{67}$$

with the economy-wide interest rate M_i having been defined in eq. (34). Hence,

$$\frac{\dot{C}_i}{C_i} = \frac{1}{\theta}\left[\frac{\pi_{r,i} + \pi_{f,i}}{e_{r,i} + e_{f,i}} + \frac{\dot{e}_{r,i} + \dot{e}_{r,i}}{e_{r,i} + e_{f,i}} - \rho\right]. \tag{68}$$

Finally, we define

$$\frac{\dot{\Gamma}_{f,1}}{\Gamma_{f,1}} = \frac{\dot{C}_1}{C_1} - \frac{\dot{N}_{f,1}}{N_{f,1}}. \tag{69}$$

as the average consumption per variety in each of the two economies. We use $\Gamma_{f,1}$ as a control variable, which must converge to zero in the balanced growth path. As the number of varieties increases, each variety's average consumption decreases. In a competitive market, in the long run, the price of each variety will be driven down to its marginal cost. As the number of varieties approaches infinity, the average consumption per variety approaches zero. This outcome reflects the idea that, with an ever-increasing number of varieties, the demand for each specific variety becomes negligible, and the market becomes highly competitive.

2.4 Analysis

2.4.1 Model Parametrization

The preceding section has shed light on the qualitative interrelations of economic growth based on the innovation and imitation of RES-based and fossil-based variants. The subsequent stage involves a meticulous quantitative examination to explore how the endogenous reaction to the change in the exogenous variables in general, and for different financial frictions, impacts the advantages and disadvantages of different financing setups and approaches to their improvement. However, conducting such a quantitative study is beyond the scope of this Chapter, as it necessitates an exact determination of the parameters of the innovation possibilities frontier and the precise extent of substitution between clean and dirty resources. Instead, we initiate progress in this direction by examining the influence of varying parameters on the economic outcomes in terms of total economic growth (as reflected by the number of total variants), the relation of growth in the leader vs. the follower economies and in the RES-based and fossil sectors, as well as the innovation intensity, i.e., the share of innovated in total variants. We select parameters that closely resemble existing quantitative studies, enabling us to emphasize the novel outcomes arising from financial frictions in an environment of directed technical change.

To determine the total sizes of the leader and the follower economies, we define the leader economies, i.e., the global North, to consist of the Group of Seven (G7) economies plus China and the Russian Federation (‘G9 economies’), and the follower economies, i.e., the global South, as the rest of the world (ROW). We, hence, approximate L_1 with the share of the gross domestic product (GDP) of the G7 economies in the total global GDP, and L_2 with the remainder. In 2021, the global nominal GDP was 96.53 trillion USD, of which 62.22 trillion USD, and, hence, approx. 65% of the total global GDP are attributed to the G9 economies (The World Bank, 2023). In our model, $Y_{k,i}$ corresponds to the respective GDPs. We set the starting values for the number of variants in economies 1 and 2 according to the GDP shares. Furthermore, the variables $A_{k,i}$, $L_{k,i}$ and $p_{k,i}$ are set in a way that $Y_{k,1}/\left(Y_{k,1}+Y_{k,2}\right) \approx 65\%$. Note that the magnitude of the variables depends on the choice of the output elasticity of the intermediate inputs, $1-\beta$. Following Acemoglu et al. (2012), we set $1-\beta$ in the range of $1/3$.

2.4.2 Benchmark—The Economy Without Financial Frictions

We analyze the economy without financial frictions to the end of providing a benchmark for the subsequent analyses, as well as to the end of visualizing and explaining the basic dynamics of the model. We show different scenarios based on different model parametrizations. Scenario I will serve as a reference scenario for the subsequent analyses, while the remainder of the scenarios explains and visualizes the model dynamics.

In a setup without financial frictions, innovators have access to capital at the cost of the economy-wide interest rate M_i, with the capital being provided by the HH directly based on their intertemporal consumption and savings preferences. The behavior of the real economy is characterized by the ratio of variants in economies 2 to economies 1, $\widehat{N_k}$, the number of variants from the RES-based and the fossil-based intermediate goods sectors, $N_{k,i}$, the ratio of RES-based variants in the total variants in both groups of economies, $N_{r,i}/\left(N_{r,i}+N_{k,i}\right)$, and the ratio of innovated variants in the number of total variants, $\lambda_{k,i}$. The behavior of the global economy depends on the relative prices, $p_{k,i}$, the relative labor supply, $L_{k,i}$, and the relative TFP, $A_{k,i}$ of economies 1 and 2 and of the sectors. Varying these parameters leads to different magnitudes of the characteristic variables. Higher prices, labor supply or TFP in an economy or sector lead to a stronger growth in the respective sector, as well as to increased innovation activity, while the transition path to the balanced growth path follows a uniform structure (see the graphs and parametrizations for scenarios I to IV in the

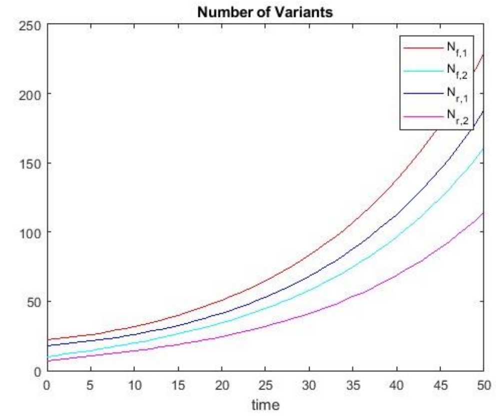
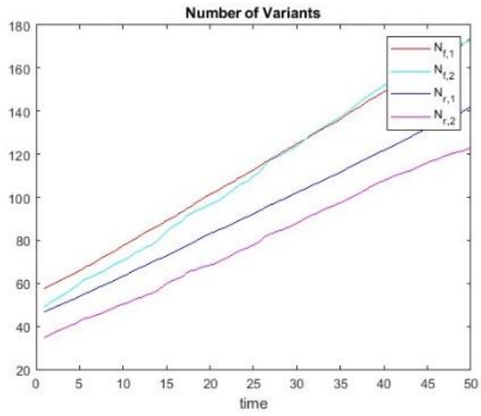
Appendix). The same applies for the effects of increases in the relative efficiency of innovation in the respective economies and sectors, $\varsigma_{k,i}$, as well as for the substitution elasticity, ε, expressing a more complementary nature of the RES-based and the fossil-based products. A decrease in innovation costs leads to an increase of the growth in the respective economies or sectors. With regards to the impact of carbon taxes, both the magnitude of the outcomes and the structure of the transition path can change since we allow for increasing carbon taxes over time. An increase in carbon taxes affects the fossil-based intermediate sectors and has both a decreasing effect on the outcome of the fossil sectors and an increasing effect on the RES sectors.

2.4.3 I—Initial State: The Economy with Financing Costs

In the following, we provide some analyses that shed light on the impact of different financial and financial frictions on the direction of innovation and imitation towards RES-based or fossil-based technological development. Building upon these analyses, we investigate the effect of different forms of setups and policy interventions fostering the development of RES-based technological development.

Firstly, we provide insights regarding an ‘initial state’, in which financing costs arise, but the financial markets are only subject to negligibly small information asymmetries, and to financiers’ preferences for debt stemming from less leveraged firms. We model the initial state in a way that it reflects a state in which the financial markets do not exhibit any differences across the regions, meaning that all parameters describing the financial markets are set to the same levels for economies 1 (E1) and economies 2 (E2). The initial state does not describe a realistic scenario, lacking all forms of market inefficiencies and differences in market inefficiencies of developed vs. developing economies prevailing in reality (see section 2.2.2). However, it serves to lay out the impact of financing costs in comparison to the benchmark scenario of the BGB without financing costs and financial frictions provided above. Going forward, it will also allow us to deploy it as a reference to compare the impact of different types and magnitudes of financial and financial frictions to this initial state, and the effect of different forms of policy intervention and regulation. Comparing the initial state with the benchmark scenarios (see section 2.4.2) reveals that both the level and the growth rates of the number of variants $N_{k,i}$—and, thus, the levels of growth of the respective two sectors in the two economies—are negatively impacted by positive financing costs, see Figure 3[40].

While this is very intuitive, it is interesting that the prevalence of financing costs also impacts the relation of the number of variants between the E1 and E2. This can be explained with the structure of the financing costs, which, especially in the case of debt finance, increase disproportionately with increasing levels of external financing. In E1, where the endogenously determined total volumes of external financing, $\varphi_{k,i}$, are higher, the economic growth rates of the two sectors are impacted disproportionately strong in comparison with the ones in the developing economies.

	Benchmark—Economy Without Financial Frictions	**I—Initial State: Economy with Financial Frictions**
$N_{k,i}$		

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[40] Exemplary display of selected results. For the full model outcomes, see Appendices B and C. Note that the time displayed in the Benchmark scenarios varies from the one displayed in the results of the scenarios with financial frictions for reasons of scenario-internal comparability.

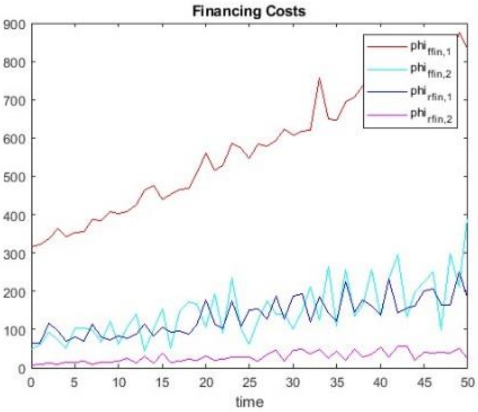
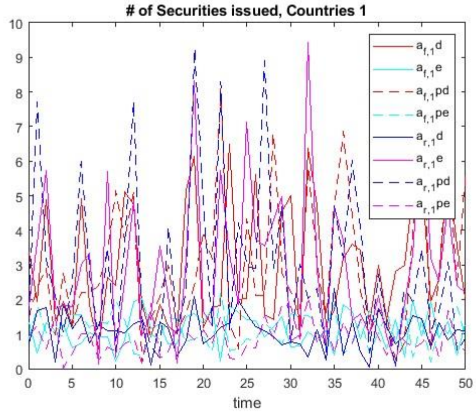
$\varphi_{k,i}$	N/A	
$a_{k,1}^{s}$	N/A	

Figure 3: Benchmark vs. Initial State

Note: We exemplarily provide the amount of securities issued for E1. In E2, while the magnitude levels differ, the structure is comparable, see the Appendix.

While we have not accounted for catch-up dynamics of developing to developed economies in the model of the economy without financial frictions, in the model with financial frictions, hence, some catch-up effects are accounted for. Concerning the composition of the external financing, a_(k,1)^s, we can observe that for the fossil sector—in line with the pecking order theory—a preference for debt financing prevails. In the case of the RES sector, where the bankability—i.e., the access to sufficient amounts of private debt—is a major issue, the model outcomes reflect higher volumes of private equity financing as well as financing via public debt.

2.4.3.1 II—Financial Frictions

In the following, we present the impact of different forms of financial frictions on the outcomes. Within this section, we display select results; again, the full range of results can be found in the Appendix. We account for three different types of financial frictions: The tax advantage of debt, inefficiencies in capital markets due to information asymmetries and uncertainties, as well as the effects of a prevalence of transaction costs (see section 2.4.2).

Firstly, following Miller and Modigliani (1977), we incorporate a ‘tax shield’ on debt, meaning that interest payments on debt are tax-deductible. While this holds true for the G9 states, i.e., the E1 in our model, it does not necessarily reflect the reality within the ROW, i.e., the E2 in our model. To account for this difference, we set the deductible tax rates such that $\tau_{k,2}^{d} < \tau_{k,1}^{d}$. Furthermore, assuming that governments intend to incentivize sustainable developments, we set $\tau_{r,i}^{d} = 1.5\tau_{f,i}^{d}$. As we can see in Figure 4, the effect on the structure of external financing is small. While we can observe higher levels of securities issuance overall (note the different calibration of the y-axes), there is only a small reduction in the levels of equity vs. debt finance in both economies and sectors. Also, the improvement of tax conditions for RES-related public debt is reflected in the related higher volumes of public debt financing. Regarding the share of RES-based in total variants, $N_{r,i}/N_{r,i}$, the higher tax advantage for RES-related debt, which we have assumed, leads to slightly higher shares of RES-based variants (see Appendix).

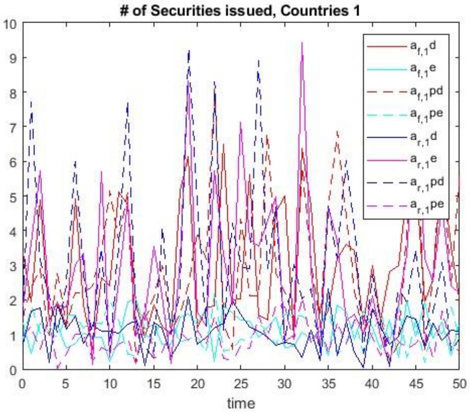
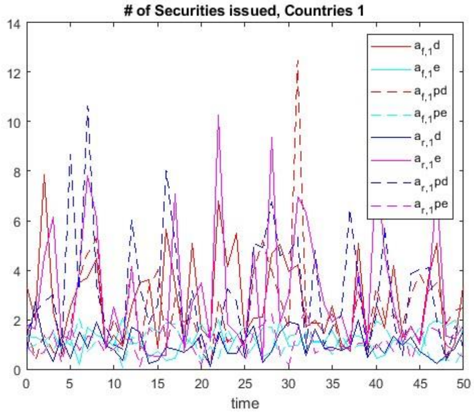
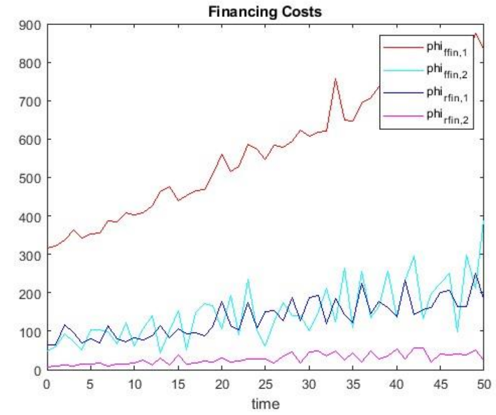
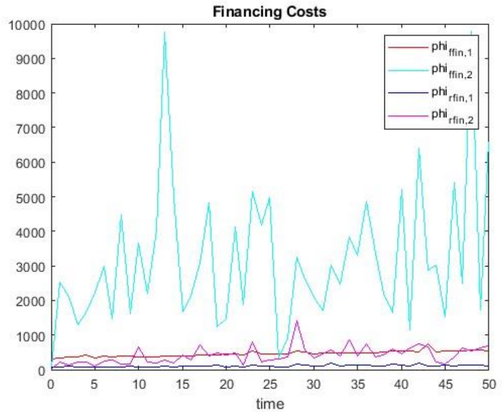
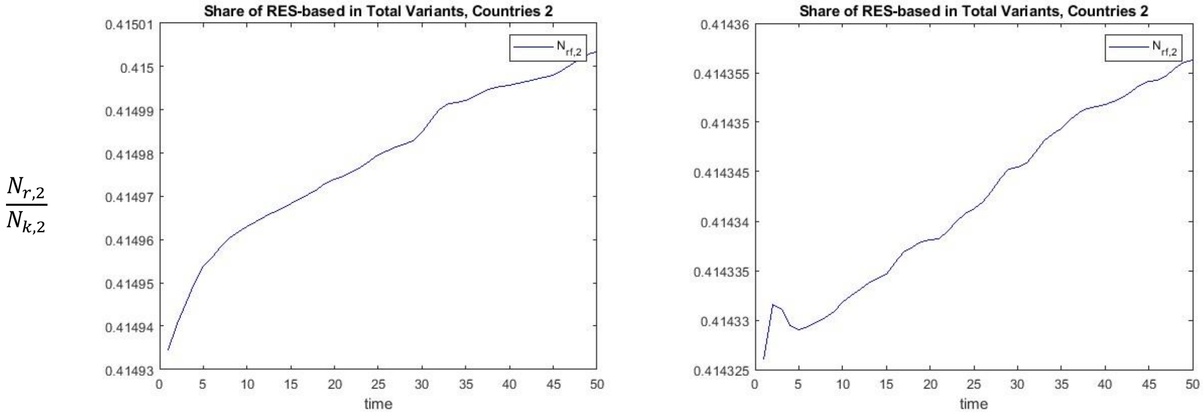
	I—Initial State	**II.a—Tax Advantage of Debt**
$a_{k,1}^{s}$		

Figure 4: Initial State vs. Tax Advantage of Debt

Secondly, we account for different asymmetric-information- and uncertainty-related inefficiencies in the capital markets. We investigate three different constellations of relative inefficiencies: Higher inefficiencies in the developing vs. developed economies, but equally high inefficiencies in the respective two sectors (II.b), higher inefficiencies in the developing vs.

developed economies, and higher inefficiencies in RES-related financing in the developing economies (II.c), and higher inefficiencies in the developing vs. developed economies, but higher inefficiencies in both RES-related financing (II.d); note that the latter two constellations reflect the considerations outlined in section 2.2.2.1. Compared to the initial state, the respective financing subject to inefficiencies becomes more expensive, reflected in a comparably higher $\varphi_{k,i}$. While equally high inefficiencies in the two sectors have a negligible impact on the share of RES-based in total intermediate goods, higher inefficiencies in the RES-related financing lead to a considerable change. Without the difference, the share of RES-based vs. fossil-based variants is degressively growing, with the difference prevailing, the share of RES-based variants declines either in just the E2 (II.c) or both economies (II.d), see Figure 5 and the Appendix. This signifies that higher inefficiencies in the RES-related financing compared to fossil-related financing, as prevalent in reality, leads to a re-direction of technical change towards non-sustainability. Sensitivity analyses reveal that this already holds true for relatively small levels of inefficiencies. The documentation of the according results is available from the authors upon written request.

	I—Initial State	**II.b—Inefficiencies in E2 Capital Markets**
$\varphi_{k,i}$		



II.c— Inefficiencies in E2 RES Capital Markets **II.d—Inefficiencies in All RES Capital Markets**

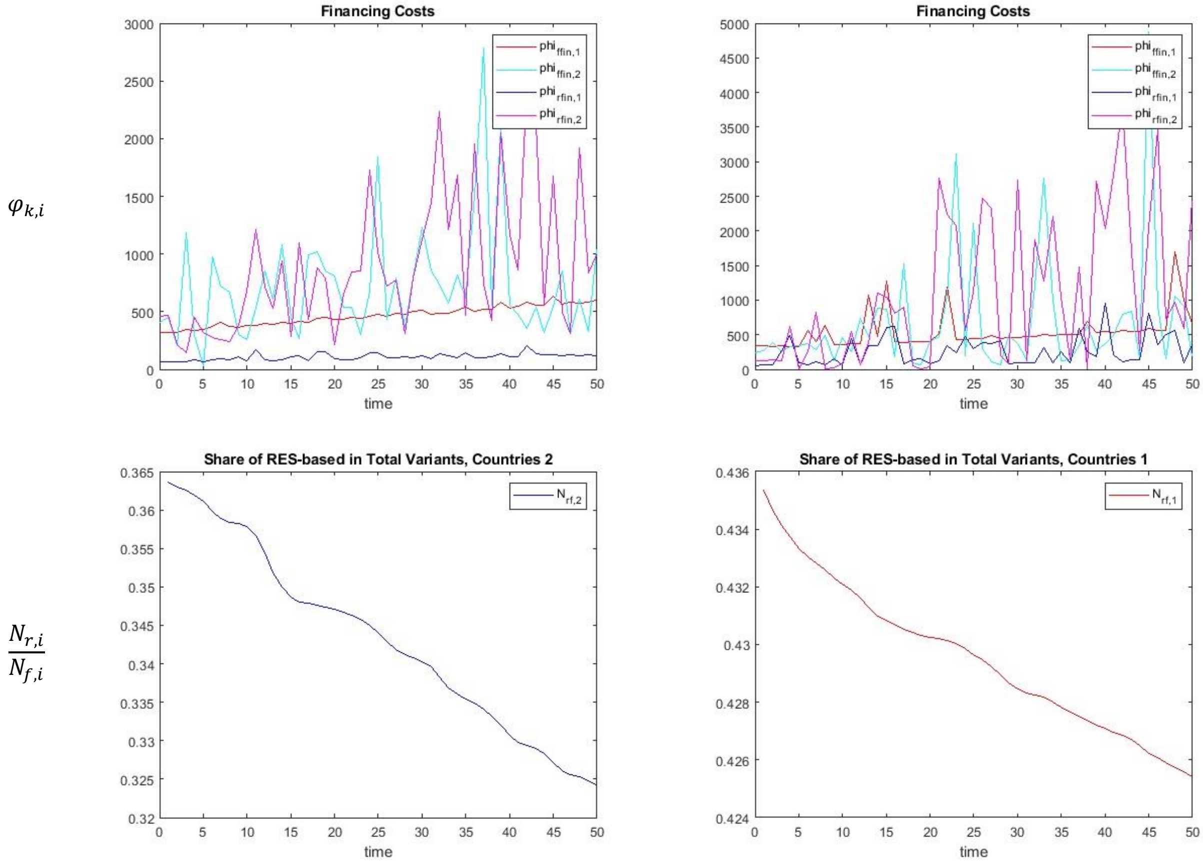


Figure 5: Initial State vs. Capital Market Inefficiencies

Thirdly, we account for capital market imperfections resulting from transaction costs. As reflected in section 2.3.5, we account for two types of transaction costs: flotation costs related to the issuance of private equity, $\varphi_{k,i}^{efix}$ (II.e) and holding costs of securities facing both private and public financial intermediaries, $h_{k,i}^{fix}$ and $h_{k,i}^{var}$ (II.f). The impact of flotation costs associated with the issuance of private equity is trivial. Higher flotation costs make private equity investments the comparatively less attractive financing option. Hence, the share of private equity finance will decrease, while the overall financing costs will be slightly elevated (see the Appendix). Holding costs facing intermediaries provide a tractable way to capture how costs of liquidity and risk-taking affect lenders to firms. Holding costs can be elevated, *inter alia*, due to lower liquidity in financial markets, elevated uncertainty and risk related to the investment, or constrained possibilities to diversify portfolios (Papoutsi et al., 2022). As outlined in section 2.2.2, all these aspects hold true for RES-related financing in particular. Again, elevated RES-related holding costs cause higher RES-related financing costs, while the volume of overall external finance decreases, accompanied by a stronger decline in the share of RES-based variants. While all this is very intuitive, imposing these two types of transaction leads to a situation where the financing needs in the RES-based sector in developing economies cannot be met, as reflected by the temporarily negative values of $\varphi_{r,2}$ in both scenarios[41], see Figure 6.

II.e—Elevated Flotation Costs **II.f—Elevated Holding Costs**

$\varphi_{k,i}$

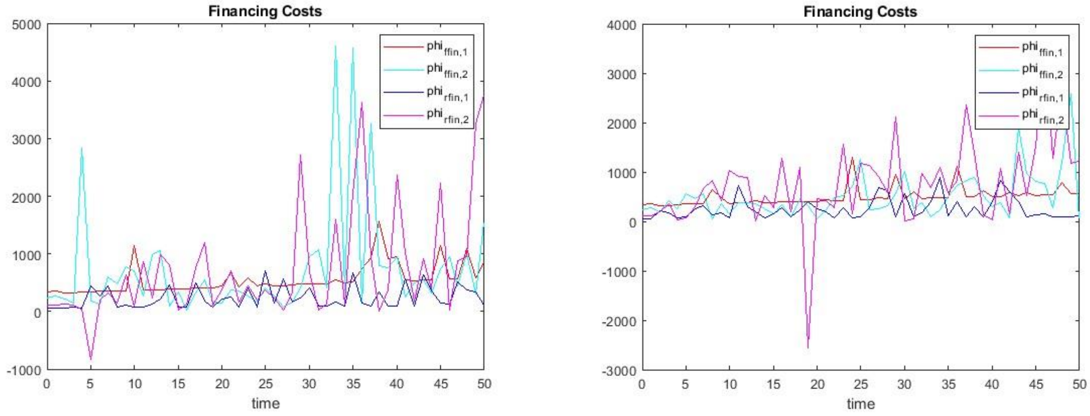


Figure 6: Elevated Transaction Costs (Flotation Costs and Holding Costs)

Due to constraints related to the model setup, this infeasibility of financing does not have any feedback effects apart from elevated RES-related financing costs in E2 on the way in which the RES-based innovation evolves. Hence, it will be interesting to further investigate situations in which external financing fails in more detail in future research. For now, we remain with the hypothesis

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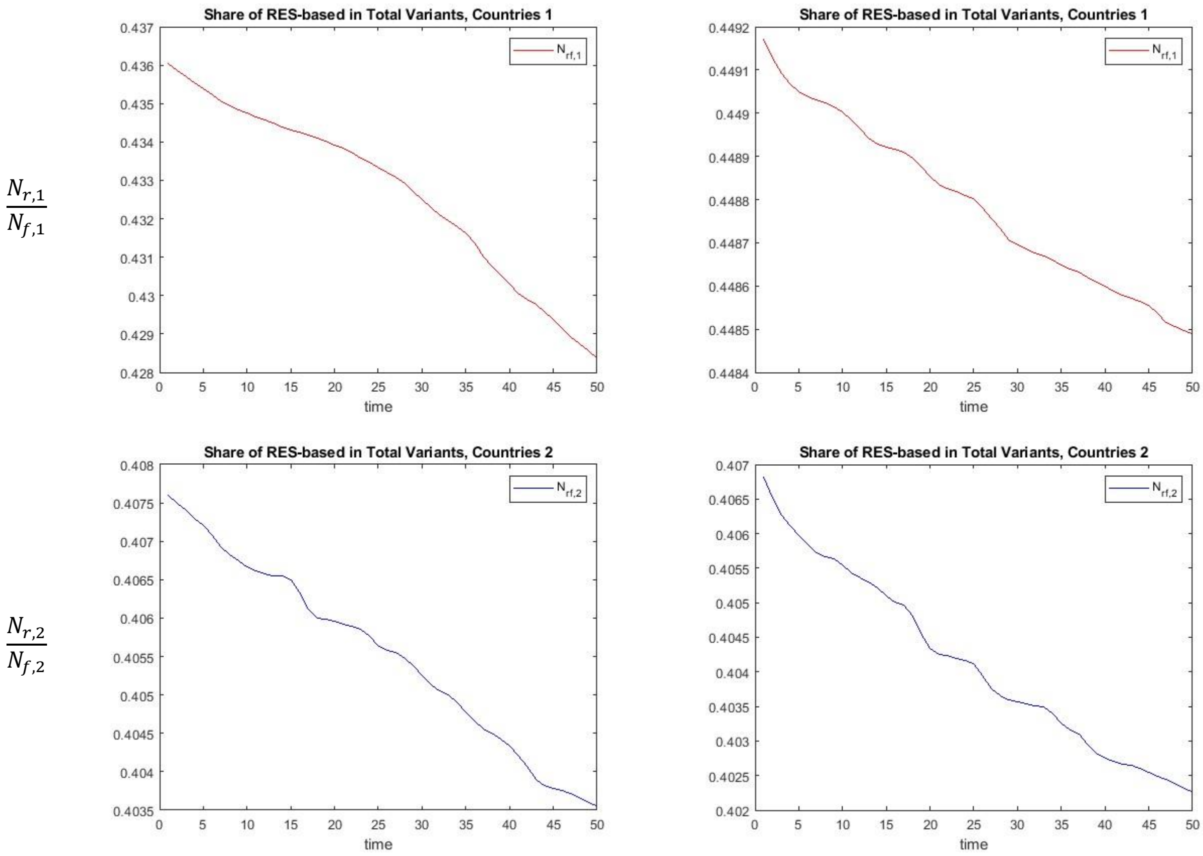
[41] The display of negative values in the case of non-solvability of the system is a particularity of the type of algorithm deployed when writing the model in MATLAB.

that those situations will have a significantly negative impact on the growth in the RES-based sector and direct technical change strongly towards non-sustainable growth.

2.4.3.2 III—Green Public Investment

The subsequent set of scenarios investigates the role and impact, which governments and public FI can play and have in fostering sustainable growth. Therefore, we compare three different types of levers, which governments and public FI can use to influence the direction of growth: The valuation of sustainability over monetary return during the capital allocation decision (III.a and III.b), the financing conditions offered to private sector firms (III.c), as well as support in the development of improved real and financial markets in developing economies (III.d), see Figure 7 and the Appendix. As introduced in section 2.3.5.2, public FI choose the extent to which they value sustainability over financial returns, as reflected in their internal carbon price p_i^{CO2}. We consider two scenarios. In (III.a) an elevated internal carbon price is set by public FI from the developing world, such as development banks, whereas in (III.b) public FI in both the developed and the developing economies set high internal carbon prices. While the former is a realistic scenario reflecting developments in real-world public financial institutions, the second scenario serves the analytical purpose to extract the *ceteris paribus* effect of a higher internal carbon price of only public FI from the developed world. Scenario (III.c) accounts for the lever of public FI to adjust the financing conditions in order to incentivize RES-related innovation. With regards to equity-types of public financing, public FI can agree upon lower dividend payments or provide debt at lower interest rates or payback schedules in favor of RES-based firms. These conditions lead to lower financing costs for RES-based intermediate goods producers. The third lever, i.e., development aid aimed at improving real and financial market conditions (III.d) goes beyond the influence of public FI. Increased efficiency in the markets can reduce overall financing costs, as long as the development aids paid do not significantly exceed efficiency gains on the developing markets. In this context, it is interesting to observe that even under a considerably high internal carbon price set by public FI, economic growth cannot be directed to a sustainable path by these levers only. Even under significantly improved financing conditions provided by public FI (III.c) and significant improvements in the efficiency of real and financial markets in the developing economies (III.d), the growth path returns to a non-sustainable one.

III.a—Sustainable Development Banks **III.b—Sustainable Public FI**



III.c—Improved Public FI Conditions for RES **III.d—International Development**

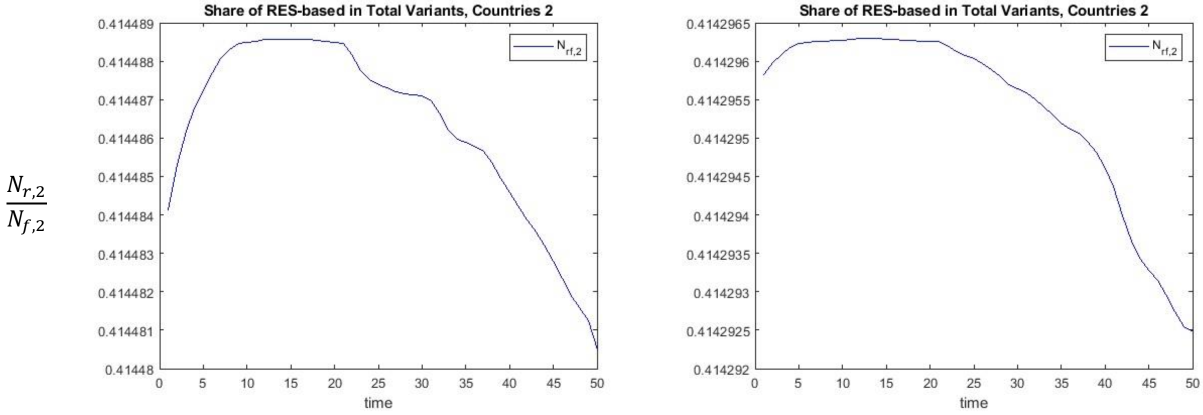
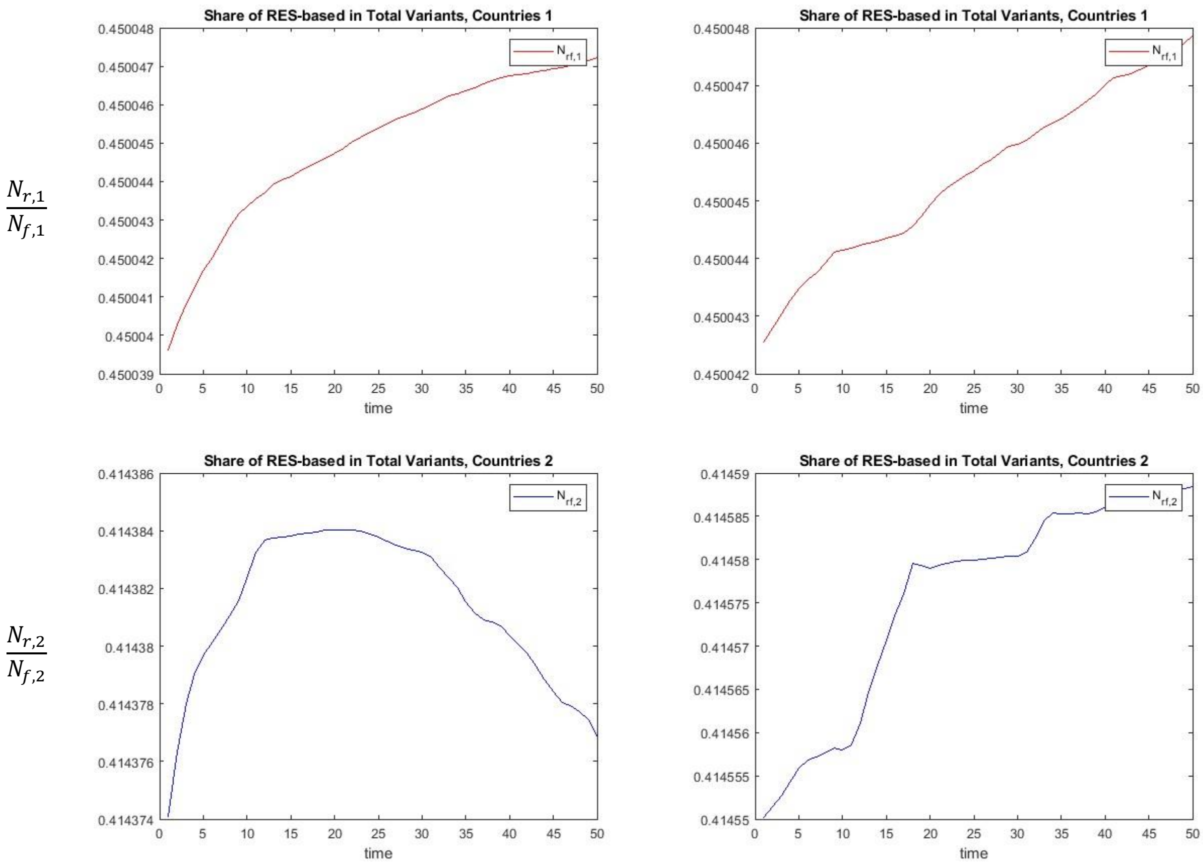


Figure 7: Sustainable Public Financial Intermediaries

2.4.3.3 IV—Sustainable Private FI Regulation and Sustainable Investment Incentives

Apart from steering the capital allocation decision of public FI towards more sustainable investments, regulation and incentives can be set to incentivize private FI to allocate a higher share of their investments to RES-related securities. In this context, we consider two cases: Firstly, regulation is put in place, which forces private FI to offer better financing conditions related to sustainable securities (IV.a). The corresponding regulation entails higher holding costs for private FI, since they are obliged to deviate from their decision-making purely based on financial returns considerations, including an optimized hedging strategy. Secondly, governments can put instruments in place, which reduce the risk for private FI and, thus allow them to offer improved financing conditions for sustainable investments (IV.b). The cost for the risk does not disappear from the economy but is borne by the public sector. However, it is often argued that the total costs associated with the risk can be reduced, as for certain types of risks the public sector is able to bear them more efficiently than the private sector (cf. e.g., OECD, 2017; 2020).

The analysis reveals that under strict regulation of private FI, the developed economies can be steered onto a sustainable growth path. This holds true under the assumption that an adequate regulation can be enforced, which is reasonable to assume in the case of developed economies. In the developing economies, however, this assumption is less reasonable. Therefore, we set the cost of regulation higher, reflecting a higher inefficiency in the implementation of the regulation. Other than in the global North, hence, in the global South, where the same set of regulatory enforcement faces a more inefficient implementation, the economy cannot be led to a sustainable growth path. We exhibit this setting in Figure 8. When imposing stricter regulation in the global South, at some point, the inefficiencies are outweighed, and the economy is led to a sustainable growth path. However, this only happens under very optimistic assumptions, making this approach potentially less feasible. In contrast, under the above-mentioned assumption that the public sector is able to bear risk more efficiently than the private sector—this assumption is at least reasonable for regulatory risk, which constitutes a considerable share of sustainability-related risk—both the global North and the global South can be led to a sustainable growth path. The edgy shape of the corresponding curve for $N_{r,2}/N_{f,2}$, however, points to an instability of this outcome.



IV.a—Sustainable Regulation Private FI **IV.b—Risk Buffering Private FI**

Figure 8: Sustainable Private FI

2.4.3.4 V—Sustainable Public and Private Financial Intermediaries

In (III) and (IV), we have made the changes to the setup *ceteris paribus*—firstly accounting for only the increased valuation of sustainability by public FI, and then only accounting for the (enforced or incentivized) increased valuation of sustainability by private FI. We now consider the two approaches jointly, accounting for coinciding increased valuation of sustainability by both the public and the private FI (V.a). The outcome of this scenario reveals that a combination of both higher valuation of sustainability of public FI and a regulation or incentivization of private FI can lead the global economy onto a sustainable growth path, see Figure 9. This outcome emphasizes the crucial role of the financial sector in the achievement of sustainable growth.

V.a—Sustainable Regulation Private FI

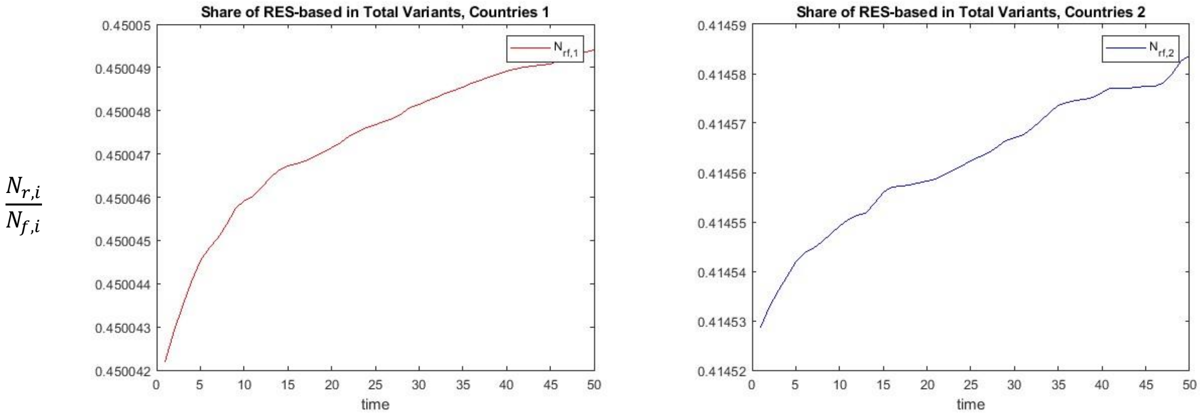
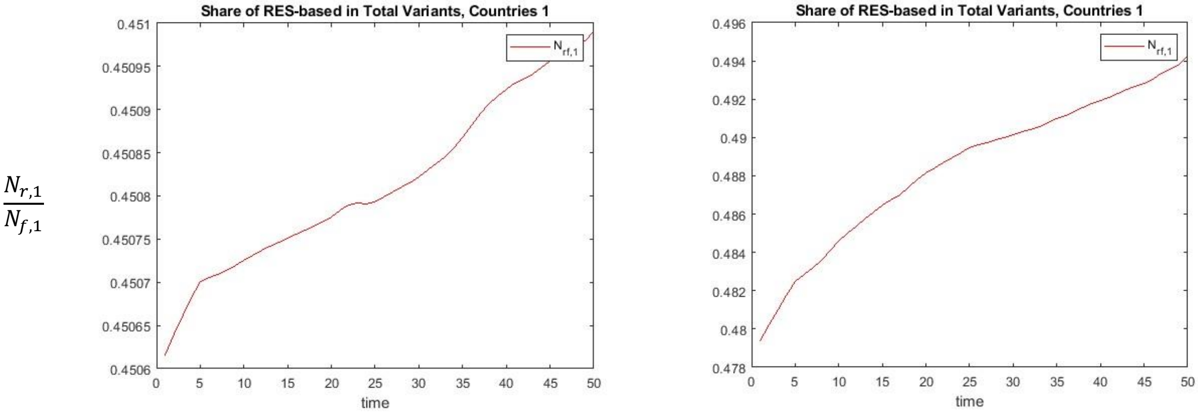


Figure 9: Sustainable Financial Sector

2.4.3.5 VI—Carbon Pricing

Lastly, we analyze the impact of a carbon price in the form of a carbon tax in both economies on the direction of technical change. We consider two different types regarding the evolution of carbon prices: A degressive increase over time and a slight decrease over time. A sufficiently high, degressively increasing carbon tax is sufficient to steer the global economy subject to financial frictions and a non-regulated or incentivized sector to a sustainable growth path, see Figure 10.

VI.a—Degressively Increasing CO_2 Tax **VI.b—Decreasing CO_2 Tax**



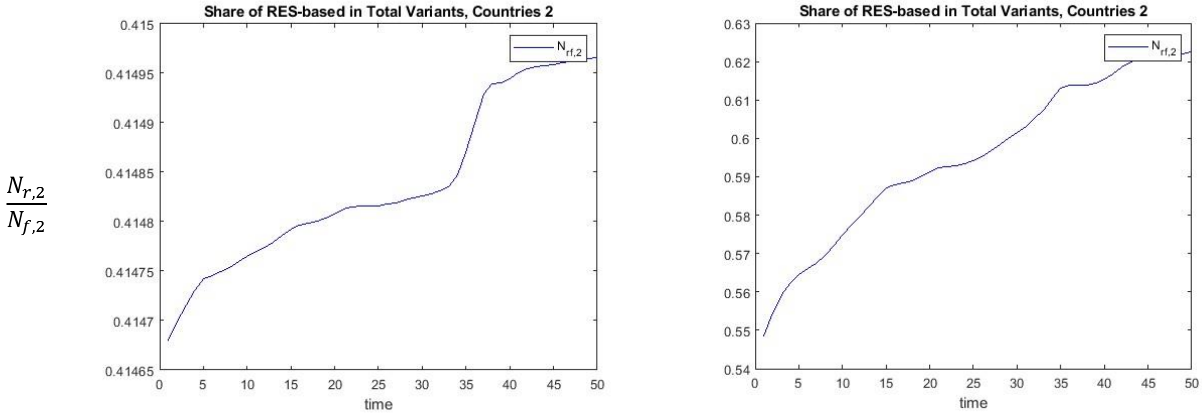


Figure 10: Carbon Taxation

However, achieving such a carbon price to be set globally is not a trivial task. Interestingly, also a decreasing carbon price suffices to lead the economy towards a sustainable growth path if the starting price is sufficiently high. However, the successful outcome of such a scenario would require immediate and very decisive action globally, to an extent that goes far beyond the current levels.

2.5 Key Findings and Policy Implications, Limitations and Future Research

2.5.1 Key Findings and Policy Implications

The analyses reveal the crucial role and high significance of both private and public financial actors in the achievement of a sustainable growth path. We have built upon a model of endogenous growth with two groups of countries and directed technical change towards a RES-based and a fossil-based sector. The extension of the model with an endogenous financing decision of RES-based vs. fossil-based innovation via different types of internal and external financing instruments allows us to investigate the role of the financing decision in achieving a sustainable vs. remaining on a (partially) non-sustainable growth path.

We find that in an economy without financial frictions, path dependencies and lock-in effects cause a settling of the relation of sustainable and non-sustainable growth at a constant level. Hence, in this setting, both RES-based and fossil-based innovation will persist. This means that the global economy is not steered onto a fully sustainable growth path, on which only RES-based innovation takes place eventually, and that non-sustainable growth will remain, eventually causing critical GHG levels in the atmosphere. This can be counteracted by setting a sufficiently high carbon price, leading the economy to a (more) sustainable growth path. While we do not elaborate on the exact time structure of the necessary intervention, these findings are in line with existing research on the topic, such as Acemoglu et al. (2012), who discuss the optimal timing and intensity of carbon reduction incentives. However, the existing studies do not consider any change in the dynamics rooted in the financial economy and neglect the explicit consideration of financing costs and financial frictions.

Accounting for a financial sector in our model of endogenous growth reveals that if financing costs prevail under quasi-perfect capital markets, the transition dynamics towards the balanced growth path are impacted, but the long-term behavior of the economy is comparable, albeit at other magnitudes of the characteristic endogenous variables. For instance, regarding the levels of sustainable vs. non-sustainable growth, the share of sustainable in total growth will also—as in the absence of financing costs—converge to a constant level, while the shape of the transition follows a different path. Also, assuming that financing costs occur at equal levels in RES-based and fossil innovation, the total growth rate will be impacted negatively, while the relative growth rates amongst sustainable and non-sustainable growth in the two economies remain unchanged.

However, *ceteris paribus*, the prevalence of different forms of financial frictions can cause a convergence of the economy towards a non-sustainable growth path, as we have shown in section 0. Tax advantages of debt do change the financing mix between private and public equity and debt. However, they do not considerably impact the growth path. Other financial frictions investigated, i.e., the prevalence of information asymmetries and uncertainty, as well as transaction costs, which are elevated related to RES do change the growth path considerably. The economy is steered onto a non-sustainable growth path, as sustainable innovation finance becomes more costly. This effect is aggravated in developing economies, where, generally, institutions including capital markets are weaker and risk is even more elevated. The financial frictions occur up to a point at which financing of RES-related innovation in the developing countries becomes unavailable, constituting a major barrier to sustainable growth.

Considering different potential cures to this issue reveals that sustainable public financing alone—i.e., the higher valuation of sustainability by public financial intermediaries—does have a positive impact on the share of sustainable in total innovation, does not suffice, however, to steer the global economy onto a sustainable growth path in the long run. This can be explained as public financiers cannot fully commit to sustainable investment but must also account for other monetary goals depending on their purpose (as discussed in section 2.3.5.2). In contrast, a stronger regulation or incentivization of private financial intermediaries can lead to a sustainable growth path, albeit only under strong assumptions. Therefore, we have considered a case where both public financial intermediaries value sustainability more strongly, and where private financial intermediaries are incentivized towards increased sustainable investment. This form of double-tracked intervention leads to a steering of the global economy to a sustainable growth path, on which also the share of sustainable in total innovation is constantly increasing. This signifies that a fully sustainable economic setup can be reached in the long run. However, referring to previous work on the timing of such intervention such as in the above-mentioned Acemoglu et al. (2012), a thorough investigation of the necessary timing of intervention related to the financial sector will be necessary in future work. This is especially to consider a 'tipping point', i.e., a critical level of carbon emissions in the atmosphere, from which onwards a self-enforcing degradation of the environmental quality will be unavoidable.

Lastly, a sufficiently high carbon price can also lead to the desired outcomes. However, it must be sufficiently high and cover a sufficient amount of carbon emissions. Also, related action must happen in a timely manner. If this is considered as unrealistic given the current landscape of global pricing, a joint deployment of all approaches outlined above might be advantageous to consider.

2.5.2 Limitations and Future Research

While some—mostly empirical—work exists that investigate the role of the financial sector in sustainable economic growth, the field is still rather rudimentarily investigated and substantial research will be necessary in the coming years to better understand the relationship of the financial and the real sectors in an environment of desired sustainable growth. While we provide a first approach to conceptualize the relationship, a lot of work can be done to further refine the assessment.

Regarding the representation of the financial sector in the model, we have selected an approach which incorporates the fundamental characteristics of financing decisions between private-sector security issuers and public and private financiers. Drawing upon sophisticated models in the field of optimal capital allocation decisions in the corporate and entrepreneurial world, such as dynamic trade-off models, the representation can be refined. For instance, in our setup, we do not consider loan maturities or any costs occurring at the point in time of default, but only reflect this type of costs in the costs of debt, which we model to be increasing in the firm leverage. Furthermore, future research can allow for a more detailed representation of different financing options or more explicitly account for the dynamics of cases in which demand for financing cannot be met. Furthermore, while having provided some quantitative analyses to show the dynamics of the modeled relations, empirical research will be necessary to substantiate the findings with more explicit numbers.

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Appendix A

Impacts of Public-Private International Sustainable Finance on Achieving Global Climate Goals Through Innovation and Technology Diffusion

A.1 Overview of Current State of the Art

Table A.2: Overview of Related Literature

Literature strand	**Sub-strand**	**Description**	**(I) Sustainability-unrelated contributions, selection**	**(II) Sustainability-related contributions, selection**
(A) Real economy: Endogenous growth and innovation	(A.1) Growth, innovation, and technological diffusion	• Macroeconomic description of technology innovation and diffusion processes • Assessment of the role of developed vs. developing economies (e.g., relative backwardness, spillover effects, technology markets) • Re. sustainability: green growth models	Rimmer (1961), Laumas (1962), Findlay (1978), Romer (1990), Segerstrom et al. (1990), Grossman and Helpman (1991), Aghion and Howitt (1992), Barro and Sala-I-Martin (1997), Young (1998), Akcigit and Kerr (2018)	Nordhaus (1994, 2013), Grossman and Krueger (1995), Goulder and Schneider (1999), Nordhaus and Boyer (2000), Smulders and Nooij (2003), Popp (2002, 2004, 2006), Stern (2007), Hart (2008), Brock and Taylor (2010), Van der Ploeg and Withagen (2012)
	(A.2) Directed technical change	• Direction of technological change based on path dependencies (e.g., market size and price effect) • Re. sustainability: application to the context of clean vs. dirty technology	Zeira (1998), Acemoglu (2002, 2005), Thoenig and Verdier (2003), Caselli and Coleman (2006), Boldrin and Levine (2008)	Newell et al. (1998), Acemogulu et al. (2012, 2016), Aghion et al. (2016), Naqvi and Stockhammer (2018), Hopenhayn and Squintani (2021)
	(A.3) Climate policy models & sector-specific models	• Models developed to assess climate change and the impact of climate policies • Models of specific sectors, often partial equilibrium models, e.g., of the energy sector • Rooted in sustainability-related contributions	N/A	Grubb et al. (2002), Gillingham et al. (2008), Goulder et al. (2016)
(B) Financial economy: Innovation finance and optimal capital structure	(B.1) Optimal capital structure decisions and private innovation financing	• Theories and empirical underpinning of theories explaining the capital structure decision of corporates • For investments in general, including innovation finance • Re. sustainability: accounting for particularities in the green investment and innovation space	Modigliani and Miller (1958), Kraus and Litzenberger (1973), Adler and Dumas (1983), Myers and Maljuf (1984), Noailly and Smeets (2015), Hennessy and Whited (2005), Straebulaev and Whited (2012), García-Quevedo et al. (2018), Ai et al. (2020)	Noally and Smeets (2016), Ongena et al. (2018), Migliorelli and Dessertine (2019), Steffen (2020), Papoutsi et al. (2021), Steffen and Waidelich (2021), Ameli et al. (2021), Egli et al. (2022)
	(B.2) Public-private innovation finance	• Theories and empirical underpinning of theories explaining the capital structure decision of corporates • For investments in general, including innovation finance	Acharya and Xu (2013)	Mazzucato (2013), Mazzucato and Semieniuk (2018), Owen et al. (2018)
(C) Real and financial economy: Impact of financing on real economy	(C.1) Finance in innovation and technological diffusion	• The impact of financial frictions on economic growth • Re. sustainability: • E.g., E3 models including a representation of a financial sector	Schumpeter (1939), Barro and Sala-i-Martin (1992), Malamud and Zucchi (2018), Itskhoki and Moll (2019), Elenev et al. (2020), Christiano (2022)	GEA (2012), IPCC (2014), Kriegler et al. (2014), Pollitt & Mercure (2018), D'Orazio and Valente (2019a, b), Mercure et al. (2019), Monasterolo et al. (2019), Polzin and Sanders (2020), De Haas and Popov (2021), Papoutsi et al. (2022), Peia and Romelli (2022)

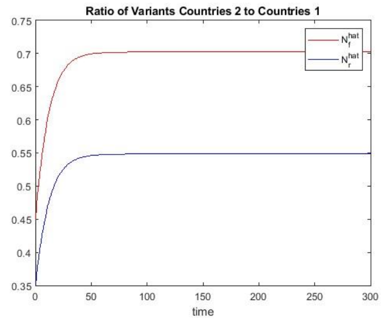
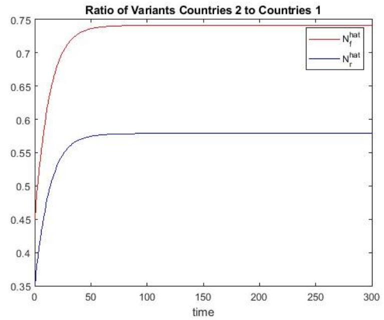
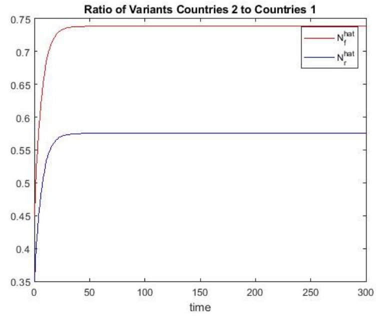
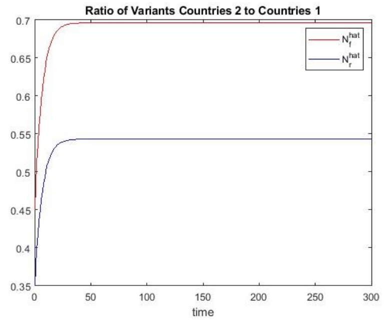
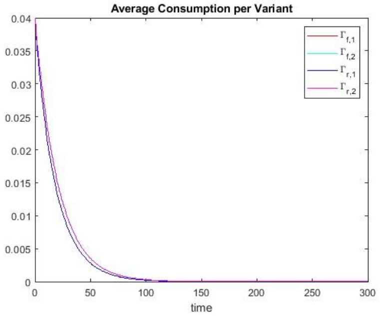
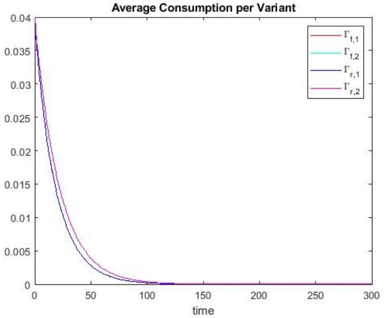
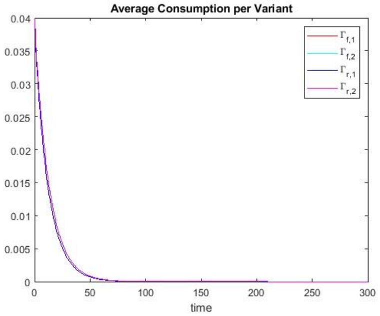
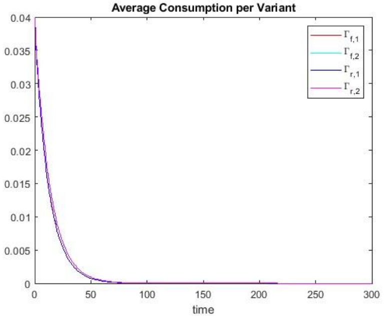
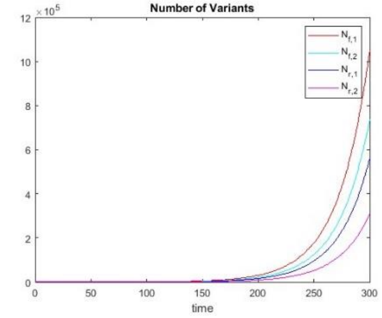
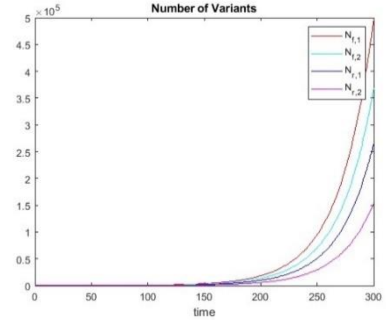
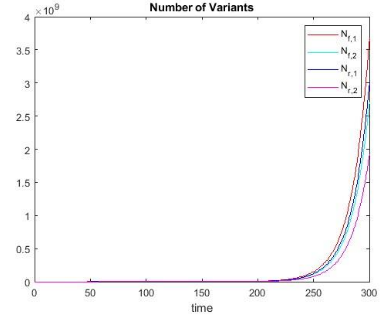
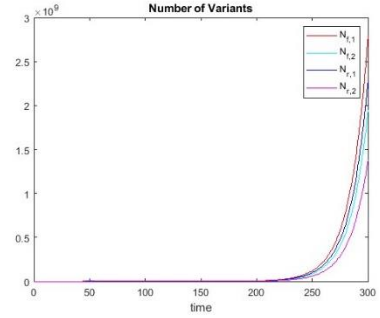
A.2 Benchmark—The Economy Without Financial Frictions

In the following, we provide the model parametrizations for the benchmarking scenarios representing the global economy without financial frictions under different initial conditions, see Table A.3 and Figure A.11 and Figure A.12.

Table A.3: Model Parametrization—Benchmark Scenarios

Parameter	**Unit**	**Description**	**Parameter Value per Benchmark Scenario**								**Comment**
			B.a	***B.b***	***B.c***	***B.d***	***B.e***	***B.f***	***B.g***	***B.h***	
β	N/A	Substitution elasticity intermediate goods sector	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	See section 4.1
θ	N/A	Elasticity of marginal utility of consumption	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	
σ	N/A	Proportion of country i innovations	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	
b	N/A	Proportion of innovations	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
ρ	N/A	HH time preference	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	Standard value, see section 4.1
γ	N/A	Initial share of RES-based final goods in total final goods	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	
ε	N/A	Substitution elasticity RES-based vs. fossil-based final goods	1.50	1.50	1.50	1.50	1.50	1.50	0.5; 3.00	1.50	$0 < \varepsilon < 1$ complements, $\varepsilon > 1$ substitutes
$A_{f,1}$	N/A	Total factor productivity (TFP), fossil sector, economies 1	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	
$A_{f,2}$	N/A	TFP, fossil sector, economies 2	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	Initial TFP uniform across sectors, lower in economies 2
$A_{r,1}$	N/A	TFP, RES sector, economies 1	4.00	4.00	4.00	8.00	4.00	4.00	4.00	4.00	
$A_{r,2}$	N/A	TFP, RES sector, economies 2	3.50	3.50	3.50	7.00	3.50	3.50	3.50	3.50	
$L_{f,1}$	#	Labor in fossil sector, economies 1	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	
$L_{f,2}$	#	Labor in fossil sector, economies 2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	Initial labor uniform across sector, lower in economies 2
$L_{r,1}$	#	Labor in RES sector, economies 1	1.50	1.50	3.00	1.50	1.50	1.50	1.50	1.50	
$L_{r,2}$	#	Labor in RES sector, economies 2	1.00	1.00	2.00	1.00	1.00	1.00	1.00	1.00	
$p_{f,1}$	EUR/#	Price fossil-based final goods, economies 1	0.70	0.35	0.70	0.70	0.70	0.70	0.70	0.70	$0 < p_{f,1} < 1$
$p_{f,2}$	EUR/#	Price fossil-based final goods, economies 2	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	$0 < p_{f,2} < 1$
$\eta_{f,1}$	EUR	Total costs of innovation activities in fossil intermediate sector, countries 1	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	
$\eta_{\dot{f},1}$	N/A	Growth of total innovation costs	0.00	0.00	0.00	0.00	0.00	10.00	0.00	0.00	
$\eta_{f,2}$	EUR	Total costs of innovation activities in fossil intermediate sector, countries 2	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	
$\eta_{\dot{f},2}$	N/A	Growth of total innovation costs	0.00	0.00	0.00	0.00	0.00	10.00	0.00	0.00	
$\eta_{r,1}$	EUR	Total costs of innovation activities in RES intermediate sector, countries 1	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	
$\eta_{\dot{r},1}$	N/A	Growth of total innovation costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	

$\eta_{r,2}$	EUR	Total costs of innovation activities in RES intermediate sector, countries 2	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	
$\dot{\eta_{r,2}}$	N/A	Growth of total innovation costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
τ_1	N/A	(Corporate) tax level, economies 1	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	$0 < \tau_1 < 1$
τ_1^{CO2}	N/A	CO2 tax, economies 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	$0 < \tau_1^{CO2} < 1$
$\tau_1^{\dot{CO2}}$	N/A	Change rate of CO2 tax, economies 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	
τ_2	N/A	(Corporate) tax level, economies 2	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	$0 < \tau_2 < 1$
τ_2^{CO2}	N/A	CO2 tax, economies 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	$0 < \tau_2^{CO2} < 1$
$\tau_2^{\dot{CO2}}$	N/A	Change rate of CO2 tax, economies 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	
$\varsigma_{f,1}$	N/A	Efficiency parameter, costs of innovation in fossil interm. Sector, countries 1	0.90	0.90	0.90	0.90	0.45	0.90	0.90	0.90	$0 < \varsigma_{f,1} < 1$
$\varsigma_{f,2}$	N/A	Efficiency parameter, costs of innovation in fossil interm. Sector, countries 2	0.90	0.90	0.90	0.90	0.45	0.90	0.90	0.90	$0 < \varsigma_{f,2} < 1$
$\varsigma_{r,1}$	N/A	Efficiency parameter, costs of innovation in RES interm. Sector, countries 1	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	$0 < \varsigma_{r,1} < 1$
$\varsigma_{r,2}$	N/A	Efficiency parameter, costs of innovation in RES interm. Sector, countries 2	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	$0 < \varsigma_{r,2} < 1$

	B.a—Reference	B.b—Rel. Price Decrease Econ. 1	B.c—Rel. Labor Increase Econ 1	B.d—Rel. TFP Increase Econ. 1
$\widehat{N_k}$				
$\Gamma_{k,1}$				
$N_{k,i}$				

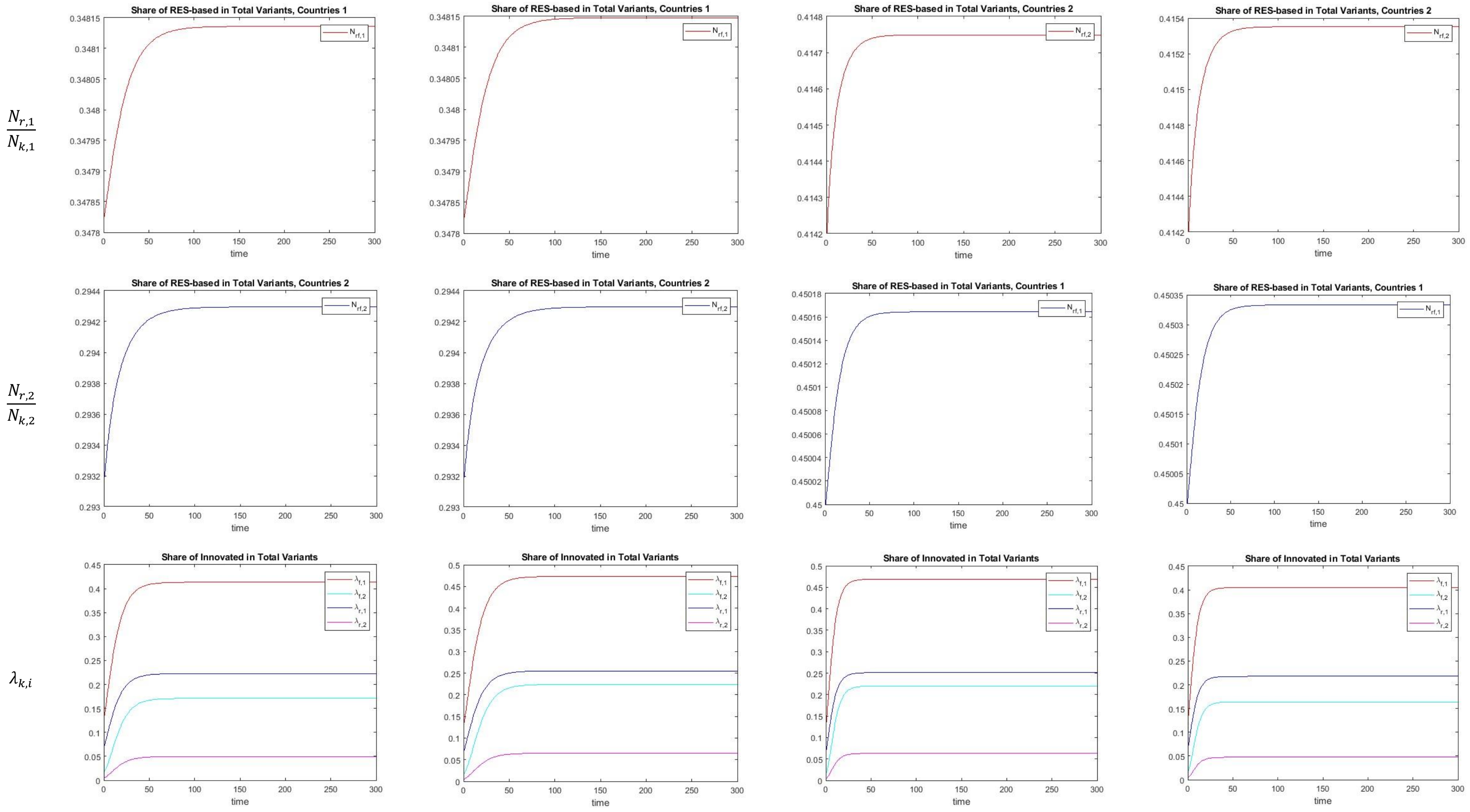
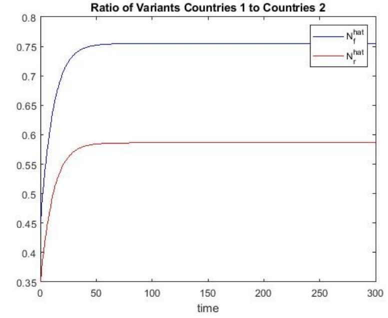
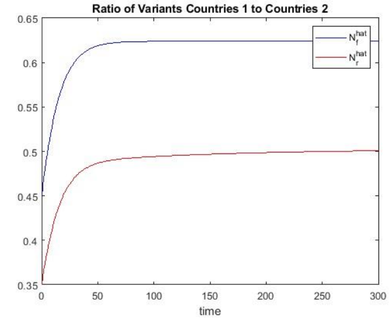
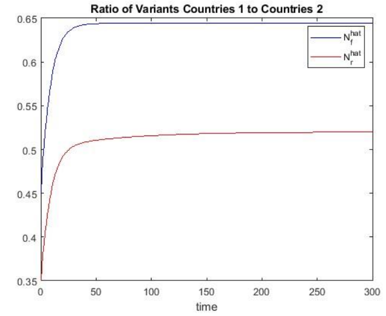
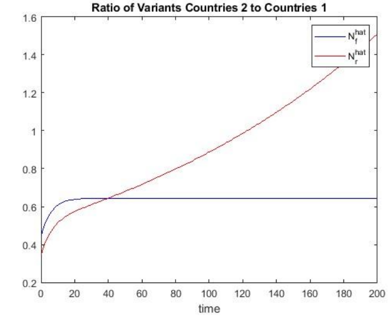
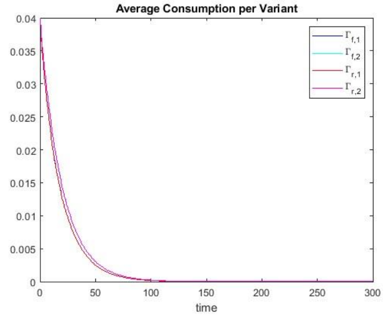
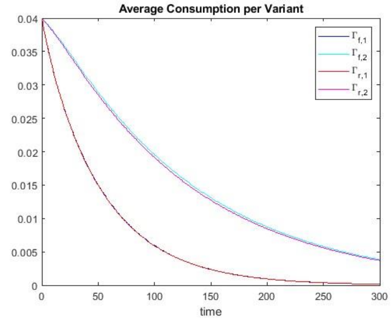
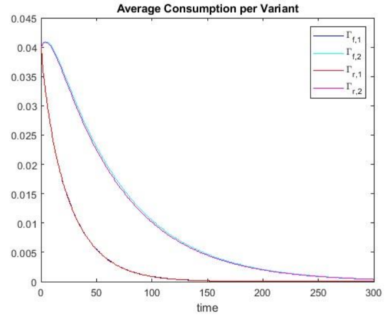
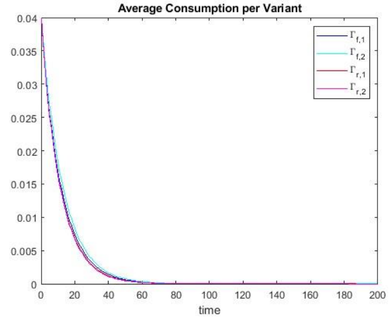
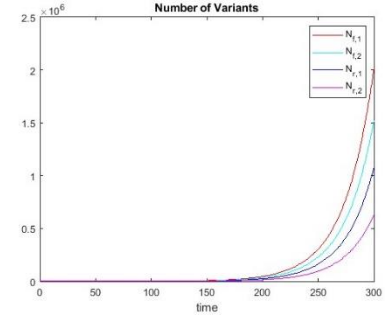
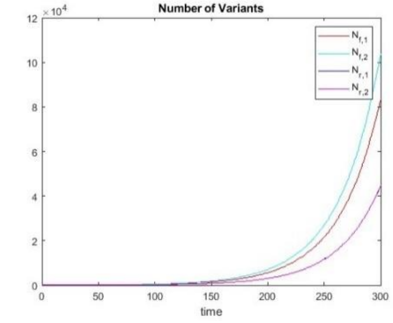
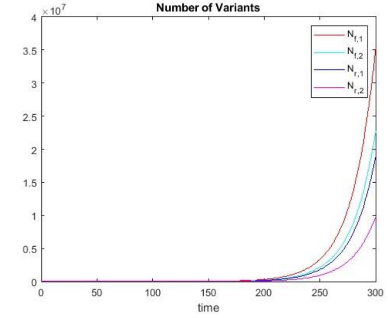
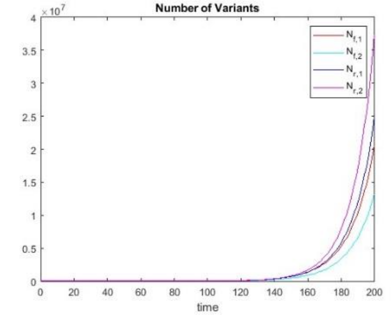


Figure A.11: Model Results for Scenarios B.I to B.IV

	B.e—Rel. Innovation Efficiency	**B.f—Innovation Cost Growth**	**B.g— Substitution Elasticity**	**B.h—Incr. CO_2 Taxation**
$\widehat{N_k}$				
$\Gamma_{k,1}$				
$N_{k,i}$				

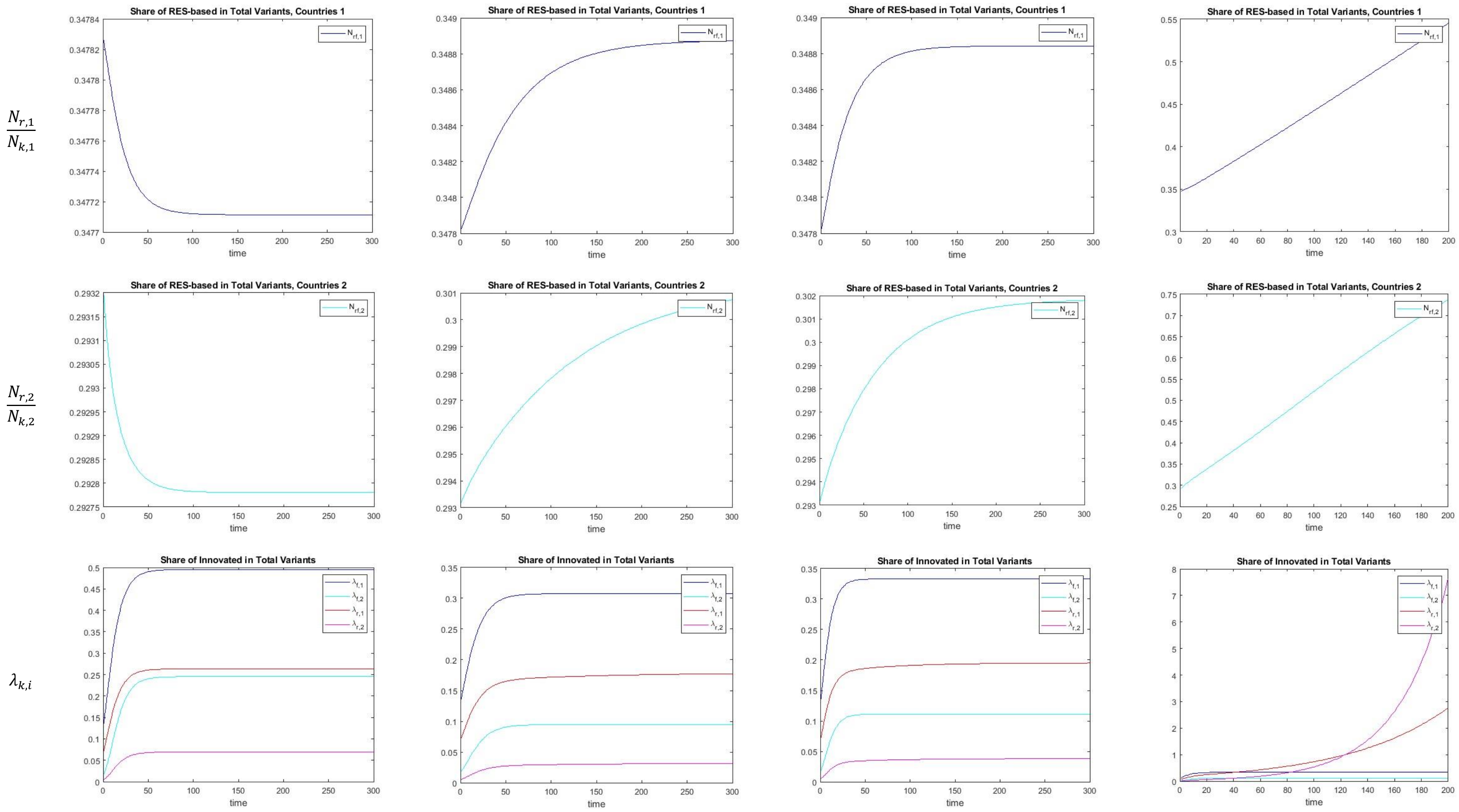


Figure A.12: Model Results for Scenarios B.a to B.h

A.3 The Economy with Financial Frictions

In the following, we provide the model parametrizations for the scenarios representing the global economy with financial frictions under different initial conditions, see Table A.3: Model Parametrization—Benchmark Scenarios, Table A.4Table A.5, and Figure A.13, Figure A.14, Figure A.15, Figure A.16, and Figure A.17.

Table A.4: Model Parametrization—Economy with Financial Frictions, Scenarios I to III.a

Parameter	Unit	Description	Parameter Value per Scenario								Comment
			I	*II.a*	*II.b*	*II.c*	*II.d*	*II.e*	*II.f*	*III.a*	
β	N/A	Substitution elasticity intermediate goods sector	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	See section 4.1
θ	N/A	Elasticity of marginal utility of consumption	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	
σ	N/A	Proportion of country i innovations	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	
b	N/A	Proportion of innovations	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
ρ	N/A	HH time preference	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	Standard value, see section 4.1
γ	N/A	Initial share of RES-based final goods in total final goods	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	
ε	N/A	Substitution elasticity RES-based vs. fossil-based final goods	1.50	1.50	1.50	1.50	1.50	1.50	0.5; 3.00	1.50	$0 < \varepsilon < 1$ complements, $\varepsilon > 1$ substitutes
$A_{f,1}$	N/A	Total factor productivity (TFP), fossil sector, economies 1	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
$A_{f,2}$	N/A	TFP, fossil sector, economies 2	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10	Initial TFP uniform across sectors, lower in economies 2
$A_{r,1}$	N/A	TFP, RES sector, economies 1	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	
$A_{r,2}$	N/A	TFP, RES sector, economies 2	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	
$L_{f,1}$	#	Labor in fossil sector, economies 1	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	
$L_{f,2}$	#	Labor in fossil sector, economies 2	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	Initial labor uniform across sector, lower in economies 2
$L_{r,1}$	#	Labor in RES sector, economies 1	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	
$L_{r,2}$	#	Labor in RES sector, economies 2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
$p_{f,1}$	EUR/#	Price fossil-based final goods, economies 1	0.70	0.35	0.70	0.70	0.70	0.70	0.70	0.70	$0 \leq p_{f,1} \leq 1$
$p_{f,2}$	EUR/#	Price fossil-based final goods, economies 2	0.60	0.70	0.60	0.60	0.60	0.60	0.60	0.60	$0 \leq p_{f,2} \leq 1$
τ_1	N/A	(Corporate) tax level, economies 1	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	$0 \leq \tau_1 \leq 1$
τ_1^{CO2}	N/A	CO2 tax, economies 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0 \leq \tau_1^{CO2} \leq 1$
$\tau_1^{\dot{C}O2}$	N/A	Change rate of CO2 tax, economies 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
τ_2	N/A	(Corporate) tax level, economies 2	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	$0 \leq \tau_2 \leq 1$
τ_2^{CO2}	N/A	CO2 tax, economies 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0 \leq \tau_2^{CO2} \leq 1$
$\tau_2^{\dot{C}O2}$	N/A	Change rate of CO2 tax, economies 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
$\varsigma_{f,1}$	N/A	Efficiency parameter, costs of innovation in	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	$0 \leq \varsigma_{f,1} \leq 1$

		fossil interm. Sector, countries 1									
$\varsigma_{f,2}$	N/A	Efficiency parameter, costs of innovation in fossil interm. Sector, countries 2	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	$0 \leq \varsigma_{f,2} \leq 1$
$\varsigma_{r,1}$	N/A	Efficiency parameter, costs of innovation in RES interm. Sector, countries 1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	$0 \leq \varsigma_{r,1} \leq 1$
$\varsigma_{r,2}$	N/A	Efficiency parameter, costs of innovation in RES interm. Sector, countries 2	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	$0 \leq \varsigma_{r,2} \leq 1$
$d_{f,1}^{e}$	N/A	Dividend payments on private equity, share of firm's net profits in fossil sector, countries 1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	$0 \leq d_{f,1}^{e} \leq 1$
$d_{f,1}^{pe}$	N/A	Dividend payments on public equity, share of firm's net profits in fossil sector, countries 1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	$0 \leq d_{f,1}^{pe} \leq 1$
$d_{r,1}^{e}$	N/A	Dividend payments on private equity, share of firm's net profits in RES sector, countries 1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	$0 \leq d_{r,1}^{e} \leq 1$
$d_{r,1}^{pe}$	N/A	Dividend payments on public equity, share of firm's net profits in RES sector, countries 1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	$0 \leq d_{r,1}^{pe} \leq 1$
$d_{f,2}^{e}$	N/A	Dividend payments on private equity, share of firm's net profits in fossil sector, countries 2	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	$0 \leq d_{f,2}^{e} \leq 1$
$d_{f,2}^{pe}$	N/A	Dividend payments on public equity, share of firm's net profits in fossil sector, countries 2	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	$0 \leq d_{f,2}^{pe} \leq 1$
$d_{r,2}^{e}$	N/A	Dividend payments on private equity, share of firm's net profits in RES sector, countries 2	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	$0 \leq d_{r,2}^{e} \leq 1$
$d_{r,2}^{pe}$	N/A	Dividend payments on public equity, share of firm's net profits in RES sector, countries 2	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	$0 \leq d_{r,2}^{pe} \leq 1$
$m_{f,1}^{d}$	N/A	Proportionality factor, dependence of costs of private debt on leverage in fossil sector, countries 1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	
$m_{f,1}^{pd}$	N/A	Proportionality factor, dependence of costs of public debt on leverage in fossil sector, countries 1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	
$m_{r,1}^{d}$	N/A	Proportionality factor, dependence of costs of private debt on leverage in RES sector, countries 1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	
$m_{r,1}^{pd}$	N/A	Proportionality factor, dependence of costs of public debt on leverage in RES sector, countries 1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	
$m_{f,2}^{d}$	N/A	Proportionality factor, dependence of costs of private debt on leverage in fossil sector, countries 2	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	

$m_{f,2}^{pd}$	N/A	Proportionality factor, dependence of costs of public debt on leverage in fossil sector, countries 2	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	
$m_{r,2}^{d}$	N/A	Proportionality factor, dependence of costs of private debt on leverage in RES sector, countries 2	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	
$m_{r,2}^{pd}$	N/A	Proportionality factor, dependence of costs of public debt on leverage in RES sector, countries 2	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	
p_{1}^{CO2}	N/A	Internal CO2 price, public financiers, countries 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
p_{2}^{CO2}	N/A	Internal CO2 price, public financiers, countries 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	
$\eta_{f,1}^{R\&D}$	N/A	Costs for R&D activities in fossil sector, countries 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
$\eta_{f,2}^{R\&D}$	N/A	Costs for R&D activities in fossil sector, countries 2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
$\eta_{r,1}^{R\&D}$	N/A	Costs for R&D activities in RES sector, countries 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
$\eta_{r,2}^{R\&D}$	N/A	Costs for R&D activities in RES sector, countries 2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
$\iota_{f,1}^{d}$	N/A	Efficiency of lending parameter, private debt, fossil sector, countries 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	$0 \leq \iota_{f,1}^{d} \leq 1$
$\iota_{f,1}^{e}$	N/A	Efficiency of lending parameter, private equity, fossil sector, countries 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	$0 \leq \iota_{f,1}^{e} \leq 1$
$\iota_{f,1}^{pd}$	N/A	Efficiency of lending parameter, public debt, fossil sector, countries 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	$0 \leq \iota_{f,1}^{pd} \leq 1$
$\iota_{f,1}^{pe}$	N/A	Efficiency of lending parameter, public equity, fossil sector, countries 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	$0 \leq \iota_{f,1}^{pe} \leq 1$
$\iota_{f,2}^{d}$	N/A	Efficiency of lending parameter, private debt, fossil sector, countries 2	1.00	1.00	0.01	1.00	1.00	1.00	1.00	1.00	$0 \leq \iota_{f,2}^{d} \leq 1$
$\iota_{f,2}^{e}$	N/A	Efficiency of lending parameter, private equity, fossil sector, countries 2	1.00	1.00	0.01	1.00	1.00	1.00	1.00	1.00	$0 \leq \iota_{f,2}^{e} \leq 1$
$\iota_{f,2}^{pd}$	N/A	Efficiency of lending parameter, public debt, fossil sector, countries 2	1.00	1.00	0.01	1.00	1.00	1.00	1.00	1.00	$0 \leq \iota_{f,2}^{pd} \leq 1$
$\iota_{f,2}^{pe}$	N/A	Efficiency of lending parameter, public equity, fossil sector, countries 2	1.00	1.00	0.01	1.00	1.00	1.00	1.00	1.00	$0 \leq \iota_{f,2}^{pe} \leq 1$
$\iota_{r,1}^{d}$	N/A	Efficiency of lending parameter, private debt, RES sector, countries 1	1.00	1.00	1.00	1.00	0.01	1.00	1.00	1.00	$0 \leq \iota_{r,1}^{d} \leq 1$
$\iota_{r,1}^{e}$	N/A	Efficiency of lending parameter, private equity, RES sector, countries 1	1.00	1.00	1.00	1.00	0.01	1.00	1.00	1.00	$0 \leq \iota_{r,1}^{e} \leq 1$
$\iota_{r,1}^{pd}$	N/A	Efficiency of lending parameter, public debt, RES sector, countries 1	1.00	1.00	1.00	1.00	0.01	1.00	1.00	1.00	$0 \leq \iota_{r,1}^{pd} \leq 1$
$\iota_{r,1}^{pe}$	N/A	Efficiency of lending parameter, public equity, RES sector, countries 1	1.00	1.00	1.00	1.00	0.01	1.00	1.00	1.00	$0 \leq \iota_{r,1}^{pe} \leq 1$

$\iota_{r,2}^{d}$	N/A	Efficiency of lending parameter, private debt, RES sector, countries 2	1.00	1.00	0.01	0.01	0.01	1.00	1.00	1.00	$0 \leq \iota_{r,2}^{d} \leq 1$
$\iota_{r,2}^{e}$	N/A	Efficiency of lending parameter, private equity, RES sector, countries 2	1.00	1.00	0.01	0.01	0.01	1.00	1.00	1.00	$0 \leq \iota_{r,2}^{e} \leq 1$
$\iota_{r,2}^{pd}$	N/A	Efficiency of lending parameter, public debt, RES sector, countries 2	1.00	1.00	0.01	0.01	0.01	1.00	1.00	1.00	$0 \leq \iota_{r,2}^{pd} \leq 1$
$\iota_{r,2}^{pe}$	N/A	Efficiency of lending parameter, public equity, RES sector, countries 2	1.00	1.00	0.01	0.01	0.01	1.00	1.00	1.00	$0 \leq \iota_{r,2}^{pe} \leq 1$
$\tau_{f,1}^{d}$	N/A	Tax benefit of private debt in fossil sector, countries 1	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	$0 \leq \tau_{k,i}^{d} \leq \tau_{k,i} \leq 1$
$\tau_{f,1}^{pd}$	N/A	Tax benefit of public debt in fossil sector, countries 1	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	$0 \leq \tau_{k,i}^{d} \leq \tau_{k,i} \leq 1$
$\tau_{r,1}^{d}$	N/A	Tax benefit of private debt in RES sector, countries 1	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	$0 \leq \tau_{k,i}^{d} \leq \tau_{k,i} \leq 1$
$\tau_{r,1}^{pd}$	N/A	Tax benefit of public debt in RES sector, countries 1	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	$0 \leq \tau_{k,i}^{d} \leq \tau_{k,i} \leq 1$
$\tau_{f,2}^{d}$	N/A	Tax benefit of private debt in fossil sector, countries 2	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	$0 \leq \tau_{k,i}^{d} \leq \tau_{k,i} \leq 1$
$\tau_{f,2}^{pd}$	N/A	Tax benefit of public debt in fossil sector, countries 2	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	$0 \leq \tau_{k,i}^{d} \leq \tau_{k,i} \leq 1$
$\tau_{r,2}^{d}$	N/A	Tax benefit of private debt in RES sector, countries 2	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	$0 \leq \tau_{k,i}^{d} \leq \tau_{k,i} \leq 1$
$\tau_{r,2}^{pd}$	N/A	Tax benefit of public debt in RES sector, countries 2	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	$0 \leq \tau_{k,i}^{d} \leq \tau_{k,i} \leq 1$
$\varphi_{f,1}^{e,fix}$	N/A	Flotation costs, fossil sector, countries 1	0.00	0.00	0.00	0.00	0.00	2.50	0.00	0.00	
$\varphi_{r,1}^{e,fix}$	N/A	Flotation costs, RES sector, countries 1	0.00	0.00	0.00	0.00	0.00	2.50	0.00	0.00	
$\varphi_{f,2}^{e,fix}$	N/A	Flotation costs, fossil sector, countries 2	0.00	0.00	0.00	0.00	0.00	5.00	0.00	0.00	
$\varphi_{r,2}^{e,fix}$	N/A	Flotation costs, RES sector, countries 2	0.00	0.00	0.00	0.00	0.00	5.00	0.00	0.00	
h_{1}^{fix}	N/A	Fixed holding costs private financiers, countries 1	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	
$h_{1}^{p,fix}$	N/A	Fixed holding costs public financiers, countries 1	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	
h_{2}^{fix}	N/A	Fixed holding costs private financiers, countries 2	0.10	0.10	0.10	0.10	0.10	0.10	1.00	0.10	
$h_{2}^{p,fix}$	N/A	Fixed holding costs public financiers, countries 2	0.10	0.10	0.10	0.10	0.10	0.10	1.00	0.10	
h_{1}^{var}	N/A	Variable holding costs private financiers, countries 1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
$h_{1}^{p,var}$	N/A	Variable holding costs public financiers, countries 1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
h_{2}^{var}	N/A	Variable holding costs private financiers, countries 2	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
$h_{2}^{p,var}$	N/A	Variable holding costs public financiers, countries 2	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
ω	N/A	Returns to scale parameter	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	

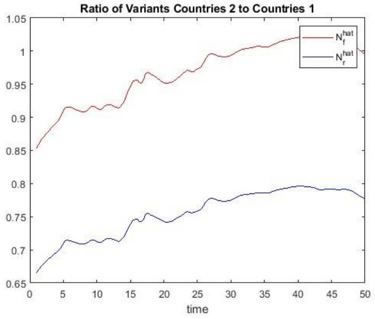
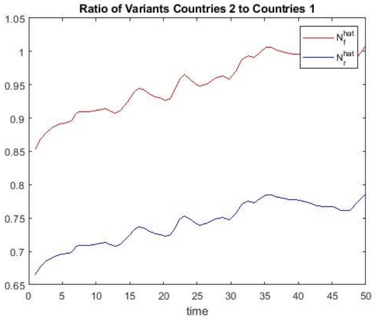
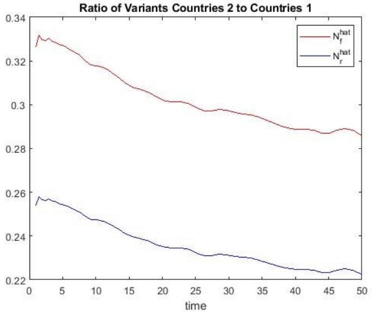
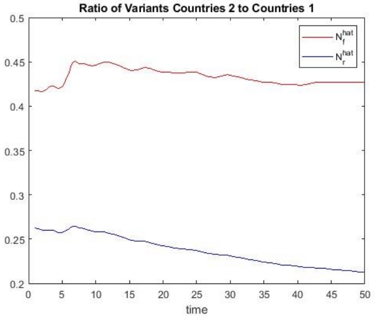
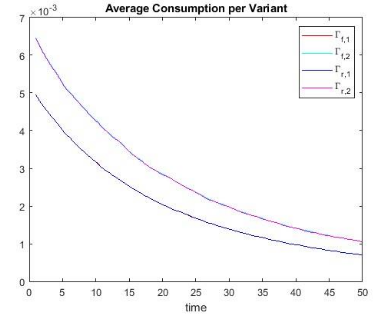
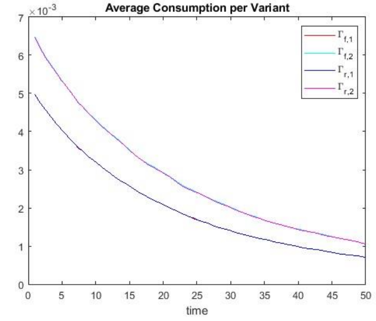
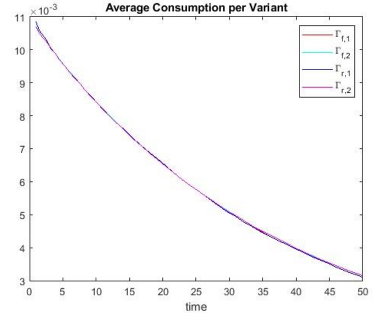
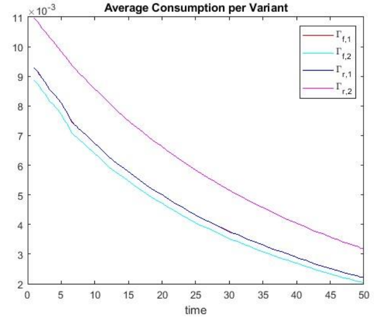
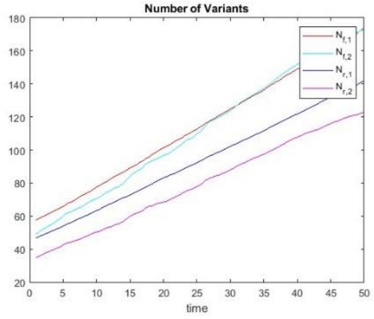
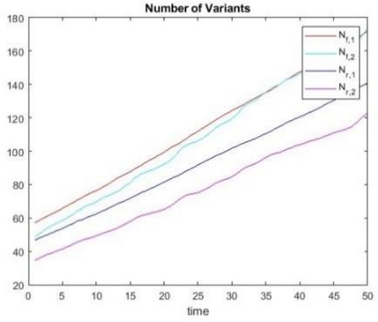
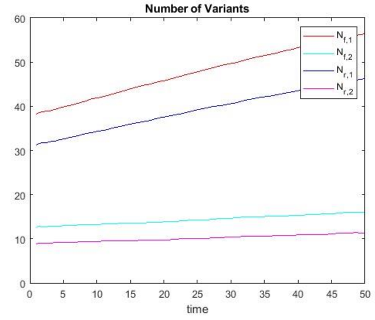
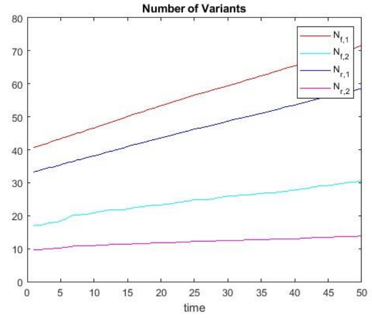
Table A.5: Model Parametrization—Economy with Financial Frictions, Scenarios III.b to VI.b

Parameter	Unit	Description	Parameter Value per Scenario								Comment
			III.b	***III.c***	***III.d***	***IV.a***	***IV.b***	***V.a***	***VI.a***	***VI.b***	
β	N/A	Substitution elasticity intermediate goods sector	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	See section 4.1
θ	N/A	Elasticity of marginal utility of consumption	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	
σ	N/A	Proportion of country i innovations	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	
b	N/A	Proportion of innovations	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
ρ	N/A	HH time preference	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	Standard value, see section 4.1
γ	N/A	Initial share of RES-based final goods in total final goods	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	
ε	N/A	Substitution elasticity RES-based vs. fossil-based final goods	1.50	1.50	1.50	1.50	1.50	1.50	0.5; 3.00	1.50	$0 < \varepsilon < 1$ complements, $\varepsilon > 1$ substitutes
$A_{f,1}$	N/A	Total factor productivity (TFP), fossil sector, economies 1	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
$A_{f,2}$	N/A	TFP, fossil sector, economies 2	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10	Initial TFP uniform across sectors, lower in economies 2
$A_{r,1}$	N/A	TFP, RES sector, economies 1	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	
$A_{r,2}$	N/A	TFP, RES sector, economies 2	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	
$L_{f,1}$	#	Labor in fossil sector, economies 1	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	
$L_{f,2}$	#	Labor in fossil sector, economies 2	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	Initial labor uniform across sector, lower in economies 2
$L_{r,1}$	#	Labor in RES sector, economies 1	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	
$L_{r,2}$	#	Labor in RES sector, economies 2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
$p_{f,1}$	EUR/#	Price fossil-based final goods, economies 1	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	$0 \leq p_{f,1} \leq 1$
$p_{f,2}$	EUR/#	Price fossil-based final goods, economies 2	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	$0 \leq p_{f,2} \leq 1$
τ_1	N/A	(Corporate) tax level, economies 1	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	$0 \leq \tau_1 \leq 1$
τ_1^{CO2}	N/A	CO2 tax, economies 1	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	$0 \leq \tau_1^{CO2} \leq 1$
$\dot{\tau_1^{CO2}}$	N/A	Change rate of CO2 tax, economies 1	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	
τ_2	N/A	(Corporate) tax level, economies 2	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	$0 \leq \tau_2 \leq 1$
τ_2^{CO2}	N/A	CO2 tax, economies 2	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	$0 \leq \tau_2^{CO2} \leq 1$
$\dot{\tau_2^{CO2}}$	N/A	Change rate of CO2 tax, economies 2	0.00	0.00	0.00	0.00	0.00	0.00	0.001	0.001	
$\varsigma_{f,1}$	N/A	Efficiency parameter, costs of innovation in fossil interm. Sector, countries 1	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	$0 \leq \varsigma_{f,1} \leq 1$
$\varsigma_{f,2}$	N/A	Efficiency parameter, costs of innovation in fossil interm. Sector, countries 2	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	$0 \leq \varsigma_{f,2} \leq 1$
$\varsigma_{r,1}$	N/A	Efficiency parameter, costs of innovation in RES interm. Sector, countries 1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	$0 \leq \varsigma_{r,1} \leq 1$
$\varsigma_{r,2}$	N/A	Efficiency parameter, costs of innovation in RES interm. Sector, countries 2	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	$0 \leq \varsigma_{r,2} \leq 1$
$d_{f,1}^e$	N/A	Dividend payments on private equity, share of firm's net profits in fossil sector, countries 1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	$0 \leq d_{f,1}^e \leq 1$

$d_{f,1}^{pe}$	N/A	Dividend payments on public equity, share of firm's net profits in fossil sector, countries 1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	$0 \leq d_{f,1}^{pe} \leq 1$
$d_{r,1}^{e}$	N/A	Dividend payments on private equity, share of firm's net profits in RES sector, countries 1	0.25	0.05	0.25	0.175	0.50	0.50	0.25	0.25	$0 \leq d_{r,1}^{e} \leq 1$
$d_{r,1}^{pe}$	N/A	Dividend payments on public equity, share of firm's net profits in RES sector, countries 1	0.25	0.05	0.25	0.175	0.25	0.25	0.25	0.25	$0 \leq d_{r,1}^{pe} \leq 1$
$d_{f,2}^{e}$	N/A	Dividend payments on private equity, share of firm's net profits in fossil sector, countries 2	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	$0 \leq d_{f,2}^{e} \leq 1$
$d_{f,2}^{pe}$	N/A	Dividend payments on public equity, share of firm's net profits in fossil sector, countries 2	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	$0 \leq d_{f,2}^{pe} \leq 1$
$d_{r,2}^{e}$	N/A	Dividend payments on private equity, share of firm's net profits in RES sector, countries 2	0.25	0.05	0.25	0.175	0.50	0.50	0.25	0.25	$0 \leq d_{r,2}^{e} \leq 1$
$d_{r,2}^{pe}$	N/A	Dividend payments on public equity, share of firm's net profits in RES sector, countries 2	0.25	0.05	0.25	0.175	0.25	0.25	0.25	0.25	$0 \leq d_{r,2}^{pe} \leq 1$
$m_{f,1}^{d}$	N/A	Proportionality factor, dependence of costs of private debt on leverage in fossil sector, countries 1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	
$m_{f,1}^{pd}$	N/A	Proportionality factor, dependence of costs of public debt on leverage in fossil sector, countries 1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	
$m_{r,1}^{d}$	N/A	Proportionality factor, dependence of costs of private debt on leverage in RES sector, countries 1	0.50	0.50	0.50	0.25	0.05	0.05	0.50	0.50	
$m_{r,1}^{pd}$	N/A	Proportionality factor, dependence of costs of public debt on leverage in RES sector, countries 1	0.50	0.50	0.50	0.25	0.50	0.50	0.50	0.50	
$m_{f,2}^{d}$	N/A	Proportionality factor, dependence of costs of private debt on leverage in fossil sector, countries 2	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	
$m_{f,2}^{pd}$	N/A	Proportionality factor, dependence of costs of public debt on leverage in fossil sector, countries 2	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	
$m_{r,2}^{d}$	N/A	Proportionality factor, dependence of costs of private debt on leverage in RES sector, countries 2	0.50	0.50	0.50	0.25	0.05	0.05	0.50	0.50	
$m_{r,2}^{pd}$	N/A	Proportionality factor, dependence of costs of public debt on leverage in RES sector, countries 2	0.50	0.50	0.50	0.25	0.50	0.50	0.50	0.50	
p_{1}^{CO2}	N/A	Internal CO2 price, public financiers, countries 1	100.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	

p_2^{CO2}	N/A	Internal CO2 price, public financiers, countries 2	100.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	
$\eta_{f,1}^{R\&D}$	N/A	Costs for R&D activities in fossil sector, countries 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
$\eta_{f,2}^{R\&D}$	N/A	Costs for R&D activities in fossil sector, countries 2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
$\eta_{r,1}^{R\&D}$	N/A	Costs for R&D activities in RES sector, countries 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
$\eta_{r,2}^{R\&D}$	N/A	Costs for R&D activities in RES sector, countries 2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
$\iota_{f,1}^{d}$	N/A	Efficiency of lending parameter, private debt, fossil sector, countries 1	1.00	1.00	0.50	1.00	1.00	1.00	1.00	1.00	$0 \leq \iota_{f,1}^{d} \leq 1$
$\iota_{f,1}^{e}$	N/A	Efficiency of lending parameter, private equity, fossil sector, countries 1	1.00	1.00	0.50	1.00	1.00	1.00	1.00	1.00	$0 \leq \iota_{f,1}^{e} \leq 1$
$\iota_{f,1}^{pd}$	N/A	Efficiency of lending parameter, public debt, fossil sector, countries 1	1.00	1.00	0.50	1.00	1.00	1.00	1.00	1.00	$0 \leq \iota_{f,1}^{pd} \leq 1$
$\iota_{f,1}^{pe}$	N/A	Efficiency of lending parameter, public equity, fossil sector, countries 1	1.00	1.00	0.50	1.00	1.00	1.00	1.00	1.00	$0 \leq \iota_{f,1}^{pe} \leq 1$
$\iota_{f,2}^{d}$	N/A	Efficiency of lending parameter, private debt, fossil sector, countries 2	1.00	1.00	0.10	1.00	1.00	1.00	1.00	1.00	$0 \leq \iota_{f,2}^{d} \leq 1$
$\iota_{f,2}^{e}$	N/A	Efficiency of lending parameter, private equity, fossil sector, countries 2	1.00	1.00	0.10	1.00	1.00	1.00	1.00	1.00	$0 \leq \iota_{f,2}^{e} \leq 1$
$\iota_{f,2}^{pd}$	N/A	Efficiency of lending parameter, public debt, fossil sector, countries 2	1.00	1.00	0.10	1.00	1.00	1.00	1.00	1.00	$0 \leq \iota_{f,2}^{pd} \leq 1$
$\iota_{f,2}^{pe}$	N/A	Efficiency of lending parameter, public equity, fossil sector, countries 2	1.00	1.00	0.10	1.00	1.00	1.00	1.00	1.00	$0 \leq \iota_{f,2}^{pe} \leq 1$
$\iota_{r,1}^{d}$	N/A	Efficiency of lending parameter, private debt, RES sector, countries 1	1.00	1.00	0.20	1.00	0.01	1.00	1.00	1.00	$0 \leq \iota_{r,1}^{d} \leq 1$
$\iota_{r,1}^{e}$	N/A	Efficiency of lending parameter, private equity, RES sector, countries 1	1.00	1.00	0.20	1.00	0.01	1.00	1.00	1.00	$0 \leq \iota_{r,1}^{e} \leq 1$
$\iota_{r,1}^{pd}$	N/A	Efficiency of lending parameter, public debt, RES sector, countries 1	1.00	1.00	0.20	1.00	0.01	1.00	1.00	1.00	$0 \leq \iota_{r,1}^{pd} \leq 1$
$\iota_{r,1}^{pe}$	N/A	Efficiency of lending parameter, public equity, RES sector, countries 1	1.00	1.00	0.20	1.00	0.01	1.00	1.00	1.00	$0 \leq \iota_{r,1}^{pe} \leq 1$
$\iota_{r,2}^{d}$	N/A	Efficiency of lending parameter, private debt, RES sector, countries 2	1.00	1.00	0.001	0.01	0.01	1.00	1.00	1.00	$0 \leq \iota_{r,2}^{d} \leq 1$
$\iota_{r,2}^{e}$	N/A	Efficiency of lending parameter, private equity, RES sector, countries 2	1.00	1.00	0.001	0.01	0.01	1.00	1.00	1.00	$0 \leq \iota_{r,2}^{e} \leq 1$
$\iota_{r,2}^{pd}$	N/A	Efficiency of lending parameter, public debt, RES sector, countries 2	1.00	1.00	0.01	0.01	0.01	1.00	1.00	1.00	$0 \leq \iota_{r,2}^{pd} \leq 1$
$\iota_{r,2}^{pe}$	N/A	Efficiency of lending parameter, public equity, RES sector, countries 2	1.00	1.00	0.01	0.01	0.01	1.00	1.00	1.00	$0 \leq \iota_{r,2}^{pe} \leq 1$
$\tau_{f,1}^{d}$	N/A	Tax benefit of private debt in fossil sector, countries 1	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	$0 \leq \tau_{k,i}^{d} \leq \tau_{k,i} \leq 1$

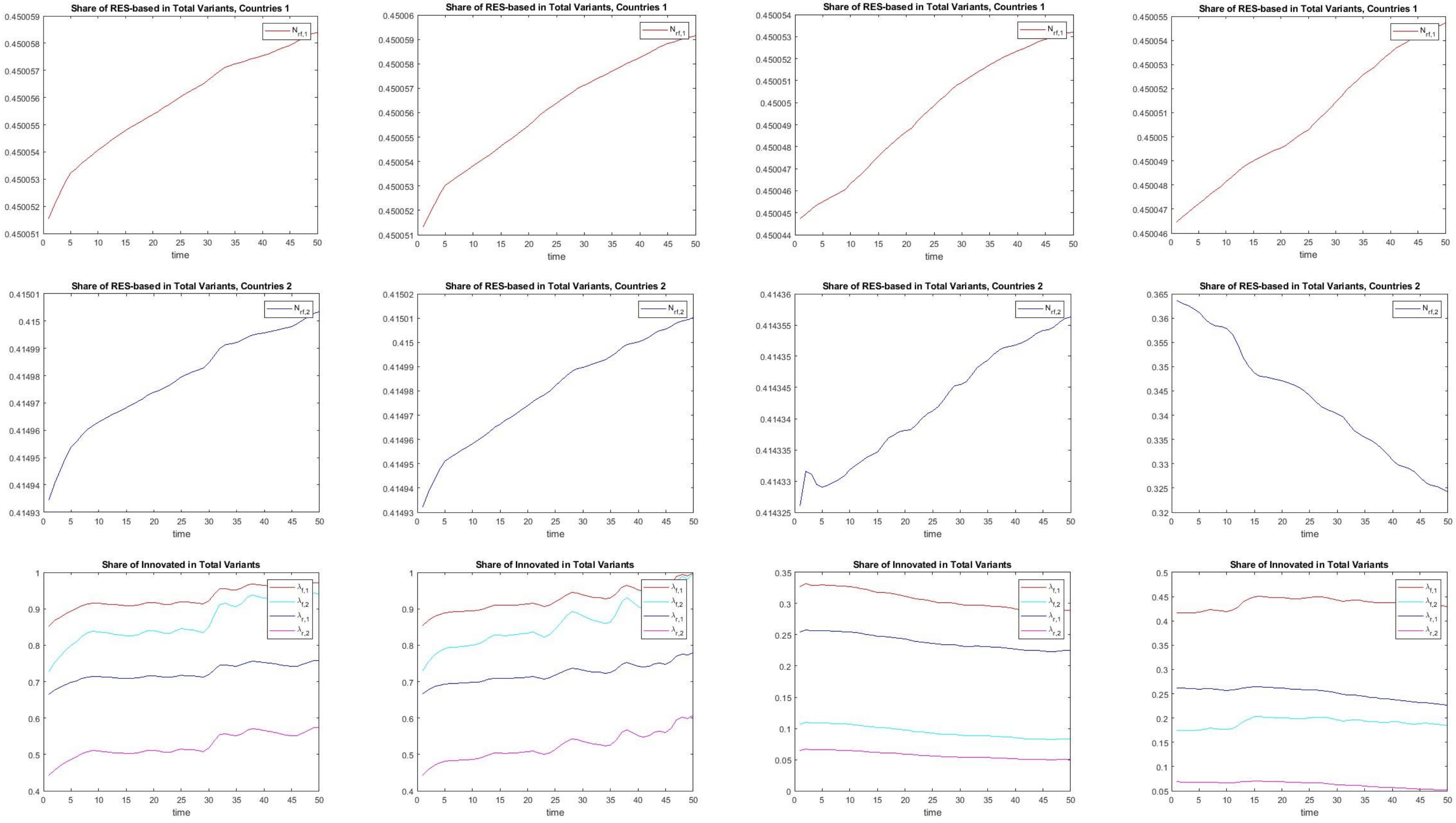
$\tau^{pd}_{f,1}$	N/A	Tax benefit of public debt in fossil sector, countries 1	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	$0 \leq \tau^{d}_{k,i} \leq \tau_{k,i} \leq 1$
$\tau^{d}_{r,1}$	N/A	Tax benefit of private debt in RES sector, countries 1	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	$0 \leq \tau^{d}_{k,i} \leq \tau_{k,i} \leq 1$
$\tau^{pd}_{r,1}$	N/A	Tax benefit of public debt in RES sector, countries 1	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	$0 \leq \tau^{d}_{k,i} \leq \tau_{k,i} \leq 1$
$\tau^{d}_{f,2}$	N/A	Tax benefit of private debt in fossil sector, countries 2	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	$0 \leq \tau^{d}_{k,i} \leq \tau_{k,i} \leq 1$
$\tau^{pd}_{f,2}$	N/A	Tax benefit of public debt in fossil sector, countries 2	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	$0 \leq \tau^{d}_{k,i} \leq \tau_{k,i} \leq 1$
$\tau^{d}_{r,2}$	N/A	Tax benefit of private debt in RES sector, countries 2	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	$0 \leq \tau^{d}_{k,i} \leq \tau_{k,i} \leq 1$
$\tau^{pd}_{r,2}$	N/A	Tax benefit of public debt in RES sector, countries 2	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	$0 \leq \tau^{d}_{k,i} \leq \tau_{k,i} \leq 1$
$\varphi^{e,fix}_{f,1}$	N/A	Flotation costs, fossil sector, countries 1	0.00	0.00	0.00	0.00	0.00	2.50	0.00	0.00	
$\varphi^{e,fix}_{r,1}$	N/A	Flotation costs, RES sector, countries 1	0.00	0.00	0.00	0.00	0.00	2.50	0.00	0.00	
$\varphi^{e,fix}_{f,2}$	N/A	Flotation costs, fossil sector, countries 2	0.00	0.00	0.00	0.00	0.00	5.00	0.00	0.00	
$\varphi^{e,fix}_{r,2}$	N/A	Flotation costs, RES sector, countries 2	0.00	0.00	0.00	0.00	0.00	5.00	0.00	0.00	
h^{fix}_{1}	N/A	Fixed holding costs private financiers, countries 1	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	
$h^{p,fix}_{1}$	N/A	Fixed holding costs public financiers, countries 1	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	
h^{fix}_{2}	N/A	Fixed holding costs private financiers, countries 2	0.10	0.10	0.10	0.10	0.10	0.10	1.00	0.10	
$h^{p,fix}_{2}$	N/A	Fixed holding costs public financiers, countries 2	0.10	0.10	0.10	0.10	0.10	0.10	1.00	0.10	
h^{var}_{1}	N/A	Variable holding costs private financiers, countries 1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
$h^{p,var}_{1}$	N/A	Variable holding costs public financiers, countries 1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
h^{var}_{2}	N/A	Variable holding costs private financiers, countries 2	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
$h^{p,var}_{2}$	N/A	Variable holding costs public financiers, countries 2	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
ω	N/A	Returns to scale parameter	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	

	I—Initial State	II.a—Tax Advantage Debt for RES	II.b—Inefficient E2 Capital Markets	II.c—Ineff. E2 RES Capital Markets
$\widehat{N_k}$	 Ratio of Variants Countries 2 to Countries 1 	 Ratio of Variants Countries 2 to Countries 1 	 Ratio of Variants Countries 2 to Countries 1 	 Ratio of Variants Countries 2 to Countries 1
$\Gamma_{k,1}$	 Average Consumption per Variant 	 Average Consumption per Variant 	 Average Consumption per Variant 	 Average Consumption per Variant
$N_{k,i}$	 Number of Variants 	 Number of Variants 	 Number of Variants 	 Number of Variants

$\frac{N_{r,1}}{N_{k,1}}$

$\frac{N_{r,2}}{N_{k,2}}$

$\lambda_{k,i}$



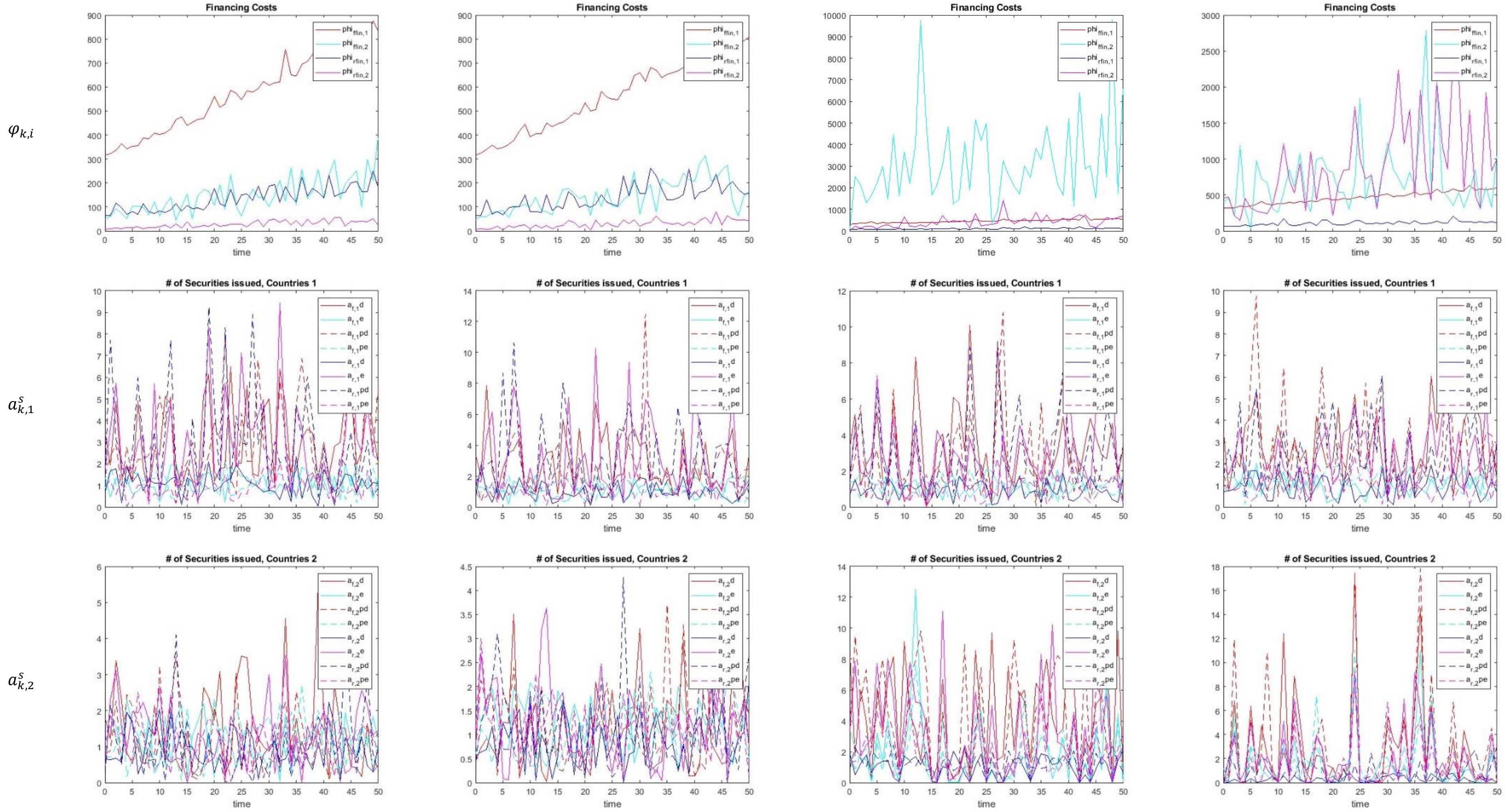
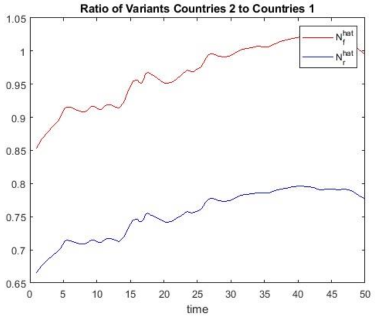
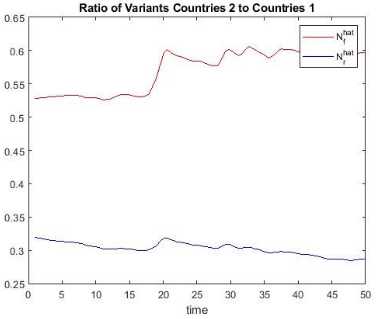
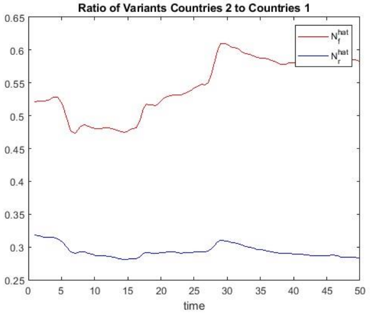
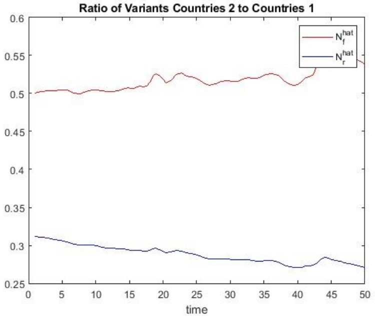
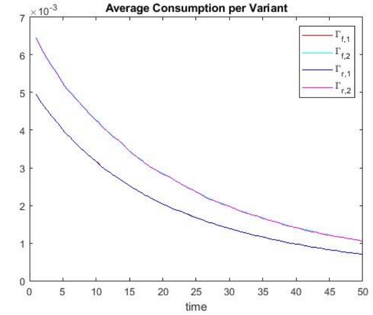
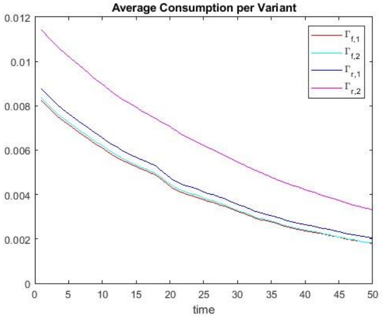
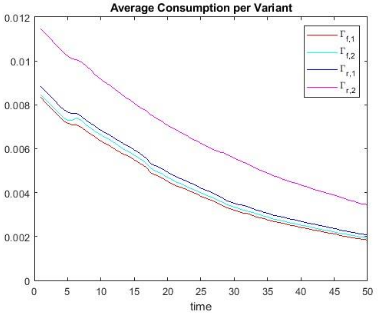
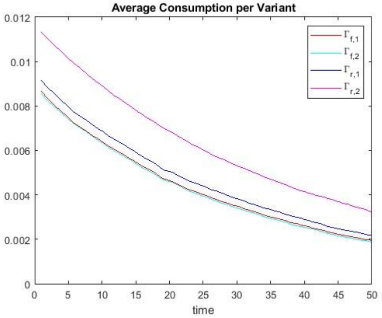
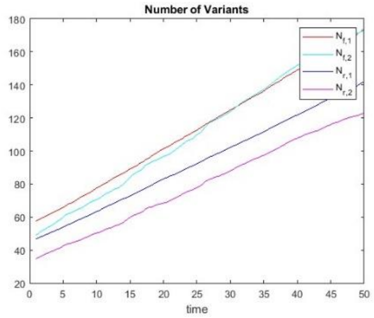
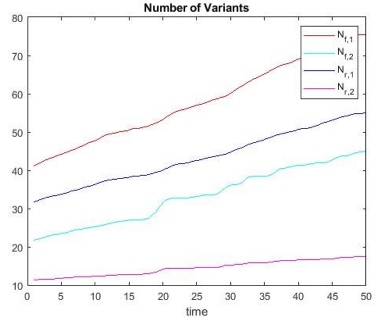
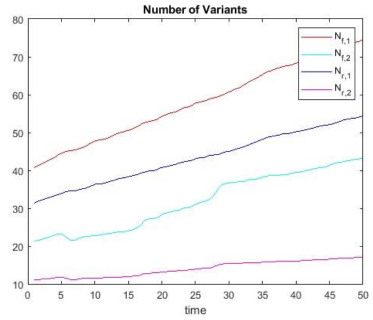
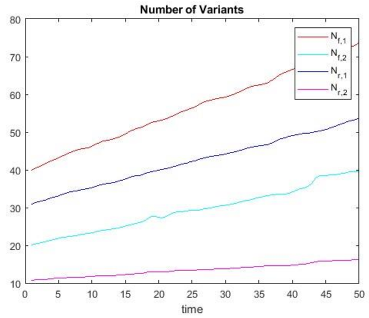
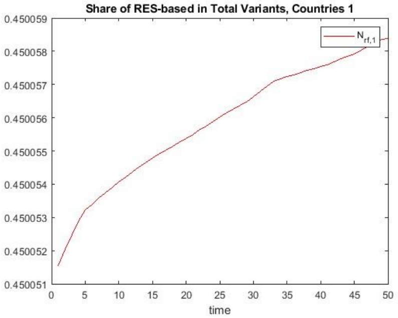
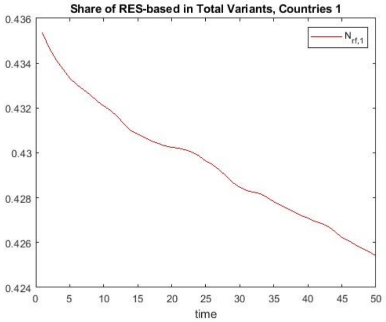


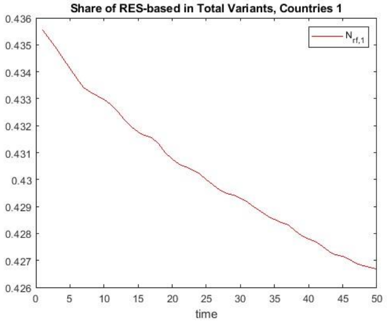
Figure A.13: Model Results for Scenarios I to II.c

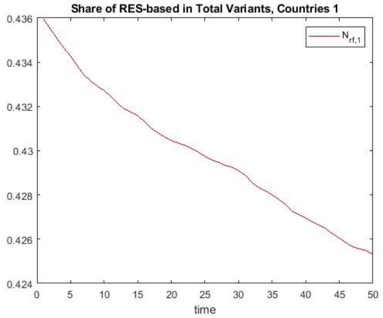
	I—Initial State (*repeated for comparison*)	**II.d—Ineff. Cap. Mark. C1&C2 for RES**	**II.e—Elevated Flotation Costs**	**II.f—Elevated Holding Costs**
$\widehat{N_k}$				
$\Gamma_{k,1}$				
$N_{k,i}$				

$$\frac{N_{r,1}}{N_{k,1}}$$

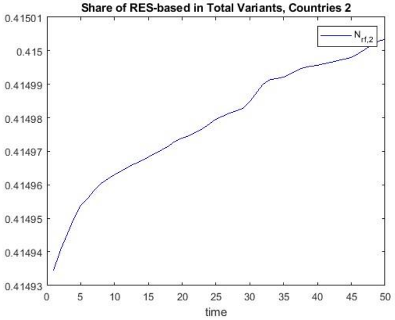


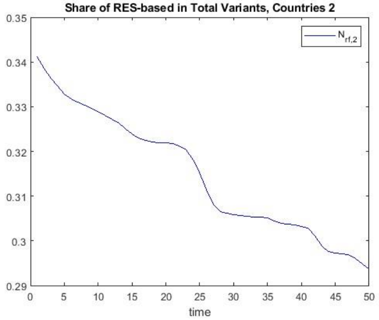


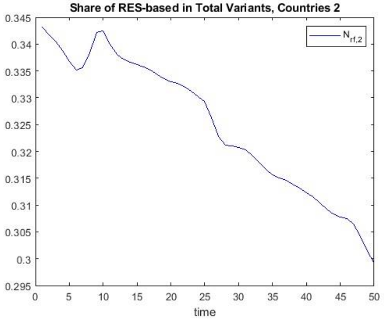


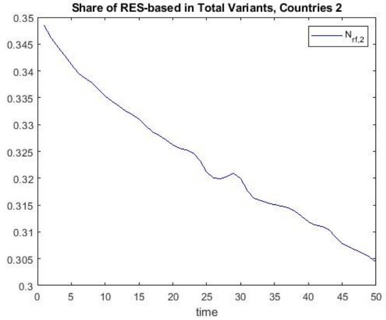


$$\frac{N_{r,2}}{N_{k,2}}$$

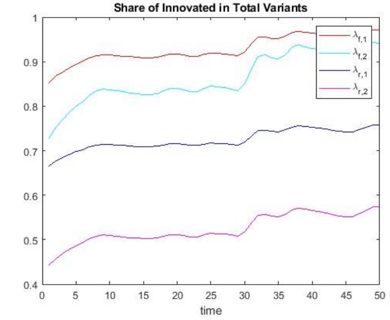


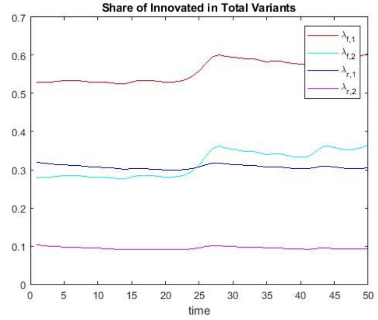


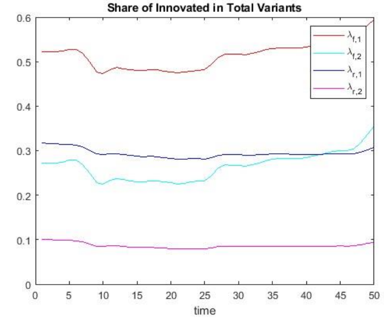


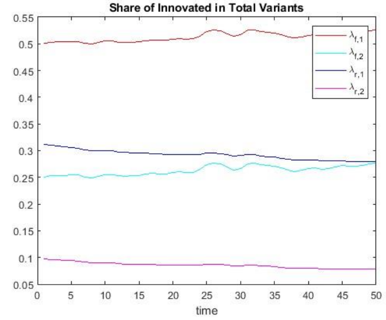


$\lambda_{k,i}$









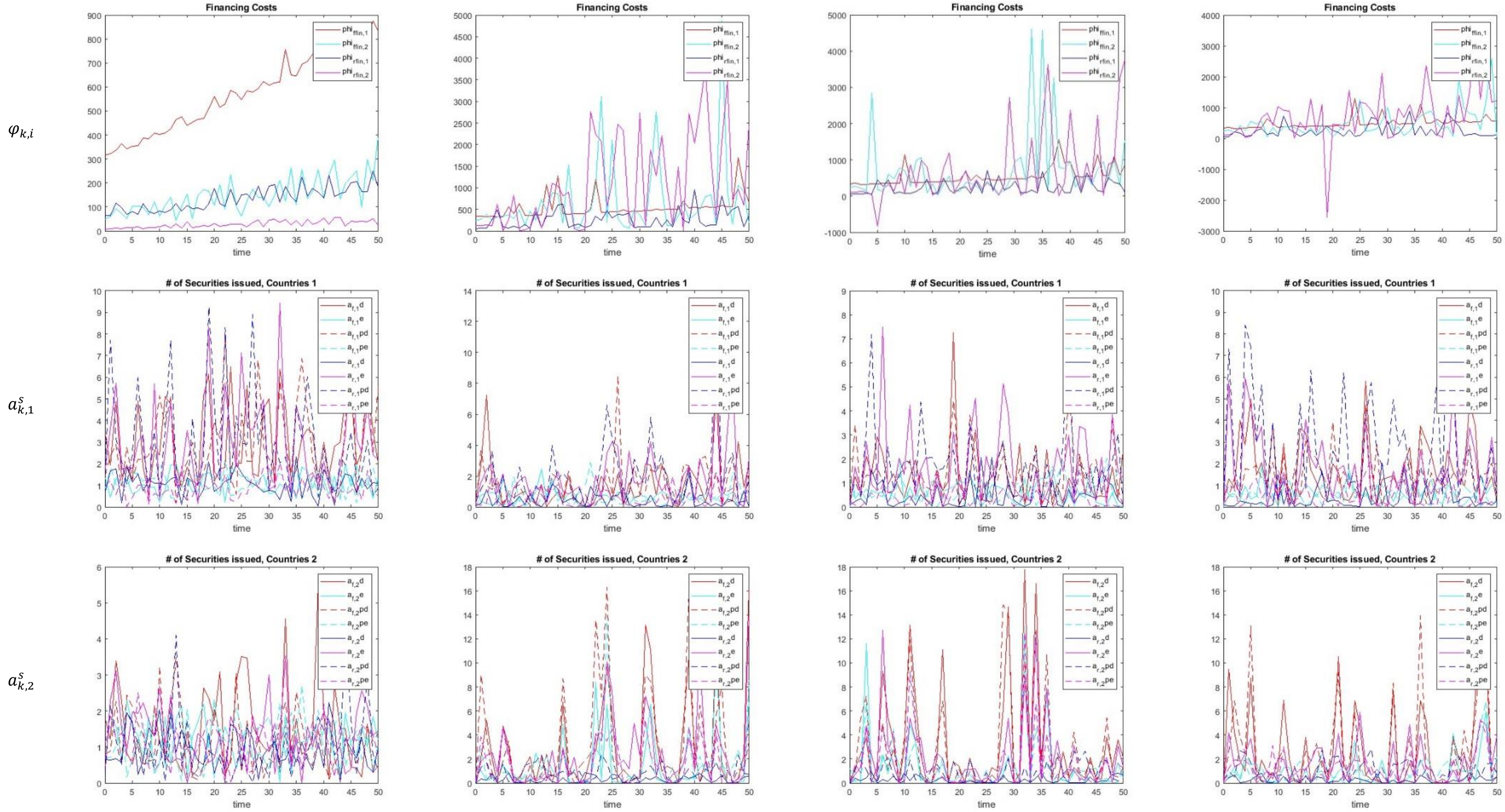
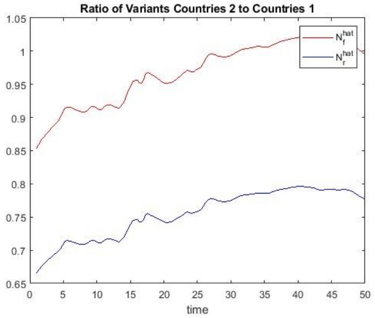
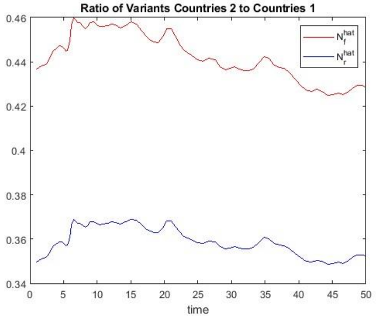


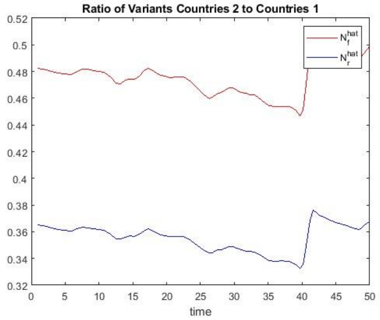
Figure A.14: Model Results for Scenarios II.d to II.f

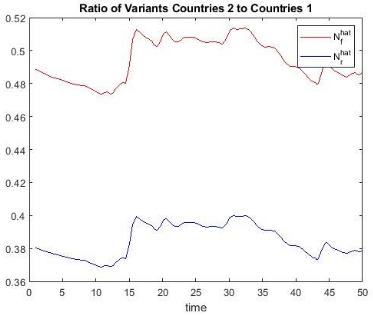
	I—Initial State (*repeated for comparison*)	**III.a—Sustainable Development Banks**	**III.b—Sustainable Public FI**	**III.c—Improved Public FI Cond. (RES)**

$\widehat{N_k}$

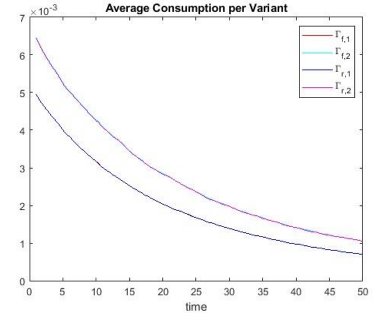


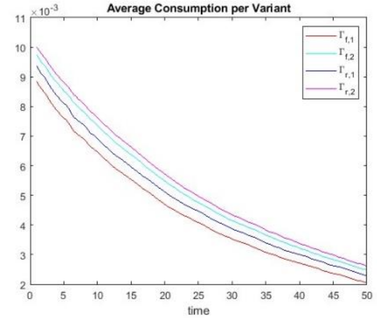


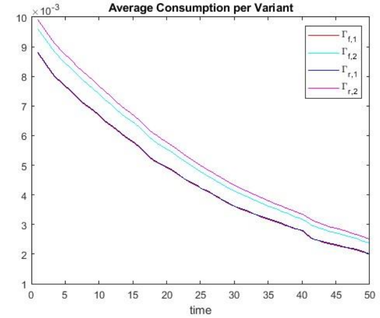


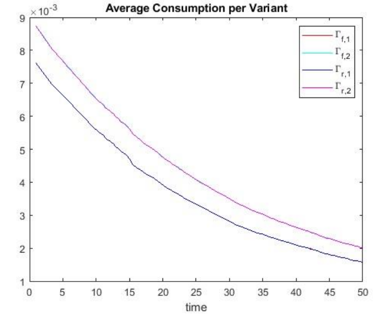


$\Gamma_{k,1}$

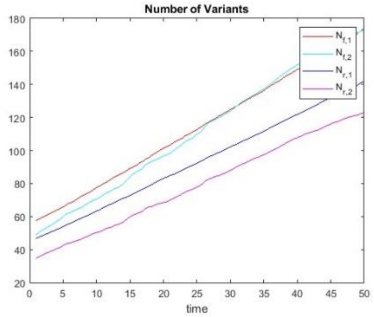


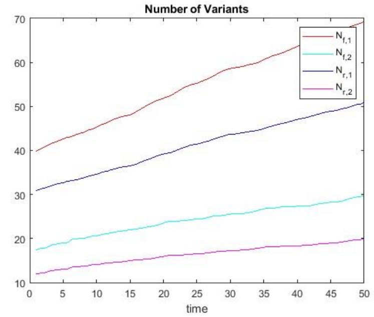


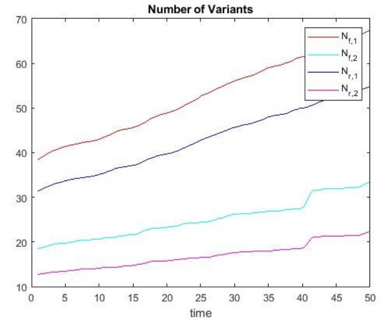


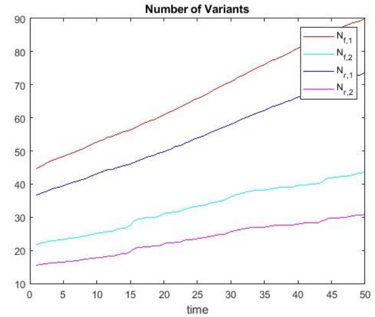


$N_{k,i}$

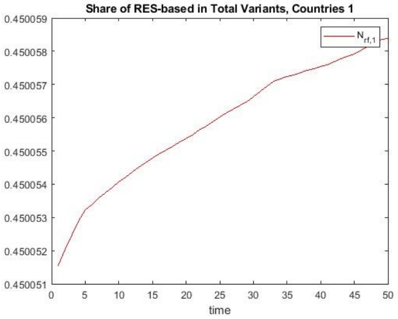


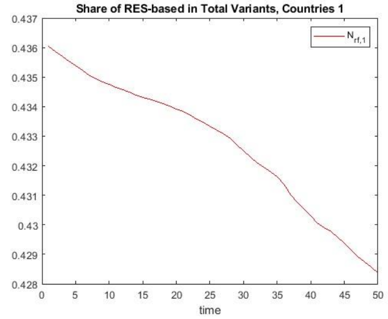


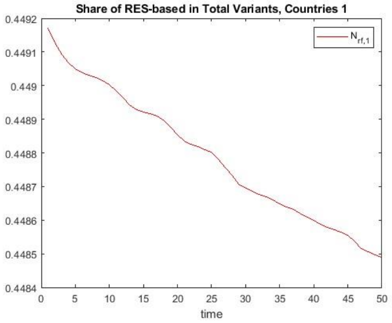


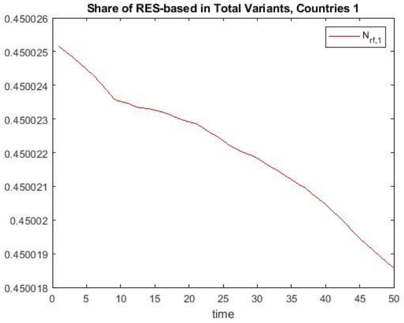


$\frac{N_{r,1}}{N_{k,1}}$

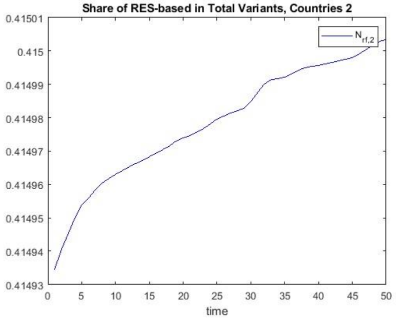


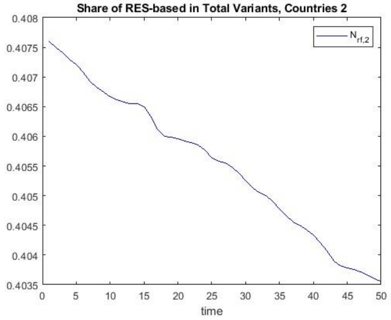


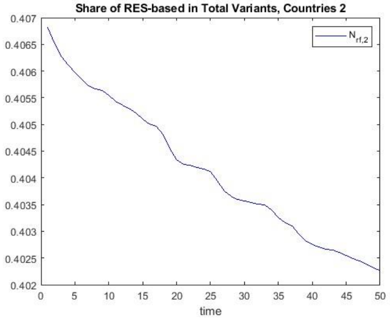


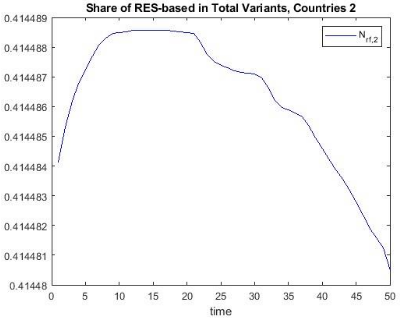


$\frac{N_{r,2}}{N_{k,2}}$

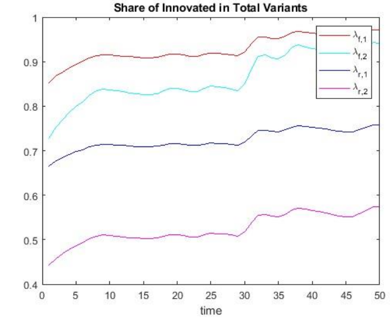


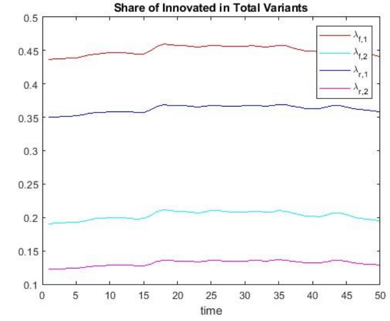


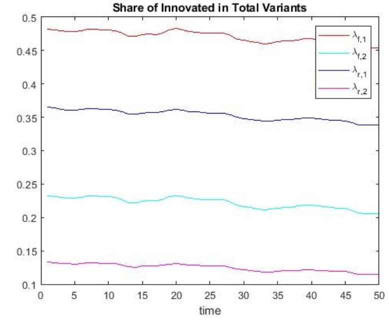


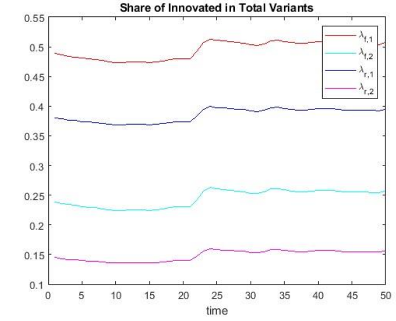


$\lambda_{k,i}$









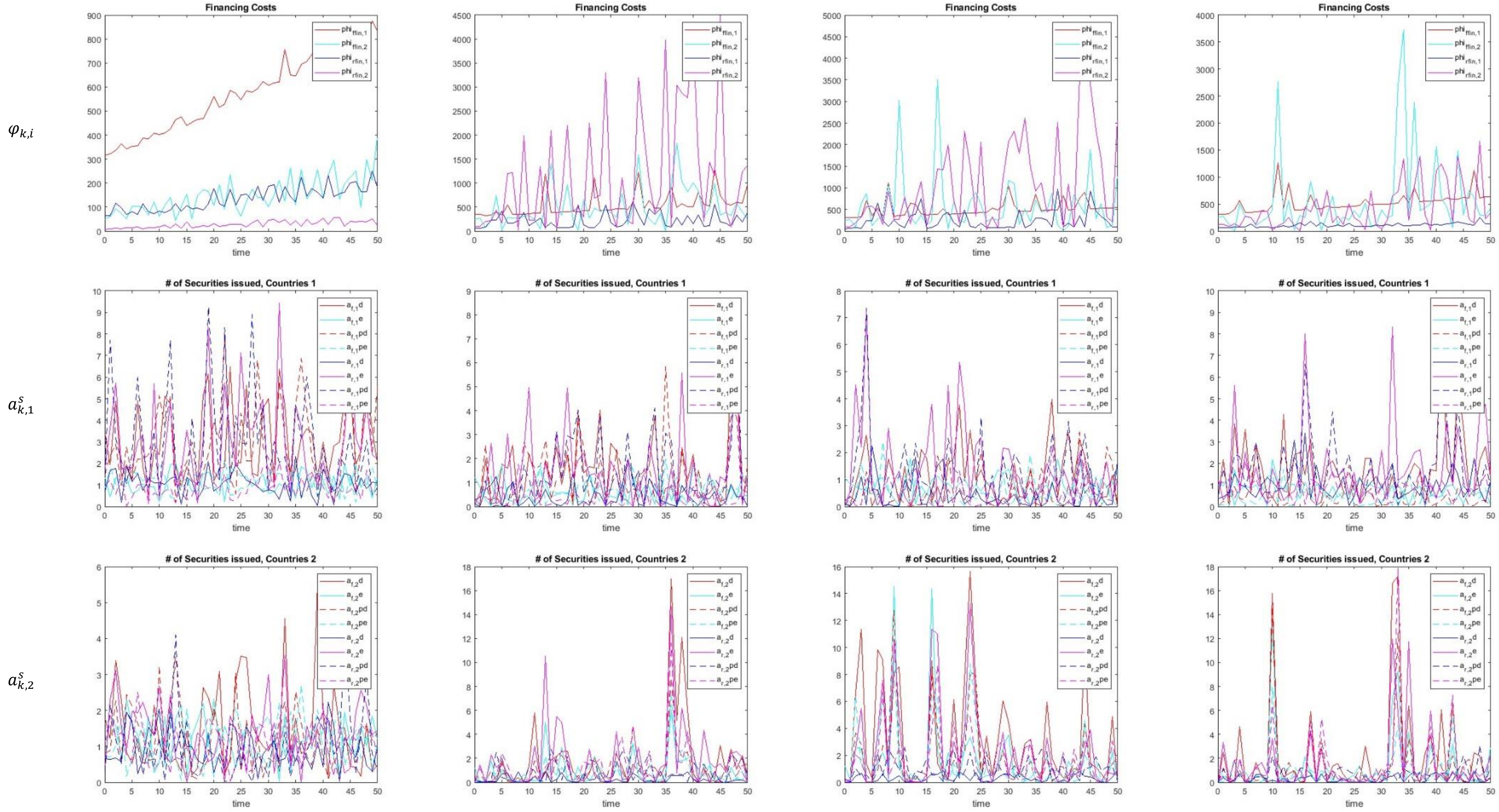
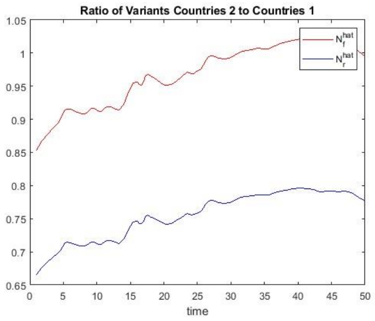
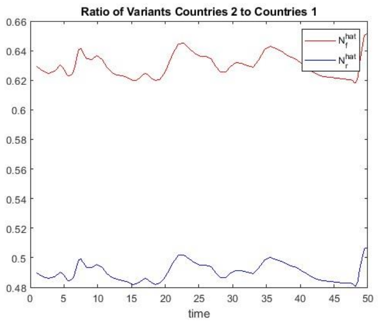
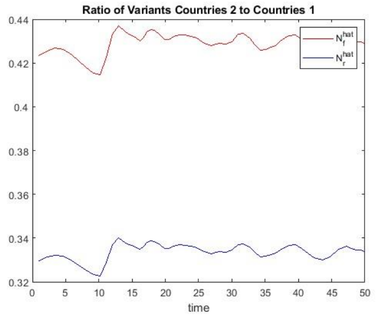
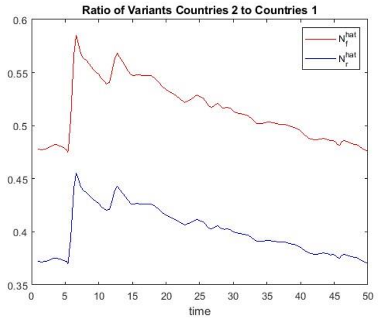
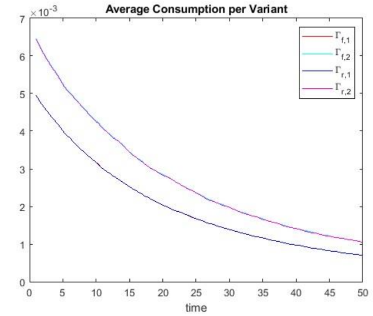
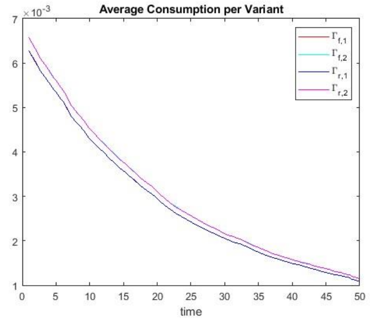
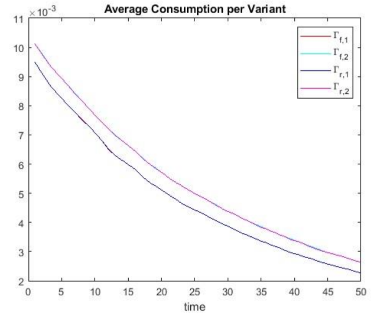
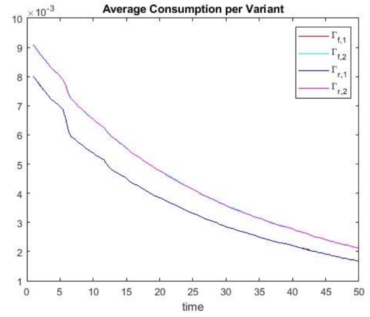
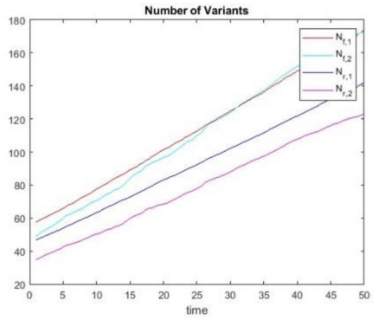
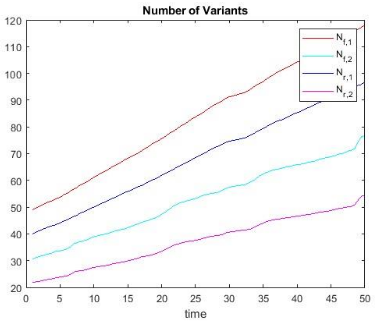
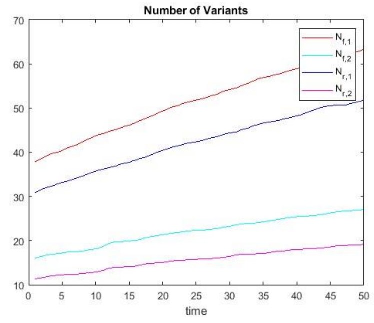
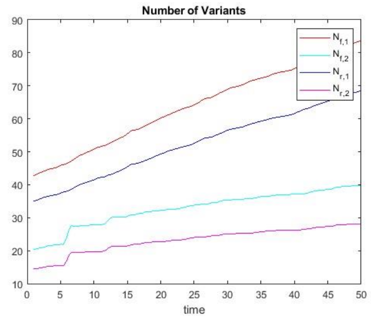
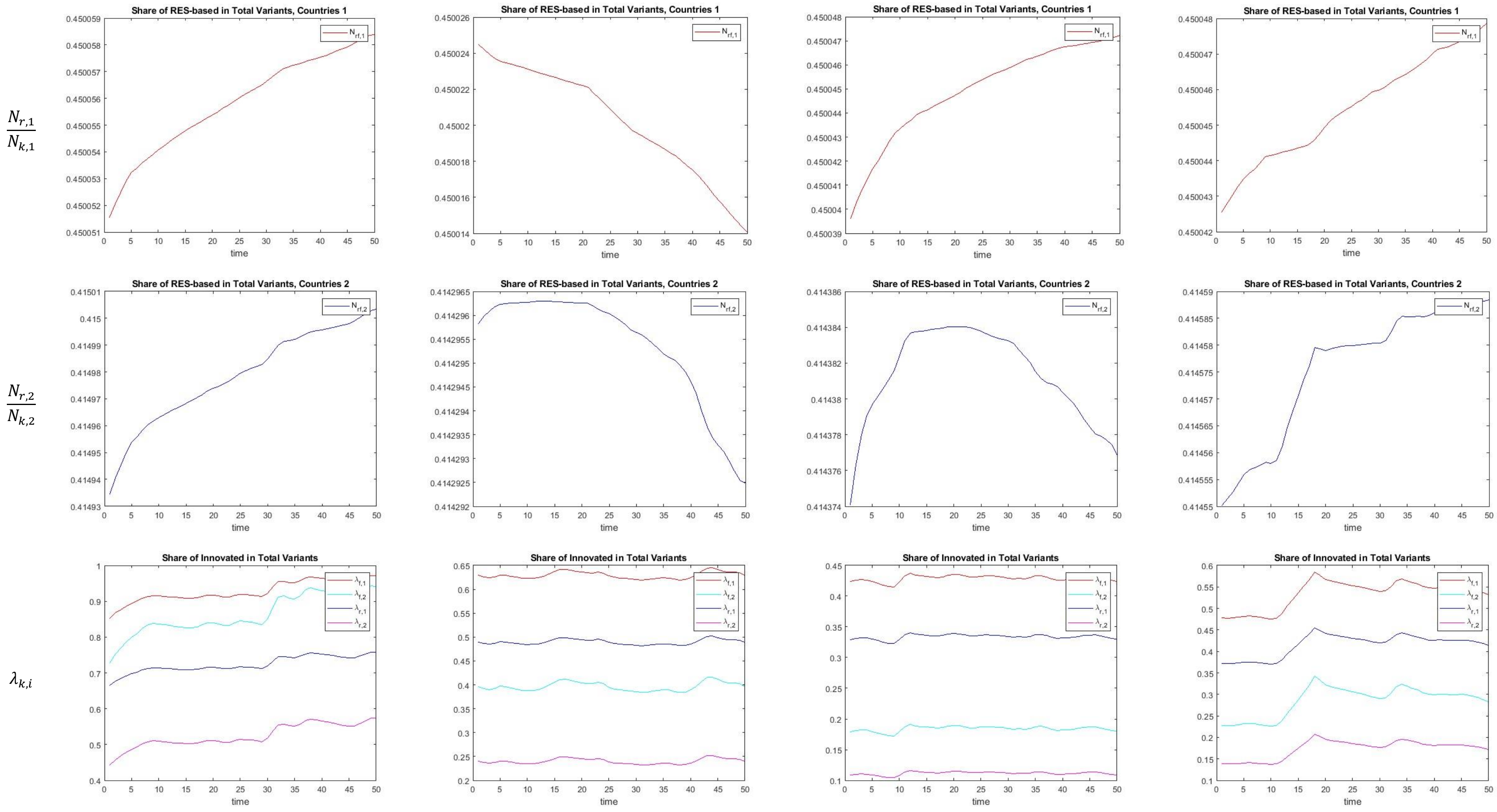


Figure A.15: Model Results for Scenarios III.a to III.c

	I—Initial State (*repeated for comparison*)	**III.d—International Development**	**IV.a—Sustainable Regulation Private FI**	**IV.b—Risk Buffering Private FI**
$\widehat{N_k}$				
$\Gamma_{k,1}$				
$N_{k,i}$				

$\frac{N_{r,1}}{N_{k,1}}$
Share of RES-based in Total Variants, Countries 1
$N_{rf,1}$
$\frac{N_{r,2}}{N_{k,2}}$
Share of RES-based in Total Variants, Countries 2
$N_{rf,2}$
$\lambda_{k,i}$
Share of Innovated in Total Variants
$\lambda_{f,1}$
$\lambda_{f,2}$
$\lambda_{r,1}$
$\lambda_{r,2}$
time

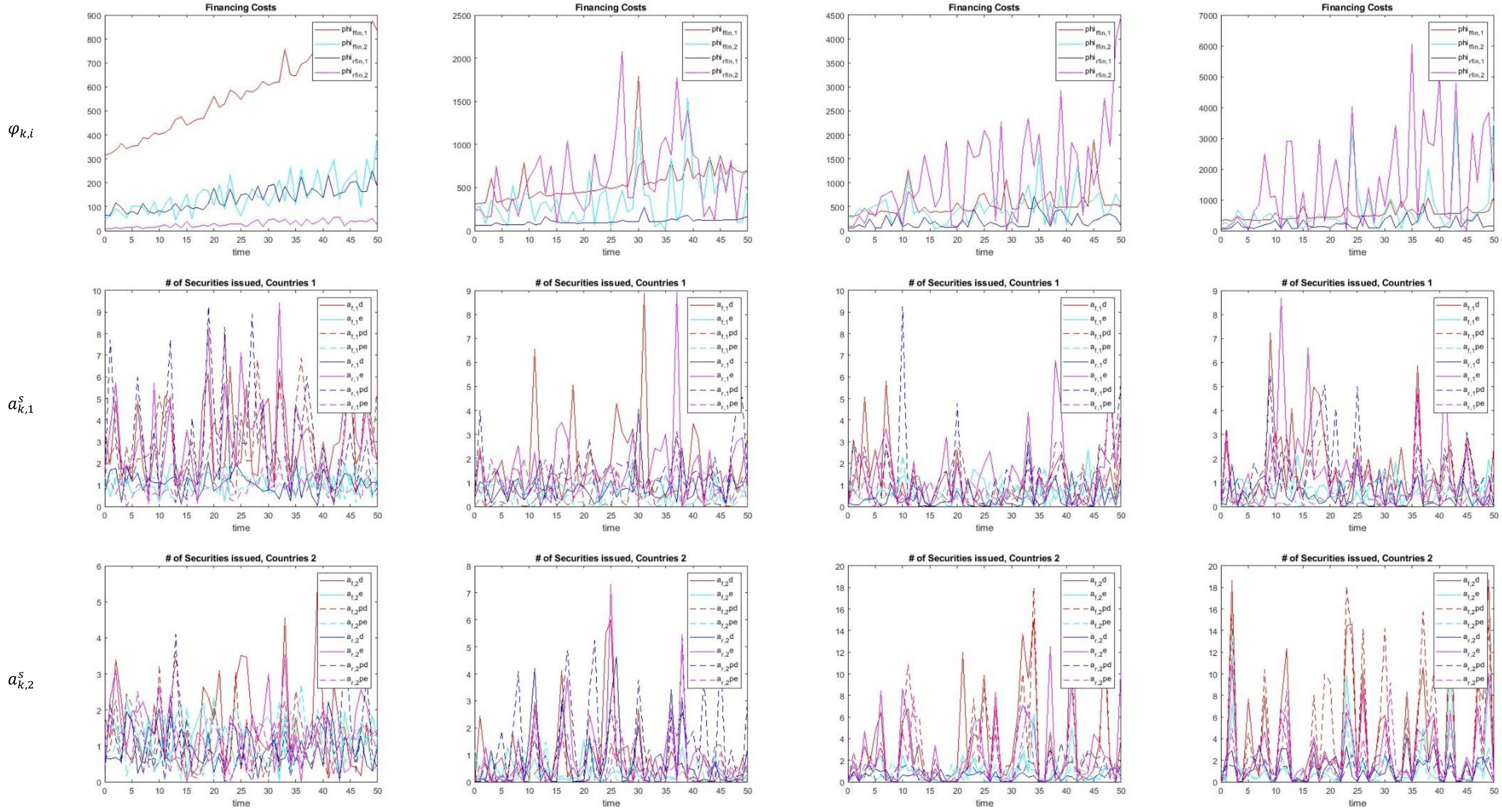
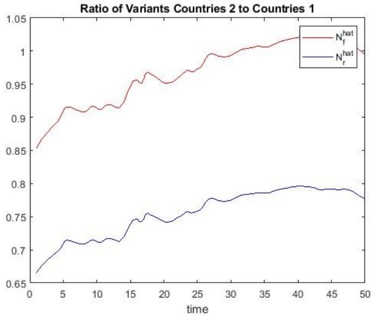
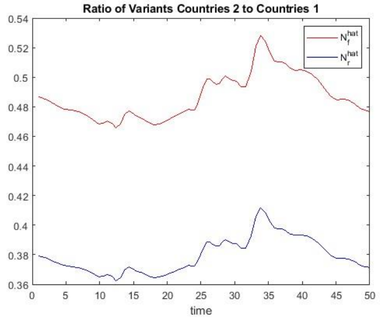
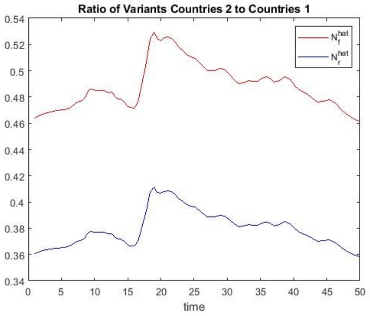
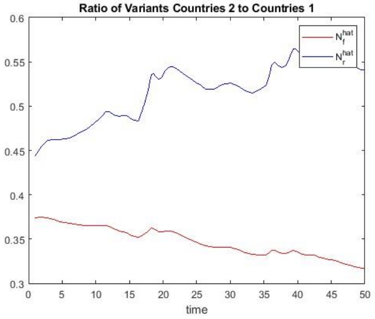
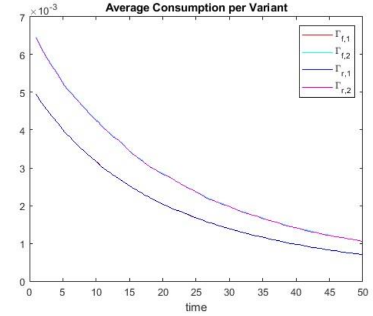
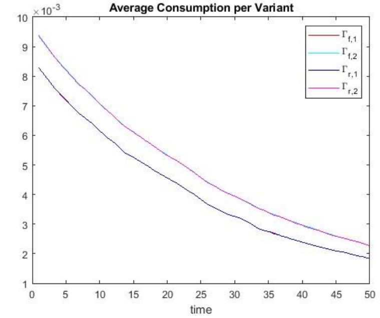
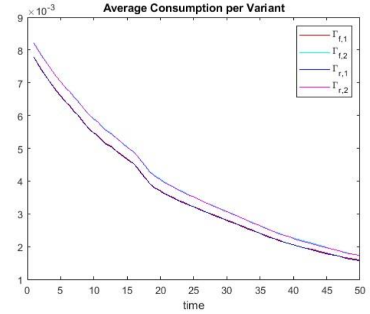
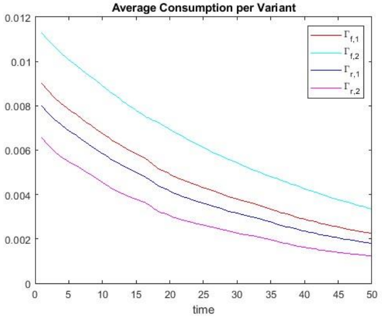
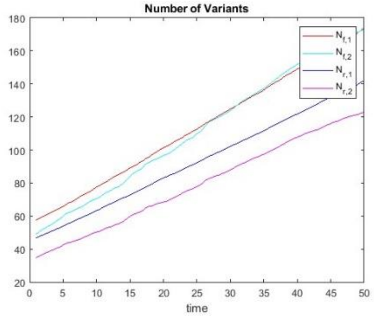
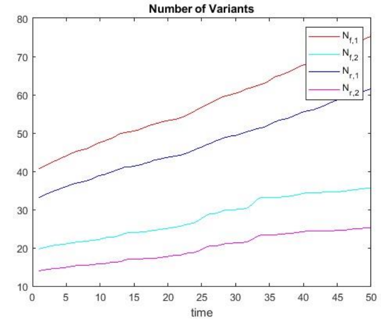
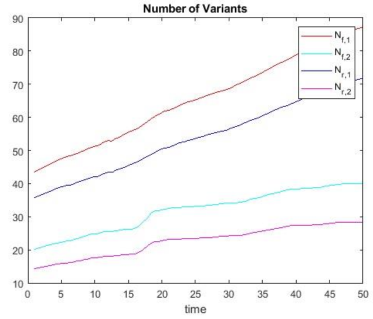
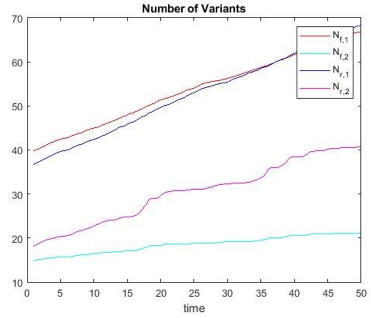
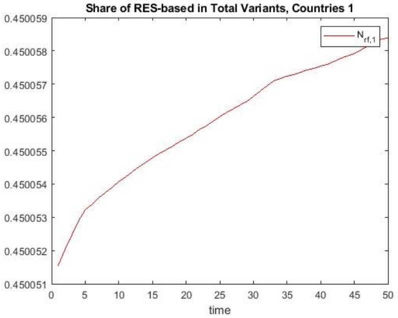
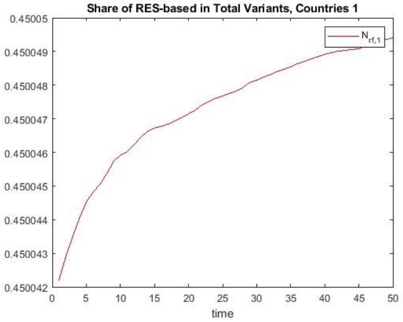


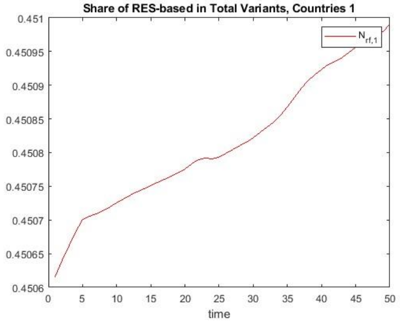
Figure A.16: Model Results for Scenarios III.d to IV.b

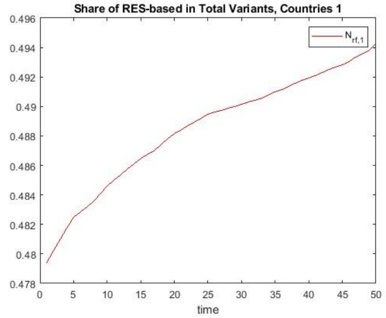
	I—Initial State (*repeated for comparison*)	**V.a—Green Public & Private FI**	**VI.a—Degressively Incr. CO$_2$ Taxation**	**VI.b—Decreasing CO$_2$ Taxation**
$\widehat{N_k}$				
$\Gamma_{k,1}$				
$N_{k,i}$				

$\frac{N_{r,1}}{N_{k,1}}$

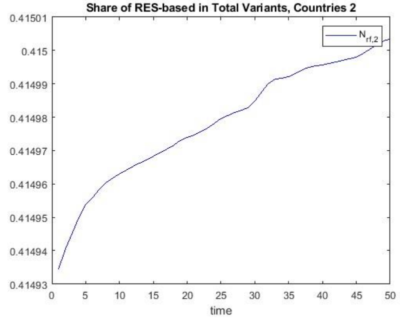

Share of RES-based in Total Variants, Countries 1

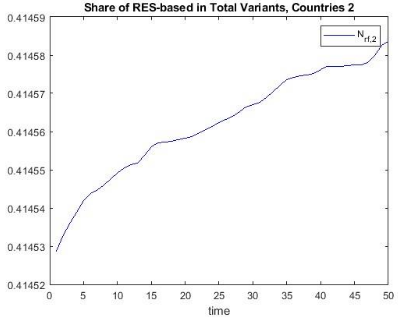

Share of RES-based in Total Variants, Countries 1

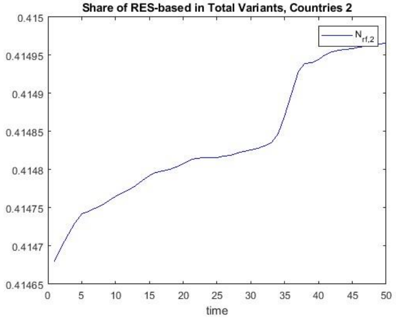

Share of RES-based in Total Variants, Countries 1

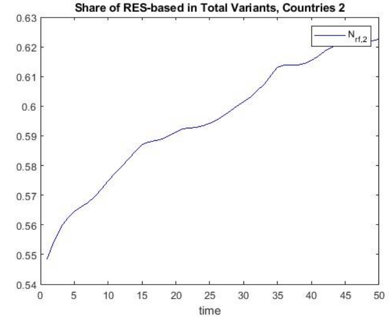

Share of RES-based in Total Variants, Countries 1

$\frac{N_{r,2}}{N_{k,2}}$

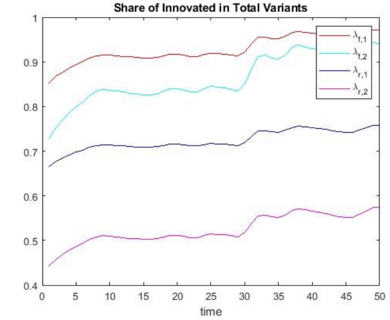

Share of RES-based in Total Variants, Countries 2

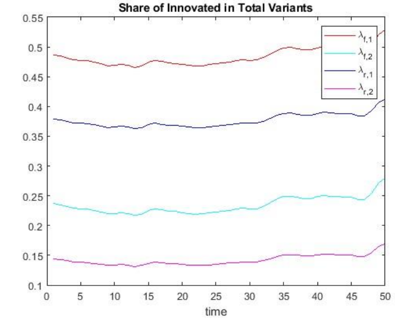

Share of RES-based in Total Variants, Countries 2

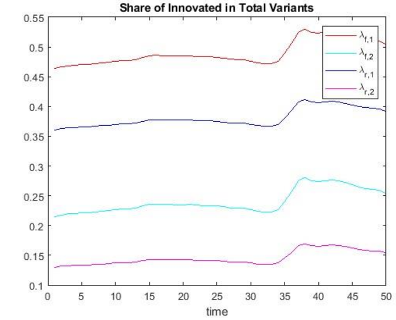

Share of RES-based in Total Variants, Countries 2

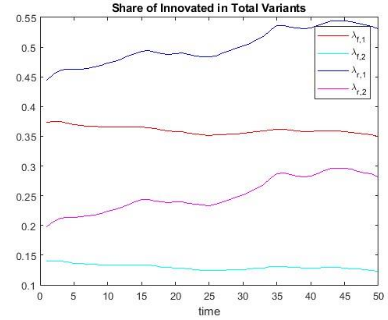

Share of RES-based in Total Variants, Countries 2

$\lambda_{k,i}$


Share of Innovated in Total Variants


Share of Innovated in Total Variants


Share of Innovated in Total Variants


Share of Innovated in Total Variants

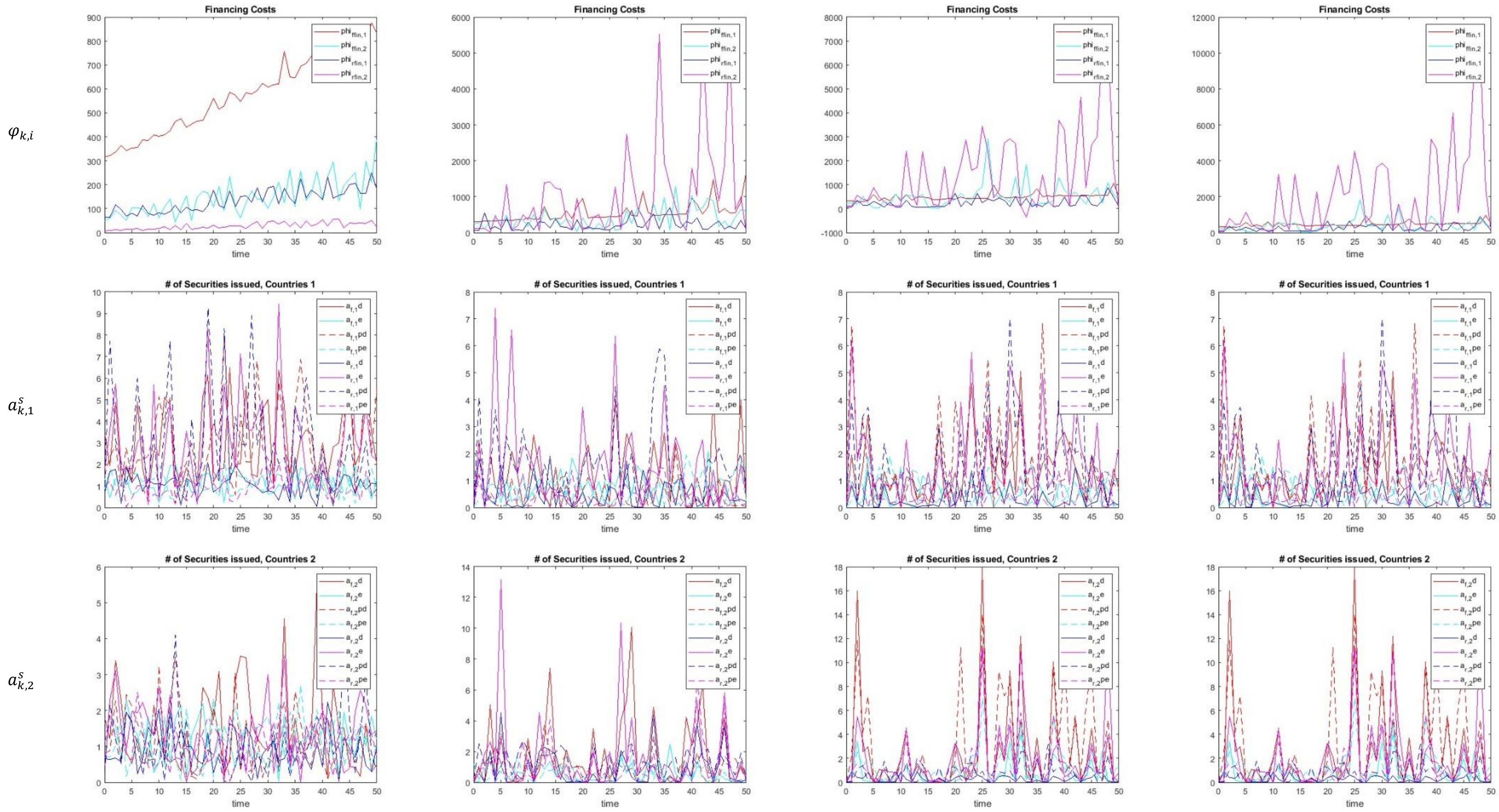


Figure A.17: Model Results for Scenarios V.a to VI.b

Chapter 3

Impacts of ESG Banking Regulation and Supervision on Financing Sustainable Mobility and Energy Technologies

List of Abbreviations

AUM	Assets under management	LSI	Less significant institutions
DiD	Difference-in-difference	RES	Renewable energy sources
ESG	Environmental, social, and governance	SFDR	Sustainable Finance Disclosure Regulation
EU	European Union	SI	Significant Institutions
EZ	Eurozone	SSM	Single Supervisory Mechanism
FI	Financial Institutions	US	United States

3.1 Introduction

How does environmental, social, and governance (ESG) related regulation and supervision of banks affect capital provision to the sustainability transition? With planetary boundaries being constantly overshot and global temperatures continuously rising, mastering the sustainability transition becomes a more and more pressing task. Meanwhile, underinvestment in sustainable technologies prevails (e.g., IPCC, 2018; BCG, 2021, 2023). Therefore—especially in the European Union (EU)—the financial sector is assigned a key role in channeling more private-sector capital into sustainable investments (e.g., UN, 2015, 2022; EC, 2023; Schreiner et al., 2023). To incentivize financial institutions (FI) accordingly, an adequate regulatory and supervisory framework is key (Schreiner and Madlener, 2023). Within this context, a mounting number of papers tackles the above question, shedding light on various aspects of ESG-related regulation, supervision, and financing the sustainability transition. For many aspects, a thorough foundation of research has already been laid, such as the interaction of ESG and the performance of FIs (de Brandt et al., 2023). A particular challenge, however, which has only been scarcely assessed, is the trade-off, which arises if the scale-up of sustainable technologies (partially) requires investments into non-ESG-compliant assets. This is the case, for instance, in the production of windmills, solar panels, and the mobility transition. Regarding the latter, an extensive shift from internal combustion engine vehicles to battery electric vehicles requires a considerable expansion of the supply of battery raw materials, such as Lithium, Cobalt, Manganese, and Nickel[42]. However, the sourcing of such materials often exhibits severe adverse ESG impacts, such as health risk of miners and child labor, corruption, and the financing of conflicts, as well as risks for the protection of land-based ecosystems including extensive energy and water consumption (BMZ, 2020). Compared to the ambitiously set battery electric vehicle policy targets (IEA, 2023), whose realization would cause an up to ten-fold increase in the demand for battery electric vehicles' battery capacity until 2030 compared to the current capacities, there is already a considerable shortage of such raw materials supply and an equally significant underinvestment regarding the expansion of sourcing capacities (Reuters, 2019; Schmid, 2020; IEA, 2022a; BCG, 2023a). If ESG-related banking regulation and supervision effectively channel capital into ESG-compliant activities, and away from non-ESG-compliant ones, such efforts might further curb ESG capital supply. Such an effect could fuel a substantial increase in the costs of capital for the mobility transition

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[42] The type of required raw materials depends on the battery technology (e.g., size, type), and, in particular, on the type of cathode used. The currently most widespread technology are Lithium-ion batteries, using a nickel-manganese-cobalt cathode (BMZ, 2020).

and could, thus, constitute a barrier in reaching battery electric vehicle policy targets[43] (BMR, 2020; Charged, 2022).

Therefore, this Chapter starts shedding light on the vastly neglected aspect of the above question by empirically studying the effect of ESG-related regulations of banks in the EU, and eurozone (EZ) banking supervision, on banks' capital allocation behavior to battery raw materials sourcing. Furthermore, we discuss implications of the findings regarding the cost of capital of battery raw material sourcing companies. Taking this two-step approach as opposed to a direct assessment of the cost of capital of battery raw material sourcing companies (e.g., an assessment of the companies' weighted average cost of capital (WACC)), allows us to also capture effects on the capital structure of the affected companies, which do not feed through to the costs of capital, as potential reductions in the capital provision by EU or euro area banks are substituted by other financiers.

Thus, we study a difference-in-difference (DiD) setup, in which we consider the introduction of the EU regulation EC 2019/2088, i.e., the Sustainable Finance Disclosure Regulation (SFDR) in 2019 (adoption in November 2019, effective as of March 2021), which marks a unique turning point regarding legally binding ESG-related disclosure requirements, as well as the introduction of the EU Taxonomy Regulation EC 2020/852 ('the Taxonomy') in 2020, which primarily aims at encouraging ESG-compliant and restricting non-ESG-compliant business activities. Using the introduction of these binding regulations in the EU as a quasi-natural experiment[44], we assess their impact on banks' public holdings in companies, which are active

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[43] This effect is amplified, as demand for such materials also increases from competing technologies, such as smartphones, other consumer electronics, and energy storage solutions in energy systems with high shares of renewable energy sources (RES).

[44] For the discussion regarding the selection of the control group see Section 3.5.1.3.

in the sourcing of battery raw materials[45]. To the end of drawing conclusions regarding the impact of the public holdings structure on the amount of capital allocation to and the cost of capital of battery raw material sourcing companies, we furthermore assess the impact of these changes in the public holdings structure on the companies' share prices.

Furthermore, we consider the introduction of climate-related banking supervision with the European Central Bank's (ECB) communication of its 'Guide on climate-related and environmental risks' (ECB, 2020), in which the ECB specifies its expectations to its supervised FIs (i.e., significant institutions, SI) with regards to their climate risk exposure and management. Having been introduced to SIs only, as opposed to banks, which have remained under the supervision of national authorities (i.e., less significant institutions, LSI) during the introduction of the Single Supervisory Mechanism (SSM) in 2014, we can assess the effect of the ECB's supervision efforts on banks' lending to such companies.

Our principal finding is that the introduction of ESG-related regulation affecting banks headquartered in the EU does indeed have a dampening effect on their public holdings in companies that are active in the sourcing of battery raw materials and, thus, EU banks' capital provision to such companies. However, share prices of the companies remain unaffected. Therefore, we can conclude that only the holders of the shares change, while demand for the holdings remains unaffected ('ownership substitution effect'). For the battery raw material sourcing companies, this implies that their access to capital is not affected by the regulations. Thus, in the assessed setup, the EU ESG regulations do not further aggravate underinvestment in the sourcing of battery raw materials. However, there are to aspects to be considered by policy makers going forward: firstly, it is often argued that shareholders of battery raw material mining companies have a strong lever to incentivize a more ESG-compliant behavior of such

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[45] We consider—jointly and separately—Lithium, Cobalt, Manganese, and Nickel, see Section 3.5.1.1.

companies. With the EU banks holding lesser shares in such companies, their influence will also diminish. Secondly, we have assessed the current global policy landscape, in which legally binding ESG regulations affecting banks form the exception. If the introduction of such regulations becomes more comprehensive globally, an ownership substitution might not remain the sole effect, but the total demand might decrease. This would then entail a decrease in share prices, and, thus, a *ceteris paribus* increase in the companies' cost of capital. Then, the introduction of ESG regulations of banks could have an aggravating effect on the underinvestment into battery materials sourcing.

Meanwhile, we do not find any significant effects of climate-related banking supervision efforts on banks' lending to such companies. This might be the case since the banking supervisory efforts are climate-specific, while the battery raw material mining companies main ESG-related issues are rather rooting back to other environmental issues such as excessive water consumption, and social controversies.

The results are based on two large novel datasets matched from S&P CapitalIQ, Refinitiv Eikon, Bloomberg, and the ECB's AnaCredit databases.

The remainder of this Chapter is structured as follows: Section 3.2 provides an overview of the current state of the research and this Chapter's contribution. Section 3.3 lays out the institutional framework regarding ESG regulation and supervision. Section 3.4 specifies the empirical strategy; Section 3.5 the data and sample selection. Section 3.6 expounds our analyses' results, and Section 3.7 concludes and provides some policy recommendations.

3.2 Current State of the Research and our Contribution

This Chapter builds upon and contributes to two increasingly overlapping research fields and strands of literature: Firstly, literature originating from the field of banking regulation and supervision, and, secondly, literature focusing on sustainable investment and finance[46].

The literature strand dealing with banking regulation and supervision *inter alia* provides theoretical rationales and empirically assesses the effects of different regulatory and supervision efforts on different impact dimensions. Independently of ESG, those are, for instance, bank funding cost, bank lending, investment, GDP, or welfare; relating to ESG, for instance, ESG risk exposure or ESG-compliant capital allocation. Within the context of this Chapter, especially the impact of ESG-specific banking regulation and supervision on different ESG impact dimensions is relevant. Impact dimensions can relate to banks directly, or to the broader financial and overall economy.

Particularly regarding the empirical estimation of the effects, contributions are numerous. The Bank for International Settlements keeps track of studies assessing economic impacts of various types of financial regulations in their online repository FRAME (Boissay et al., 2019; BIS, 2023). There are five broad types of banking regulation and supervision, which can be distinguished: (i) macro-prudential, (ii) balance-sheet-related (e.g., capital, reserve, and liquidity requirements, leverage ratios), (iii) governance- and process-oriented (e.g., risk assessment methodology, corporate governance), (iv) information and disclosure requirements

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[46] With the increased focus on sustainability and ESG, as well as the above-mentioned key role, which has been assigned to the financial sector to provide the financial means to realize the sustainability transition, the overlap between the two research fields and strands of literature has increased significantly.

incl. stress tests[47], and (v) steering—e.g., restricting—business activities (e.g., Shirai, 2023). In principle, all these types of regulation can be applied in sustainable finance. Within the context of this Chapter, the two latter are particularly relevant, due to the SFDR's focus on banks' ESG disclosure, the Taxonomy's focus on ESG-compliant steering of banks' business activities, and the ECB's climate-related supervision efforts' focus on climate risk stress testing and disclosure.

Generally, numerous empirical assessments find risk-mitigating and market-discipline-increasing effects of information and disclosure requirements incl. stress testing (for an extensive literature review see Schreiner et al., 2023). Regarding the impact on bank-level ESG risk exposure and management, Di Tommaso (2020) and Tóth et al. (2021) find reducing effects of EU banks' increased ESG disclosure on banks' risk taking and on the ratio of non-performing loans, pointing to a reduction of ESG risk materialization. In line with this finding, Schreiner et al. (2023) find a significant impact of the ECB's climate-risk-related supervision efforts on a reduction of banks' exposure to unmanaged climate risks. Regarding the impact on ESG-compliant capital allocation, Roychowdhury et al. (2019) provide a literature review, covering contributions until 2018/19. Basu et al. (2022) find that increased social disclosure has an adverse effect on home mortgage lending to disadvantaged communities, pointing to 'social washing'. On a more positive note, Wang (2023) finds that ESG disclosure regulations incentivize banks' debtors to improve their ESG performance. Similarly, Becker et al. (2022),

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[47] Regarding information and disclosure requirements, literature has identified different transmission mechanisms regarding the way in which such requirements can impact the target dimensions. The most relevant transmission mechanisms are a reduction of information asymmetries between banks and their business partners, an incentivization of (costly) information generation closer to a (welfare-)optimal level, and a signaling effect, that other regulatory or supervisory efforts, such as capital requirements, might be introduced in the future (Steuer and Tröger, 2022; Schreiner et al., 2023) Furthermore, banks' reaction to public pressure represents another way in which increased disclosure impacts bank behavior (Wang, 2023).

Dai et al. (2023) and Badenhoop et al. (2023) find disclosure under the SFDR causing a decarbonization of banks' portfolios, an increase in investments in green funds, however, a coinciding decrease in the share of social investments. Regarding the impact of the Taxonomy, empirical evidence is less clear. Different potential impacts of the regulation are, for instance, shown by Pastor et al. (2021), Kirschenmann (2022) and Sautner et al. (2022). Regarding the ECB's climate-risk-related supervisory efforts, Schreiner et al. (2023) find a positive impact on banks' green bond issuance, ESG assets under management (AUM), and lending to debtors with a higher environmental rating. Regarding the impact on systemic ESG risk, Aevoae et al. (2023) assess the impact of increased ESG disclosure (ESG scores), documenting a beneficial impact of the ESG scores disclosure on banks' contribution to system-wide distress. Also, Tóth et al. (2021) find a significant impact of EU banks' ESG disclosure on financial stability. Regarding the impact on the achievement of ESG targets, Campiglio (2016) discusses the role of banking regulation and monetary policy in financing the transition to a low-carbon economy. Dikau and Volz (2018) discuss the legitimacy and potential instruments of banking supervision to support banks' provision of sustainable finance. Gasparini et al. (2023) provide a general discussion of the effect of financial regulations on the transition to net zero. However, empirical literature quantifying such impacts is still scarce. In addition to the contributions rooted in the banking regulation and supervision literature, also contributions from the broader field of sustainable investment and finance describe such effects from a slightly different angle, treating (banks') capital provision as one factor amongst others in achieving (components of) sustainability targets. For instance, Schreiner and Madlener (2023) provide an extensive literature review and discuss the role of financial sector regulation on the achievement of global climate goals. Related to battery electric vehicles' raw materials sourcing, Schmid (2020) discusses Challenges to the European automotive industry in securing critical raw materials for electric mobility.

Our original contribution is, hence, twofold: within the context of banking regulation and supervision, we provide a novel assessment of ESG regulation on the structure of public holdings as well as an assessment of the impact of climate-risk-related banking supervision, based on two large novel datasets. Within the context of sustainable investment and finance, we contribute to the debate by assessing the vastly neglected aspect that ESG regulation and supervision potentially aggravate the underinvestment into assets, which are necessary to achieve sustainability targets, however, exhibit adverse ESG impacts.

3.3 Institutional Framework

3.3.1 ESG Regulation

Given the considerable investments, which are required to comply with ESG targets worldwide, and recognizing the potential of the financial sector to channel the required capital into ESG-compliant investments, as well as the need for adequate regulation and supervision of FIs to realize this potential, many economies have started to set up sustainable finance initiatives[48]. However, outside the EU, legally binding regulations are very scarce (cf., e.g., Feridun and Güngör, 2020; Wang, 2023). Distinctively, within the EU, as part of the

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[48] Such initiatives exist on both the national and the supra-national level, and primarily comprise non-binding classifications, recommendations, and action plans. On the national level, for instance, Australia has set up its Federal Government's sustainable financing strategy in 2022, and the Canadian Securities Administrators (CSA) have been considering new climate-related disclosure standards. In the United States (US), ESG policies are less homogenous. On the one hand, for instance, rules on climate-related disclosures were announced in March 2022, on the other hand, in particular on the state level, a number of anti-ESG rules has been introduced, such as the No Boycott Legislation or the Prohibition of ESG Discrimination (Morgan Lewis, 2023). On the supra-national level, the Task Force on Climate-related Financial Disclosures of the Financial Stability Board has published disclosure standards in 2015, the Network for Greening the Financial System, established in December 2017, provides recommendations regarding the enablement of sustainable finance, as well as the United Nations Environment Programme Finance Initiative (UNEP FI). For an overview see Table B.1 and Table B.2 in the Appendix.

Sustainable Finance Action Plan, the SFDR (2019, 2021) and the Taxonomy (2020) have been introduced as two of the first legally binding and far-reaching ESG regulations affecting banks[49]. This fact allows us to use their introduction as quasi-natural shocks to banks. The SFDR's disclosure requirements aim at generating 'all the information necessary to properly inform end investors about the sustainability-related impacts of their investments'. The Taxonomy aims at reallocating capital flows from brown to green firms. It establishes criteria that determine whether an economic activity is ESG-compliant ('Taxonomy-aligned') with a strong focus on environmental sustainability (Schütze et al., 2020; Sautner et al., 2022). Thus, it provides the first standardized criteria for sustainable finance and forms the basis for further regulation steering FIs' business activities (Kirschenmann, 2022).

3.3.2 ESG Supervision

In 2014, as the first element of the so-called EU Banking Union, the Single Supervisory Mechanism (SSM) has been introduced, mandating the ECB to exercise prudential supervision of banks located in the euro area. Significant institutions (SIs) are directly supervised by the ECB's own supervisory arm, while the less significant institutions (LSIs) are under the supervision of the national banking authorities (NBAs)[50] (Ampudia et al., 2023).

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[49] The SFDR applies to financial market participants headquartered in the EU. Financial market participants with fewer than 500 employees are not required to produce a principal adverse impact statement, though they must explain why if they choose not to cooperate. In addition to the legally binding regulations, within the EU and on the Member States' national level, other non-binding measures exist (González Martínez, 2021; Bruno and Lasagio, 2022).

[50] The criteria for a bank being classifed as an SI are the following: - size (the total value of its assets exceeds 30 billion); - economic importance (for the specific country or the EU economy as a whole); - cross-border activities (the total value of its assets exceeds 5 billion and the ratio of its cross-border assets/liabilities in more than one other participating Member State to its total assets/liabilities is above 20- direct public financial assistance (it

With regard to ESG-related banking supervision, the ECB has initiated their efforts to supervise climate-related risk in 2020 with the communication of its ‘Guide on climate-related and environmental risks’ (ECB, 2020). In the Guide, the ECB specifies its expectations to the SIs relating to business model and strategy, governance and risk appetite, risk management and disclosure in a climate risk context. All expectations will be gradually implemented until 2024, and are accompanied by concrete supervisory exercises, namely the Climate Risk Stress Test, the Thematic Review and the Short-term Exercise, which have been carried out for the first time in 2022 as a component of the stress testing in the context of the ‘Supervisory Review and Evaluation Process’ as set out in article 100 of the Capital Requirements Directive IV (ECB, 2021; ECB, 2022a; 2022b). The climate-related supervisory exercises aim at generating transparency regarding and improving the availability of climate-related information and capabilities (Schreiner et al., 2023). We exploit the fact that the described climate-related supervisory efforts apply for the SIs only, allowing us to treat their introduction as a quasi-natural experiment.

3.4 Empirical Strategy

Our goal is to study two effects related to the introduction of banks’ ESG regulation and supervision as an external shock: firstly, the impact of ESG regulations (i.e., the introduction and entering into force of the SFDR and the introduction of the Taxonomy) on banks’ public holdings of battery raw material sourcing companies and on the corresponding share prices to derive implications regarding capital provision to the companies; secondly, the introduction of the ECB’s climate-related supervisory efforts on euro area banks’ lending to such companies.

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has requested or received funding from the European Stability Mechanism or the European Financial Stability Facility), see https://www.bankingsupervision.europa.eu/banking/list/criteria/html/index.en.html (Ampudia et al., 2023).

For both analyses, we estimate a Difference-in-Difference (DiD) panel regression model with multi-dimensional fixed effects of the following structure:

$$\begin{aligned} Y_{ibct} = \beta_{i0} + \beta_{i1} treat_{ibct} + \beta_{i2} post_{ibct} + \beta_{i3} treat_{ibct} \times post_{ibct} + X_{ibct} \gamma_i^T \\ + a_{ibct} + \varepsilon_{ibct} \,, \end{aligned} \tag{1}$$

where $Y_{ibct}, i \in (1,2)$ represents the two different main dependent variables (1) public holdings structure of bank b and (2) lending of bank b to battery raw material sourcing company c at time t, $treat_{ibct}$ defines the treatment vs. control groups, $post_{ibct}$ specifies the shock, X_{ibct} the matrix of the control variables, a_{ibct} the fixed effects, and ε_{ibct} the error term. Using Stata's *reghdfe* ordinary least squares (OLS) method allows for the inclusion of fixed effects by means of 'absorbing'[51], and for multi-level clustering (Correia, 2016).

3.4.1 Effects of ESG Regulations

As discussed, we study the impact of the introduction of ESG regulations of banks on financing the sustainability transition, i.e., banks' capital provision to the sourcing of battery

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[51] The concept of 'absorbing' fixed effects in Stata's *reghdfe* command refers to a methodology that allows to handle high-dimensional fixed effects in ordinary least squares regression analysis, developed by Correia (2016). The approach is particularly useful in handling large datasets with many fixed effects like ours, where estimating individual coefficients for each fixed effect is computationally challenging. The fixed effects are 'absorbed' by transforming the data in a way that removes the fixed effects without having to estimate a coefficient for each one explicitly. The transformation is generally achieved by means of an 'within transformation', i.e., centering the data by subtracting group-specific means from each observation. For panel data and for time fixed effects, this involves subtracting the mean of each variable for each panel unit (e.g., individual, firm, country) over time, removing the time-invariant component of the data. Once the data is transformed, the regression is run on the centered variables. Since the fixed effects have been 'removed' by centering the data around each unit's mean, the regression does not need to include a separate dummy variable for each fixed effect. The estimated coefficients from this regression are then interpreted as the effects of the independent variables, controlling for the fixed effects, even though the fixed effects are not explicitly included in the regression model.

raw materials, which are necessary to realize aspects of the sustainability transition, but which exhibit adverse ESG impacts.

We consider the following two-step effect: In the first step, we investigate the shock's impact on EU banks' holding of shares in battery raw material sourcing companies. This allows us to observe potential effects of the introduction of the SFDR and the Taxonomy on the holder structure of such shares, i.e., the amount of shares held by EU banks. A change in the holder structure—which, in the case of our analysis, is a reduction in EU banks' public holdings in such companies, implying that EU banks sell such shares—has two potential consequences. These are assessed in a second step: either the previous EU banks' demand of such shares is replaced by an increasing demand of other investors' demand ('ownership substitution effect'), or the overall demand diminishes ('demand reduction effect'). To the end of gaining insight into which of the two effects prevails, we consider the development of the corresponding share prices. In the case of an ownership substitution effect, share prices of companies whose shares were held by the treated banks remain unaffected by the shocks, while in the case of a demand reduction effect, such share prices will decrease.

3.4.1.1 Effects of ESG Regulations on Public Holdings of Mining Companies

Regarding the first step, we assess the introduction of the SFDR in Q4/2019 and its entering into force in Q1/2021, as well as the introduction of the Taxonomy in Q3/2020 (cf. Ampudia et al., 2023). In our main regression, we estimate the staggered introduction of the SFDR according to the following model:

$$\begin{aligned} Y_{1bct} = \beta_{10} + \beta_{11} treat_{1bct} + \beta_{12} post_{1bct}^{Q4/2019} + \beta_{13} treat_{1bct} \times post_{1bct}^{Q4/2019} \\ + \beta_{14} post_{1bct}^{Q1/2021} + \beta_{15} treat_{1bct} \times post_{1bct}^{Q1/2021} + X_{1bct}\gamma_1^T + a_{1bct} \\ + \varepsilon_{1bct} , \end{aligned} \qquad (2)$$

and the introduction of the Taxonomy in Q3/2020 according to

$$Y_{1bct} = \beta_{10} + \beta_{11} treat_{1bct} + \beta_{12} post_{1bct}^{Q3/2020} + \beta_{13} treat_{1bct} \times post_{1bct}^{Q3/2020} \\ + X_{1bct} \gamma_1^T + a_{1bct} + \varepsilon_{1bct} \,. \tag{3}$$

We separately assess banks' public holding structure Y_{1bct} of companies active in the sourcing of (1.1) Lithium, (1.2) Cobalt, (1.3) Manganese, and (1.4) Nickel.

Regarding the explanatory variables, $treat_{1bct}$ is a dummy variable equal to unity if the bank is headquartered in the EU and is, thus, affected by the shock, and zero, if the banks is headquartered outside the EU, and thus not affected by any legally binding ESG regulation[52]. $post_{1bct}^{Q4/2019}$ is a dummy variable equal to one from Q4/2019 to Q4/2020, while the SFDR has been introduced, but not yet entered into force; $post_{1bct}^{Q3/2020}$ a dummy variable equal to one from Q1/2021 onwards. $post_{1bct}^{Q3/2020}$ is a dummy variable equal to one from Q3/2020 onwards. $treat_{1bct}$ is interacted with the time dummies to construct the DiD setup.

We include several macroeconomic, bank-specific, company-specific, and ESG-specific control variables in our analysis. We account for GDP growth, inflation, banks' total public holdings, companies' ESG ratings and disclosure, companies' dividends, share prices, revenues, and credit risk as well as the introduction of non-binding ESG measures and US anti-ESG regulations. Furthermore, we include raw material prices, which—assuming well-functioning markets—reflect all drivers for raw materials supply and demand. On the supply side, those drivers are, for instance, production challenges caused by the pandemic and the geopolitical environment (e.g., Nickel supply from Russia), and structural underinvestment in new supply capacity during the three years preceding 2021 when metal prices were low. On the demand side, drivers include, for instance, battery electric vehicle targets, demand from competing use of the raw materials, as well as demand changes due to technological

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[52] For a discussion of the exact composition of the treatment and control group, see Section 3.5.1.3.

developments. In addition to the controls, we also include country, time, company- and bank-level fixed effects to account for the according time-invariant factors.

As a robustness check since in the baseline regression models (eqs. (2) and (3)), we test the effects of the SFDR and the Taxonomy separately, we also investigate whether results change if basing the analyses on a single regression model including all three shocks, i.e., the introduction of the SFDR in Q4/2019, the introduction of the Taxonomy in Q3/2020, and the entering into force of the SFDR in Q1/2021:

$$\begin{aligned} Y_{1bct} = \beta_{10} + \beta_{11} treat_{1bct} + \beta_{12} post_{1bct}^{Q4/2019} + \beta_{13} treat_{1bct} \times post_{1bct}^{Q4/2019} \\ + \beta_{12} post_{1bct}^{Q3/2020} + \beta_{13} treat_{1bct} \times post_{1bct}^{Q3/2020} + \beta_{14} post_{1bct}^{Q1/2021} \\ + \beta_{15} treat_{1bct} \times post_{1bct}^{Q1/2021} + X_{1bct} \gamma_1^T + a_{1bct} + \varepsilon_{1bct} \, . \end{aligned} \tag{4}$$

3.4.1.2 Effects of ESG Regulation on Capital Provision to Mining Companies

Regarding the second step, to the end of identifying whether an ownership substitution effect or a demand reduction effect prevails, we assess the share prices of the companies, whose shares are held by banks of our treatment and control groups and compare the development of these two groups of shares in the post-treatment period. In the case of an ownership substitution effect, share prices of companies whose shares are held by the treated banks remain unaffected by the shocks, i.e., exhibit parallel trends. In the case of a demand reduction effect, the share prices of companies, whose public holdings were held by the treated banks, decrease relative to the control group. In order to demonstrate whether parallel trends prevail, we make use of the normalized difference approach proposed by Imbens and Wooldridge (2009). The test suggests that, if parallel trends prevail, the normalized differences of the prices of the two groups of shares are smaller than 0.25.

A potential change in share prices has implications regarding the mining companies' overall cost of capital (e.g., WACC) in different ways. When issuing new shares while share prices are low, the company can raise less capital per share. This implies that more shares must be issued to raise the needed funds, and decrease the company’s maximum amount of capital, which it can raise. Furthermore, the company’s cost of equity is directly affected by the share price. Decreasing share prices generally reflect an unfavorable market view of a company’s future prospects. This can increase its cost of equity, since the return required by investors is generally higher if they perceive higher risk associated with the company's future. Finally, the cost of debt may also be influenced, albeit indirectly. A decreasing share price often correlates with a deteriorating financial position and credit ratings, which can lead to higher interest rates on debt because lenders perceive the company as riskier.

3.4.2 Effects of ESG Supervision

Regarding ESG supervision, we study the impact of the introduction of the ECB’s climate-risk-related supervisory efforts on banks’ lending to companies active in the sourcing of battery raw materials and, thus, on financing the sustainability transition.

Again, we investigate the shock’s impact on euro area banks’ lending to companies active in battery raw material sourcing. A change in the amount of lending—which, in the case of our analysis, is a reduction in SI’s lending to such companies—has two potential consequences. Either the previous SI‘s lending is replaced by increased lending of other actors (‘substitution effect’), or the overall lending diminishes (‘reduction effect’). To the end of gaining insight into which of the two effects prevails, we can consider the development of the corresponding costs of lending, such as the loan spreads. In the case of a substitution effect, the costs of lending of companies, which received loans from SIs remain unaffected by the shock, while in the case of a reduction effect, such costs of lending will increase.

3.4.2.1 Effects of ESG Supervision on Bank Lending to Mining Companies

To assess the effect of the introduction of the ECB's climate-related supervisory efforts on banks' lending to battery raw material companies, we analogously estimate

$$\begin{aligned} Y_{2bct} = \beta_{20} + \beta_{21} treat_{2bct} + \beta_{12} post_{2bct}^{Q1/2020} + \beta_{23} treat_{2bct} \times post_{2bct}^{Q1/2020} \\ + X_{2bct} \gamma_2^T + a_{2bct} + \varepsilon_{2bct} \, . \end{aligned} \tag{5}$$

While the structure of the regression is comparable to the one presented in equations (eq.) (2) and (3), in (5), $treat_{2bct}$ is a dummy variable equal to one if the bank is an SI, and equal to zero if the bank is an LSI. $post_{2bct}^{Q1/2020}$ is a dummy variable equal to one from Q1/2020 onwards. The interaction of $treat_{2bct}$ with the time dummy creates the DiD setup.

Again, we account for the above-introduced set of control variables and fixed effects. Instead of banks' total amount of public holdings, however, we consider banks' total lending.

3.4.2.2 Effects of ESG Supervision on the Cost of Capital of Mining Companies

As described above, if we observe effects of the introduction of the ECB's climate-risk-related supervisory efforts on bank lending, we can further assess potential implications regarding the cost of capital for battery raw material mining companies, as measured, e.g., by the loan spreads. If the substitution effect prevails, the cost of capital will remain constant, if the reduction effect prevails, the cost of debt, and, thus, the cost of capital will increase. If the latter is the case, capital provision to the sourcing of battery raw materials is negatively affected.

3.4.3 Parallel Trends

Critical to the validity of our findings is the exogeneity of changes in banks' public holdings in and lending to battery raw material sourcing companies. Therefore, we have to make sure that the differences in the trends we capture have not preceded the introduction of the SFDR and the Taxonomy from 2019 onwards, i.e., that the banks headquartered in the EU were not already before 2019 starting to hold less shares in battery raw material sourcing companies, and we are not simply picking a continuation of longer-term trends (see, e.g., Angrist and Pischke, 2008; Ampudia et al., 2023). The same applies for bank lending during the period preceding the introduction of the ECB's climate-risk-related supervision in 2020. To the end of testing the 'parallel trends assumption', we perform two different tests (see also Schreiner et al., 2023): Firstly, we follow the normalized difference approach by Imbens and Wooldridge (2009) to examine trends in banks' public holdings and lending preceding the shocks in 2019 and 2020. According to this test, there must not be a divergence of the dependent variables (all battery raw materials, Lithium, Manganese, Cobalt, Nickel public holdings; bank lending to battery raw material sourcing companies) prior to the treatment. To test this, we calculate the normalized differences as averages by treatment status scaled by the square root of the sum of the variances. This approach has an advantage over the t-test, as it is a scale-free measure of differences in distributions independent of the sample size (Imbens and Wooldridge, 2009). An absolute normalized difference smaller than 0.25 indicates that there is no significant difference in the evolution of characteristics between treated and control groups (Mueller et al., 2023).

Table B.11 and Table B.13 report the normalized differences between the treatment and control groups during the pre-treatment period until Q3/2019 (for public holdings) or until Q1/2020 (for bank lending). For all dependent variables (all battery raw materials, Lithium, Manganese, Cobalt, Nickel public holdings; bank lending to battery raw material sourcing companies), the normalized differences (0.00; 0.12; 0.05; 0.22; 0.13; 0.14) remain well below the 0.25 rule of thumb. The same holds for the normalized differences of the majority of the controls. The most severe deviation from the threshold is for the total public holdings of banks holding Lithium, Cobalt, Manganese and Nickel shares, as well as for banks' total loans provided to battery raw material companies. To demonstrate that these deviations between the treatment and control groups in the pre-treatment period do not undermine the informative value of our results, we perform robustness checks excluding the respective control variables from our analyses, finding that the results remain unchanged with regards to significance levels. Furthermore, for banks' public holdings in Manganese companies, we find the majority of the normalized differences of the company-specific controls exceeding the 0.25 threshold. Here, we perform two robustness checks suggesting that these results do not undermine the informative value of our results: on the one hand, considering the outcomes of the sequential regressions (see Table B.14, Table B.15, and Table B.16), we see that the absence of the controls does not change the significance of the results. On the other hand, the consideration of the pre-treatment period below suggests that parallel trends prevail.

Secondly, we perform additional tests and consider the pre-treatment period before the introduction of the SFDR, the Taxonomy and the ECB's climate-risk-related supervisory efforts, i.e., the time period from Q1/2015 until the respective introduction of the ESG regulation and supervision. We split the time period into the quarters Q1/2015 to Q1/2017 (Q2/2017) (first period I) and Q1/2017 (Q2/2017) to Q3/2019 (Q4/2019) (second period I), as well as into the quarters Q1/2015 to Q3/2017 (Q4/2017) (first period II) and Q3/2017 (Q4/2017) to Q3/2019 (Q4/2019) (second period II). We then estimate the following models:

$$Y_{ibct} = \beta_{i0} + \beta_{i1} treat_{ibct} + \beta_{i2} post^{n}_{ibct} + \beta_{i3} treat_{ibct} \times post^{n}_{ibct} + X_{ibct}\gamma_i^T + a_{ibct} + \varepsilon_{ibct} \, , \tag{6}$$

with $n \in$ (Q1/2017, Q2/2017, Q3/2017, Q4/2017). The results in Table B.12, demonstrating no significant trend change in the pre-treatment period (exemplarily displayed for first and second period I).

3.5 Data and Sample Selection

In the following, we discuss the data we use to test the relationships introduced in Section 3.4, including a detailed discussion of the dependent and independent variables (for an overview see Table B.8), as well as the selection of the samples for control and treatment groups. We do so separately for the analyses of the impact of ESG regulation and supervision.

3.5.1 Data and Sample Selection ESG Regulation

3.5.1.1 ESG Regulation: Dependent Variables

As introduced above, as the dependent variable, we both jointly and separately consider banks' public holdings in battery raw material companies, which are active in the exploration and mining of Lithium, Cobalt, Manganese and Nickel. While the exact demand for these raw materials is dependent on several factors including the development of different battery technologies, in each development scenario, they constitute key components of battery electric vehicles' batteries (BMZ, 2020; IEA, 2022). To construct the dependent variable, we use different data sets from S&P's CapitalIQ. CapitalIQ provides quarterly financial data of companies and financial institutions worldwide, such as ownership structure and balance sheet information.

To identify relevant battery material companies, we perform keyword and thematic searches on CapitalIQ, which we quality check by comparing them with lists of relevant players in the Lithium, Cobalt, Manganese and Nickel markets, which are published in several market reports, as well as by visiting the companies' websites. There are two types of battery material companies serving the market: the major shares of the market are served by large-scale mining companies (which can be either public or private), while further mining is performed by artisanal and small-scale miners (BMZ, 2020; BCG, 2023). Amongst large-scale mining companies, two setups can be distinguished in terms of reporting: either, the mining is performed directly under the aegis of the mining company, with the corresponding activities appearing on the respective company's balance sheet, or a special purpose vehicle is set up. In the latter case, the mining activities do not directly appear on the company's balance sheet but are reported separately. Regarding CapitalIQ's coverage of the different types of companies and setups, coverage for large-scale mining companies is the best, and also, special purpose vehicles are included in the database, while small-scale miners are not included. Considering public holdings as a dependent variable, our main interest is in large-scale public companies, which also constitute a major share of the market. Based on CapitalIQ data, we identify the banks, which hold shares of the companies, and obtain quarterly data of banks' public holdings of battery raw material mining companies for a time period from Q1/2015 to Q3/2023. To account for the fact that especially large-scale mining companies are often active in the mining of multiple raw materials, we further adjust the total public holdings identified for the respective company by the share of the companies' activities in the mining of the relevant raw material based on the capital expenditure breakdown available on the balance sheet[53]. Following this procedure, we obtain the following samples: For 'Overall'[54] (Lithium, Cobalt, Manganese, Nickel), we identify 3,424 (870, 786, 346, 1422) bank-company combinations, of which 312 (65, 95, 44, 108) involve banks headquartered in the EU and are, thus, part of the treatment group.

3.5.1.2 ESG Regulation: Independent Variables—Controls

As introduced in Section 3.4, we account for different macroeconomic, company-related, bank-related, and ESG-related control variables. We obtain GDP growth and inflation data from CapitalIQ, as well as banks' total public holdings, companies' dividends, share prices, revenues, and credit risk. Companies' ESG ratings and disclosure are based on the Bloomberg database,

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[53] We choose the capital expenditure as opposed to the revenues to approximate the companies' activities related to the relevant raw material to avoid endogeneity effects, which would arise since revenues are highly correlated which raw material prices.

[54] I.e., the joint consideration of public holdings in companies active in the sourcing of the four battery raw materials.

which is one of the few ESG ratings providing also historical data reaching back to 2015. Carbon prices are obtained from the World Bank's Carbon Pricing Dashboard; and raw material prices from the Refinitiv Eikon database. Furthermore, we account for bank- and company-level, as well as country and time fixed effects, as further indicated below the output tables.

3.5.1.3 ESG Regulation: Treatment and Control Groups

As described in Sections 3.3 and 3.4, we, generally, use banks headquartered in the EU as the treatment groups, and banks headquartered outside the EU as the control groups. Regarding the treatment groups, we exclude any banks which have been subject to major changes in their setup, such as major mergers and acquisitions. Regarding the control group, we exclude any banks from the sample, which are headquartered in countries, in which legally binding ESG regulations have been introduced. This is the case for banks headquartered in China and Hong Kong. Furthermore, in the UK, a legally binding ESG regulation has been announced. Since this regulation is announced only for 2025, we keep banks headquartered in the UK in the sample in the basis regression, however, perform a robustness check with a control group excluding UK-headquartered banks.

3.5.2 Data and Sample Selection ESG Supervision

3.5.2.1 ESG Supervision: Dependent Variables

Unlike in the analyses of the effects of banking regulation, in the analysis of the impact of the ECB's ESG supervision (i.e., climate-risk-related supervisory efforts), we consider only one single dependent variable comprising banks' lending to companies, which are active in the exploration and mining of a broader range of battery raw materials, i.e., Lithium, Cobalt, Manganese, Nickel. Copper, Aluminum and Tin. We obtain the according data from the ECB's

AnaCredit database[55], which provides quarterly data of SIs' and LSIs' issued loans and the according debtors from Q1/2018 onwards. The database contains information about the debtors' sectors according to the Nomenclature of Economic Activities[56] classification. In a first iteration, we include lending to all debtors from the 'B – Mining and Quarrying' sector, which we refine in a second and third iteration based on the companies' business descriptions available in CapitalIQ and then on the business descriptions available on the companies' websites. Thus, we obtain a sample of 251 bank-company combinations, of which 191 are classified SIs, and, thus, constitute the treatment group.

3.5.2.2 ESG Supervision: Independent Variables—Controls

As for the analysis of the effect of ESG regulation introduced in Section 3.5.1.2, we account for macroeconomic, company-related, bank-related, and ESG-related control variables. We consider YY GDP growth and YY inflation, banks' total lending to all debtors, companies' revenues, and credit risk (all from CapitalIQ). Furthermore, we control for companies' ESG ratings and disclosure (Bloomberg). Since in this analysis, we consider lending to companies active in all battery raw materials sourcing jointly, we also control for all relevant raw material prices, i.e., Lithium, Cobalt, Manganese, Nickel, Copper, Aluminum and Tin prices (Refinitiv Eikon). We also account for bank- and company-level, as well as country and time fixed effects.

3.5.2.3 ESG Supervision: Treatment and Control Groups

As described above, we, generally, use euro area banks classified as SIs under the SSM as the treatment group, and euro area banks classified as LSIs as the control group. Regarding the treatment group, we exclude any banks which have been subject to major changes in their setup,

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[55] See https://www.ecb.europa.eu/stats/money_credit_banking/anacredit/html/index.en.html (accessed 12/2023).

[56] See https://nacev2.com/en (accessed 12/2023).

such as major mergers and acquisitions. Regarding the control group, we exclude any banks from the Netherlands and Croatia. The Netherlands are the only economy, which has introduced a climate risk stress test for all banks, insurers, and pension funds independently of their system significance. Furthermore, we have excluded all banks from Croatia, which has joined the euro area only in 2022, i.e., during the considered time period.

3.6 Empirical Results

In the following, we present the results of the empirical analysis, including the main results as well as outcomes of the robustness checks. Furthermore, we discuss the role of battery raw material mining companies' ESG performance by means of additional analyses involving subsets of the data sets. We present the results separately for the analyses of the impact of ESG regulations and ESG supervision.

3.6.1 Empirical Results ESG Regulation

3.6.1.1 The Impact of ESG Regulation on Public Holdings in Mining Companies

In Table B.14, Table B.15, and Table B.16, we present the main results (sequential regressions) of the models introduced in the equations (eqs.) (2) and (3), estimating the effects of the SFDR and the Taxonomy on the banks' public holdings (again, results are displayed for all battery raw materials jointly, separate representations are available in the supplementary material upon request. Furthermore, Table B.17, Table B.18, and Table B.19 display the results of the analysis concerning lagged effects by one, two and three quarters. The bank- and company-level, as well as country and time fixed effects accounted for are indicated below the respective output tables.

Concerning the overall analysis of all battery raw materials, we find that the introduction of all three regulatory interventions has statistically significant dampening effects on EU banks' public holdings in battery raw material mining companies. Comparing the magnitude of the effects, the entering into force of the SFDR in Q3/2021 has the strongest dampening effects, followed by the introduction of the Taxonomy in Q3/2020 and the introduction of the SFDR in Q1/2019. These findings are robust comparing the results based on eqs. (2) and (3) with the results based on eq. (4), i.e., the separate vs. the joint assessment of the SFDR and the Taxonomy. Furthermore, we observe significant lagged effects by one, two and three quarters. The results are robust to the inclusion and exclusion of the control variables (see sequential regressions), as well as to the consideration or disregarding the different fixed effects (see Table B.20, and Table B.21). In terms of the control variables, we generally observe a more pronounced effect for bigger companies (proxy: revenues), and for younger companies.

Within the separate analyses of the four battery raw materials (Lithium, Cobalt, Manganese, Nickel) or each of the dependent variables, regarding the effects of the introduction and entering into force of the SFDR in Q4/2019 and Q1/2021, we observe more negative and more significant effects of the entering into force of the SFDR in Q1/2021 as compared to the introduction in Q4/2019 (Tables available in the supplementary material upon request). Regarding the introduction of the Taxonomy in Q3/2020, we observe statistically significant negative effects (Tables available in the supplementary material upon request). In the following, we discuss the results in detail for both the introduction and entering into force of the SFDR and the introduction of the Taxonomy on each of the four dependent variables.

Regarding treated banks’ Lithium public holdings, both the introduction and the entering into force of the SFDR have a significant dampening effect. In comparison, the effect of the entering into force in Q1/2021 is stronger than the one of the introduction in Q4/2019. Further, the introduction of the Taxonomy also has a significant dampening effect. These effects remain similar performing the robustness check of the regression model presented in eq. (5), including the staggered introduction of the SFDR, the introduction of the Taxonomy, and the entering into force of the Taxonomy. In terms of the controls, the company size has a further statistically significant effect within both analyses, revealing that a larger company size also dampens public holdings of Lithium companies. Furthermore, within both analyses, we observe also lagged effects by one and two quarters. Regarding the Cobalt public holdings, only the entering into force of the SFDR has a dampening effect of a moderate statistical significance, while the introduction does not have any impact of statistical significance. Also, for the introduction of the Taxonomy, we observe statistically significant dampening effects on treated banks' Cobalt public holdings. Again, this result is robust to the check testing all three effects in the model presented in eq. (5). For both the introduction of the Taxonomy and the entering into force of the SFDR, we also observe effects lagged by one, two and three quarters. Regarding the Manganese public holdings, we observe statistically significant dampening effects of the introduction of the Taxonomy and the entering into force of the SFDR. This result is robust to the analysis results of the model in eq. (5). Again, we observe lagged effects, in particular for the introduction of the Taxonomy. For the Nickel public holdings, we, similarly, observe dampening effects of the entering into force of the SFDR and the introduction of the Taxonomy of moderate statistical significance. Again, this result is robust to the comparison with the results of the model in eq. (5). We observe lagged effects by one, two and three quarters.

3.6.1.2 The Impact of ESG Regulation on the Cost of Capital of Mining Companies

In order to draw conclusions from the above observations on the mining companies' cost of capital, we consider the share prices development as described in Section 3.4.1.2. The analysis of the normalized differences reveals that the parallel trends within the share prices prevail in the consideration of all battery raw materials, as well as in the separate analyses for Lithium, Cobalt, and Nickel. This suggests that only the holders of the shares change, while demand remains unaffected, meaning that an ownership substitution effect prevails. For the battery raw material sourcing companies, this implies that their cost of capital is not affected by the regulations. Thus, in the assessed setup, the EU ESG regulations do not have a direct further aggravating effect on the already prevailing underinvestment into the sourcing of battery raw materials. However, there are two aspects to be considered by policy makers going forward: Firstly, it is often argued that shareholders of battery raw material mining companies have a strong lever to incentivize a more ESG-compliant behavior of such companies. With the EU banks holding lesser shares in such companies, their influence will also diminish. Secondly, we have assessed the current global policy landscape, in which legally binding ESG regulations affecting banks form the exception. If the introduction of such regulations becomes more comprehensive globally, an ownership substitution might not remain the sole effect, but the total demand might decrease. This would then entail a decrease in share prices, and, thus, a *ceteris paribus* increase in the companies' cost of capital. Then, the introduction of ESG regulations of banks could have an aggravating effect on the underinvestment into battery materials sourcing.

3.6.1.3 ESG Regulation: The Impact of Mining Companies' ESG Performance

To the end of generating further insight regarding the impact of the environmental, social and governance ratings and disclosure on the banks' public holding structure, we take a twofold approach: on the one hand, we consider the impact of the ESG-related control variables within the above analysis results, on the other hand, we perform additional analyses splitting the banks into ESG low and high performers.

Within the above analysis results (i.e., the joint analysis of all battery raw materials companies), we find a statistically significant, but small positive impact of the disclosure-adjusted S-rating of the mining companies, both in the context of the SFDR and the Taxonomy, while we do not observe any statistically significant impact of the disclosure-adjusted E-rating.

For the additional analysis, we consider all companies within the first to third quartiles of the disclosure-adjusted E-, S- and G-ratings as ESG low performers, and all companies within the fourth quartile as ESG high performers. For these two groups, we analyze the bank behavior based on eq. (2) to (4). The additional analyses reveal that for the ESG low performers, the results remain unchanged, and we keep observing dampening effects for the introduction and entering into force of the SFDR, as well as for the introduction of the Taxonomy. For the ESG high performers, we do not observe any statistically significant effects. These results suggest that the dampening effect only applies to public holdings of battery raw material mining companies with a comparably bad ESG rating, while the public holdings of battery raw materials with comparably good ESG ratings remain unaffected (see Table B.24, Table B.25, and Table B.26).

Bringing these two findings together, we can conclude that the introduction and execution of ESG regulation—on the example of the SFDR and the Taxonomy—has a dampening effect on banks' public holdings in those battery raw material companies with a comparably bad ESG rating, and that improvements in the ESG rating, especially in the S-rating, can mitigate those effects.

3.6.2 Empirical Results ESG Supervision

3.6.2.1 The Impact of ESG Supervision on Lending to Mining Companies

In Table B.22, we present the results of the analysis specified in eq. (6), i.e., the effect of the introduction of the ECB's climate-risk-related supervisory efforts in Q2/2020 on banks' lending to battery raw material mining companies. We do not find any statistically significant effects of the shock, neither immediately in Q2/2020, nor lagged by one, two or three quarters (see Table B.23). Considering the control variables, we find a statistically significant positive effect of the E-rating of the debtor, meaning that banks provide more loans to debtors with better environmental performance. Since we do not observe any significant effects on the banks' lending, we do not further assess the impact on companies' cost of capital, as, e.g., measured by loan spreads.

3.7 Conclusion

3.7.1 Key Results

ESG banking regulation and supervision can be an effective lever to support sustainable growth and the implementation of a sustainability transition. However, there is a potential trade-off between incentivizing banks to allocate capital in a more ESG-compliant way and to not inhibit capital provision to activities, which are (still) less ESG-compliant, however, necessary in order to reach set sustainability policy targets, such as the provision of battery raw materials.

We have assessed this potential trade-off by analyzing the impact of EU ESG regulations affecting banks—i.e., the SFDR and the Taxonomy—as well as of the ECB's climate-risk-related supervisory efforts in two steps: firstly, we have analyzed the impact on banks' capital allocation—i.e., on their public holdings of and lending to battery raw material companies. Secondly, we have investigated the impact on banks' cost of capital, to the end of further understanding whether the potential decreases in public holdings and lending entail a real effect on the affected companies' ability to raise capital.

Regarding the effect of EU ESG regulations affecting banks, we find statistically significant dampening effects of the introduction and entering into force of the SFDR and the Taxonomy on the banks' public holdings in companies active in the sourcing of battery raw materials (Lithium, Cobalt, Manganese and Nickel). Those effects are more pronounced for the entering into force of the regulation as compared to its introduction. Furthermore, assessing the role of the (disclosure-adjusted) ESG-rating of the companies, we find that the dampening effect does not prevail for those companies, which are best in class (i.e., which belong to the fourth quartile of the sample). Concerning the share prices, we observe continued parallel trends of share prices of companies, whose shares are held by banks affected by the ESG regulation, and those, whose shares are held by the unaffected banks. From this observation, we can conclude that the decreasing demand for shares of the affected banks is compensated by an increasing demand of the unaffected banks, i.e., that we observe an ownership substitution effect. This implies that there are no *ceteris paribus* changes in the cost of capital of battery raw material mining companies caused by the introduction of the ESG regulations SFDR and the Taxonomy. Still, the change in the shareholder structure has two implications: firstly, the lever of EU banks to incentivize a more ESG-compliant behavior of battery raw material mining companies diminishes with the decrease in their shares held. Secondly, if the introduction of similar regulations becomes more comprehensive globally, an ownership substitution might not remain the sole effect, but the total demand might decrease. This might entail an increase in the cost of capital of battery raw material mining companies if they do not manage to increase their ESG performance.

Regarding the effect of the ECB’s climate-risk-related banking supervision, we do not find any statistically significant impact on banks’ lending to battery raw material mining companies. A potential explication therefore is that the supervisory efforts are not ESG-wide, but climate-specific, and climate-related impact is not the main issue of the battery raw material mining companies.

3.7.2 Implications and Policy Recommendations

The above findings have several implications with regard to ESG regulation and supervision. First and foremost, the observation that banks, which are affected by the SFDR and the Taxonomy decrease their public holdings in battery raw materials, and especially in those, which do not perform well across the ESG dimensions, implies that the regulations lead to the intended effects. Also, in the current setup, there is no coinciding increase in the companies' share prices and, thus, cost of capital. Hence, the ESG regulations currently do not aggravate the underinvestment in battery raw materials sourcing. However, as mentioned above, this might be changed if comparable regulations are introduced more comprehensively on a global level. Furthermore, the lever to incentivize companies to increase their ESG performance diminishes.

This being said, policy makers should continue efforts incentivizing companies to increase their ESG performance going beyond national or EU borders. This can, for instance, be realized by forging alliances and promoting internationally harmonized regulations, such as intended by the German *Bundeskanzler* Scholz announcing 'climate clubs' during the 2023 United Nations' COP28 climate summit in Dubai (Nordhaus, 2015; Reuters, 2023). Such clubs could be extended by not only covering climate, but also other environmental, social and governance targets. Furthermore, policy makers can propose other legislation indirectly impacting companies internationally, such as Germany's Supply Chain Act[57].

Generally speaking, it remains the key challenge to maintain the balance between disincentivizing the financial sector to provide capital to ESG-uncompliant companies or assets, while not sacrificing the leverage to incentivize more ESG-compliant behavior.

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[57] See https://www.bafa.de/DE/Lieferketten/Multilinguales_Angebot/multilinguales_angebot_node.html (accessed 06/2023).

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Appendix B

Impacts of ESG Banking Regulation and Supervision on Financing Sustainable Mobility and Energy Technologies

B.1 ESG Measures and Regulations

Table B.6: Sustainable Finance—Non-binding Measures and Binding Regulations

Country	Non-binding measures	Binding regulations
AU	Announcement of Federal Government’s sustainable financing strategy (12/2022)	n.a.
CA	Canadian Securities Administrators’ (CSA) proposition of climate-related disclosure requirements (10/2021, subject to public consultation)	n.a.; *CSA’s proposed climate-related disclosure requirements may become legally binding in the future*
CH	Report on sustainability in the financial sector with 15 measures for implementation between 2022 and 2025	n.a.
CN	Various regulations and measures introduced (2017) (Wang and Ziying, 2023)	Various regulations and measures introduced (2017) (Wang and Ziying, 2023)
HK	Various regulations and measures introduced in 2019 (HKMA, 2023)	Various regulations and measures introduced in 2019 (HKMA, 2023)
JP	Basic Guidelines on Climate Transition Finance (05/2022) (FSA, 2021)	Cabinet Office Ordinance on Disclosure of Corporate Information (01/2023)
OM	Green Financing Roadmap (09/2023) (FCME, 2023)	n.a.
SG	• Guidelines on Environmental Risk Management (Banks) (MAS, 2020) (12/2020) • Information Paper on Environmental Risk Management (Banks) (MAS, 2022) (05/2022) • ASEAN Taxonomy for sustainable Finance (11/2021) (ASEAN, 2021)	n.a.
UK	UK Green Finance Strategy (03/2023)	UK Sustainable Disclosure Regulation (SDR) (04/2022) announcing legally binding regulation for 2025 onwards
US	No harmonized national measures	No comprehensive national regulation; various and specific regulations on the state level (e.g., California’s Divestiture of Thermal Coal)
ZA	Technical Paper Financing a Sustainable Economy (01/2021), (National Treasury, 2021)	n.a.

Table B.7: Supra-national Non-binding Measures

*Non-binding Measures**					
Coordinator	United Nations	G20	Basel Committee	Financial Stability Board	EU
Measure Name	United Nations Environment Programme Finance Initiative (UNEP FI)	G20 Sustainable Finance Working Group	Principles for the effective management and supervision of climate-related financial risks	Task-force on Climate-related Financial Disclosures	Non-binding components of Renewed Sustainable Finance Strategy (RSFS) incl. Sustainable EU Investment Plan (part of EU Green Deal)
Issuance / Founding Date	1992	2016	06/2022	2015	2019
Participating Economies*					
EU	x	x		x	x
EZ	x	x	x	x	x
BE	x		x	x	
CY	x		x	x	
CZ	x			x	
DE	x	x	x	x	
DK	x			x	
FR	x	x	x	x	
IE	x		x	x	
IT	x	x	x	x	
LU	x		x	x	
NL	x		x	x	
AU	x	x		x	
CA	x	x	x	x	
CH	x		x	x	
CN	x	x		x	
HK	x			x	
IM	x				
JP	x	x	x	x	
OM	x				
SA	x	x		x	
SG	x			x	
UK	x	x	x	x	
US	x	x	x	x	
ZA	x	x		x	

* Coordination involving public institutions, e.g., international organizations. In addition, may initiatives amongst private sector player stakeholders only exist, which are not listed here.

** x indicates for which economies the non-binding measures apply.

B.2 Variables Overview and Descriptive Statistics

Table B.8: Variables Overview

Variable Name	**Variable**	**Unit**	**Description**	**Database**
Public holdings battery raw material mining companies	*_ph (meaning batmat_ph ni_ph, cob_ph, mn_ph, ni_ph)	EUR	Banks' public holdings Lithium, Cobalt, Manganese, Nickel exploration & mining activities of companies	S&P CapitalIQ
All public holdings	all_ph	EUR	Banks' total public holdings	S&P CapitalIQ
Loans to battery material companies	bat_mat_loans	EUR	Banks' loans to battery raw materials companies	ECB AnaCredit
All loans	all_loans	EUR	Banks' overall loans to all debtors	ECB AnaCredit
Carbon price	co_hq_co2_pr	EUR	Carbon price at the mining companies' headquarter location	World Bank
Companies' share prices	co_share_pr	EUR	Quarterly share price of battery raw material companies	S&P CapitalIQ
Companies' dividends	co_div	EUR	Dividends of battery raw material companies	S&P CapitalIQ
Companies' revenues	co_rev	EUR	Revenues of battery raw material companies	S&P CapitalIQ
Companies' credit risk	co_credit_risk	Scale 0 to 1	Credit risk (S&P Credit rating) of battery raw material companies	S&P CapitalIQ
Companies' headquarter location	co_hq_loc	n.a.	Country in which the company's headquarter is legally registered	S&P CapitalIQ
Companies' environmental rating	co_E_rtg	Scale 0 to 10	Companies' environmental rating on a scale from 0 (lowest) to 10 (highest)	Bloomberg
Companies' environmental disclosure	co_E_disc	%	Companies' disclosure of data points constituting the Bloomberg environmental score	Bloomberg
Companies' social rating	co_S_rtg	Scale 0 to 10	Companies' environmental rating on a scale from 0 (lowest) to 10 (highest)	Bloomberg
Companies' social disclosure	co_S_disc	%	Companies' disclosure of data points constituting the Bloomberg social score	Bloomberg
Companies' governance rating	co_G_rtg	Scale 0 to 10	Companies' environmental rating on a scale from 0 (lowest) to 10 (highest)	Bloomberg
Companies' governance disclosure	co_G_disc	%	Companies' disclosure of data points constituting the Bloomberg governance score	Bloomberg
Non-binding ESG measures	bnk_esg_nbm	dummy	Dummy variable indicating introduction of non-binding ESG measures	See Tables A.1 and A.2
Binding ESG regulations	bnk_esg_breg	dummy	Dummy variable indicating introduction of binding ESG regulations. Robustness check: exclusion of banks headquartered in countries, where such regulations exist	See Table A.1
Binding anti-ESG regulations	bnk_anti_esg_breg	dummy	Dummy variable indicating introduction of binding anti-ESG regulations in some US states	Various
Lithium price	li_price	EUR	Lithium price; average Lithium Carbonate and Lithium Hydroxite	Refinitiv Eikon
Cobalt price	cob_price	EUR	Cobalt price	Refinitiv Eikon
Manganese price	mn_price	EUR	Manganese price	Refinitiv Eikon
Nickel price	ni_price	EUR	Nickel price; average class 1 (premium) and class 2 Nickel	Refinitiv Eikon

Copper price	cop_price	EUR	Copper price	Refinitiv Eikon
Aluminum price	al_price	EUR	Aluminum price	Refinitiv Eikon
Tin price	tin_price	EUR	Tin price	Refinitiv Eikon
YY GDP change	yy_gdp_chg	%	YY GDP change	S&P CapitalIQ
YY inflation	yy_infl	%	YY inflation	S&P CapitalIQ

This table provides an overview of all main variables used throughout the empirical analysis for banks' public holdings and lending. All variables are available quarterly from Q1/2015 to Q3/2023.

Table B.9: Public Holdings Battery Raw Materials—Descriptive Statistics

VARIABLES	Observations (matched)	Mean	Std. Dev.	Min	P25	Median	P75	Max
batmat_ph	119,526	$1.4*10^{6}$	$1.8*10^{7}$	0.00	0.00	0.00	0.00	$1.1*10^{9}$
batmat_ph_s	119,526	0.14	1.76	0.00	0.00	0.00	0.00	108.48
all_ph	119,526	$4.3*10^{9}$	$1.5*10^{10}$	$(3.1*10^{6})$	$1.3*10^{7}$	$2.2*10^{8}$	$1.9*10^{9}$	$1.0*10^{12}$
all_ph_s	119,526	4.31	15.39	(0.00)	0.01	0.22	1.92	1,042.22
co_share_pr	119,526	45.83	178.42	(0.25)	0.04	3.13	18.91	4,352.43
co_share_pr_s	119,526	4.58	17.84	(0.03)	0.00	0.31	1.89	435.24
co_div	119,526	0.06	0.19	0.00	0.00	0.00	0.02	14.88
co_credit_risk	119,526	0.20	0.30	0.00	0.00	0.00	0.58	0.75
co_rev	119,526	1,225.54	3,718.93	(569.09)	0.00	31.43	901.37	64,300.26
co_rev_s	119,526	1.23	3.72	(0.57)	0.00	0.03	0.90	64.30
co_E_rtg	119,526	1.58	2.37	0.00	0.00	0.00	3.44	8.26
co_E_disc	119,526	0.20	0.30	0.00	0.00	0.00	0.44	1.00
co_E	119,526	1.00	1.70	0.00	0.00	0.00	1.50	7.13
co_S_rtg	119,526	1.52	2.37	0.00	0.00	0.00	2.55	8.30
co_S_disc	119,526	0.18	0.46	0.00	0.00	0.00	0.29	1.00
co_S	119,526	0.95	3.07	0.00	0.00	0.00	0.77	7.20
co_G_rtg	119,526	2.58	3.24	0.00	0.00	0.00	6.31	8.62
co_G_disc	119,526	0.38	0.48	0.00	0.00	0.00	1.00	1.00
co_G	119,526	2.50	3.23	0.00	0.00	0.00	6.25	8.62
co_hq_co2_pr	119,526	18.47	32.09	0.00	0.00	0.00	32.07	207.30
yy_gdp_chg	119,526	0.03	0.02	(0.03)	0.03	0.04	0.03	0.06
yy_infl	119,526	0.04	0.02	0.03	0.03	0.04	0.03	0.09
li_price	119,526	20,221.74	20,375.20	4,879.25	6,555.64	10,509.27	23,087.15	73,319.68
li_price_s	119,526	2.02	2.04	0.49	0.66	1.05	2.31	7.33
cob_price	119,526	18.51	6.79	10.16	12.52	15.91	23.00	33.06
mn_price	119,526	4.42	0.72	2.67	3.98	4.41	4.90	6.52
ni_price	119,526	6.25	2.28	3.64	4.56	5.51	7.13	12.82
bnk_esg_nbm	119,526	0.04	0.19	0.00	0.00	0.00	0.00	1.00
bnk_esg_breg	119,526	0.08	0.27	0.00	0.00	0.00	0.00	1.00
bnk_anti_esg_breg	119,526	0.01	0.07	0.00	0.00	0.00	0.00	1.00

Descriptive statistics for the variables used in the main empirical analysis for banks' public holdings in the overall battery raw material sourcing. The baseline sample consists of 119,526 batmat_ph observations between Q1/2015 and Q3/2023. See Table B.8 for detailed variable definitions incl. units. Rounded values shown.

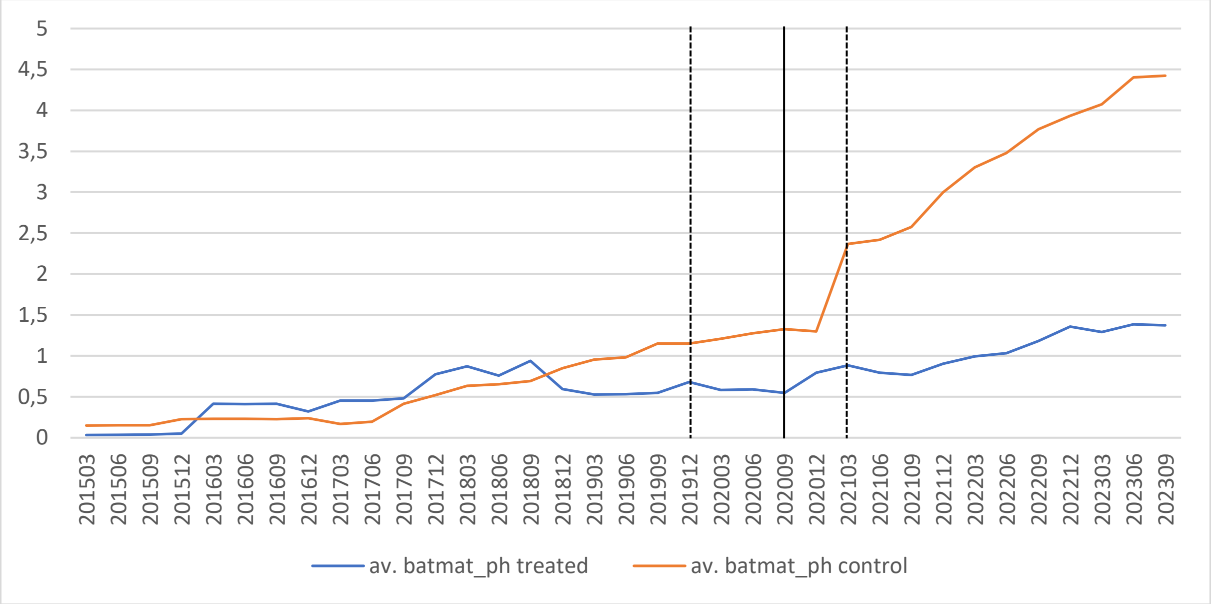
Table B.10: Loans All Battery Raw Materials—Descriptive Statistics

VARIABLES	Observations (matched)	Mean	Std. Dev	Min	P25	Median	P75	Max
bat_mat_loans	5,522	$2.9*10^{6}$	$1.8*10^{7}$	(9,999.00)	0.00	0.00	526.60	$7.8*10^{8}$
bat_mat_loans_s	5,522	2.93	18.40	(0.01)	0.00	0.00	0.00	779.15
all_loans	5,522	$2.4*10^{10}$	$3.9*10^{10}$	0.00	$2.5*10^{7}$	$3.0*10^{9}$	$2.8*10^{10}$	$2.1*10^{11}$
all_loans_s	5,522	23.55	38.90	0.00	0.02	3.00	27.54	205.05
co_rev	5,522	0.52	1.31	0.00	0.00	0.00	0.15	19.00
co_credit_risk	5,522	0.04	0.15	0.00	0.00	0.00	0.00	0.72
co_E_rtg	5,522	1.03	2.00	0.00	0.00	0.00	0.00	7.64
co_E_disc	5,522	0.12	0.24	0.00	0.00	0.00	0.00	0.93
co_S_rtg	5,522	0.75	1.70	0.00	0.00	0.00	0.00	8.40
co_S_disc	5,522	0.08	0.18	0.00	0.00	0.00	0.00	0.94
co_G_rtg	5,522	1.25	2.38	0.00	0.00	0.00	0.00	9.02
co_G_disc	5,522	0.20	0.38	0.00	0.00	0.00	0.00	1.00
yy_gdp_chg	5,522	0.03	0.03	(0.02)	0.03	0.04	0.04	0.06
yy_infl	5,522	0.05	0.02	0.03	0.04	0.04	0.07	0.09
li_price	5,522	20,221.74	20,375.20	4,879.25	6,555.64	10,509.27	23,087.15	73,319.68
li_price_s	5,522	2.52	2.38	0.49	0.79	1.19	3.97	7.33
mn_price	5,522	4.57	0.47	3.80	4.18	4.62	4.90	5.27
ni_price	5,522	7.03	2.30	4.51	5.23	6.33	9.38	12.82
cob_price	5,522	21.24	6.64	12.52	15.33	20.73	27.21	33.06
cop_price	5,522	3.01	0.65	2.07	2.46	2.60	3.67	4.25
al_price	5,522	0.89	0.20	0.62	0.76	0.83	1.02	1.38
tin_price	5,522	9.50	2.94	6.63	7.64	7.95	11.04	18.50

This table reports descriptive statistics for the variables used in the main empirical analysis for banks' lending to battery raw material companies. The baseline sample consists of 5,522 bat_mat_loans observations between Q1/2018 and Q2/2023. See Table B.8 for detailed variable definitions incl. units.
Rounded values shown.

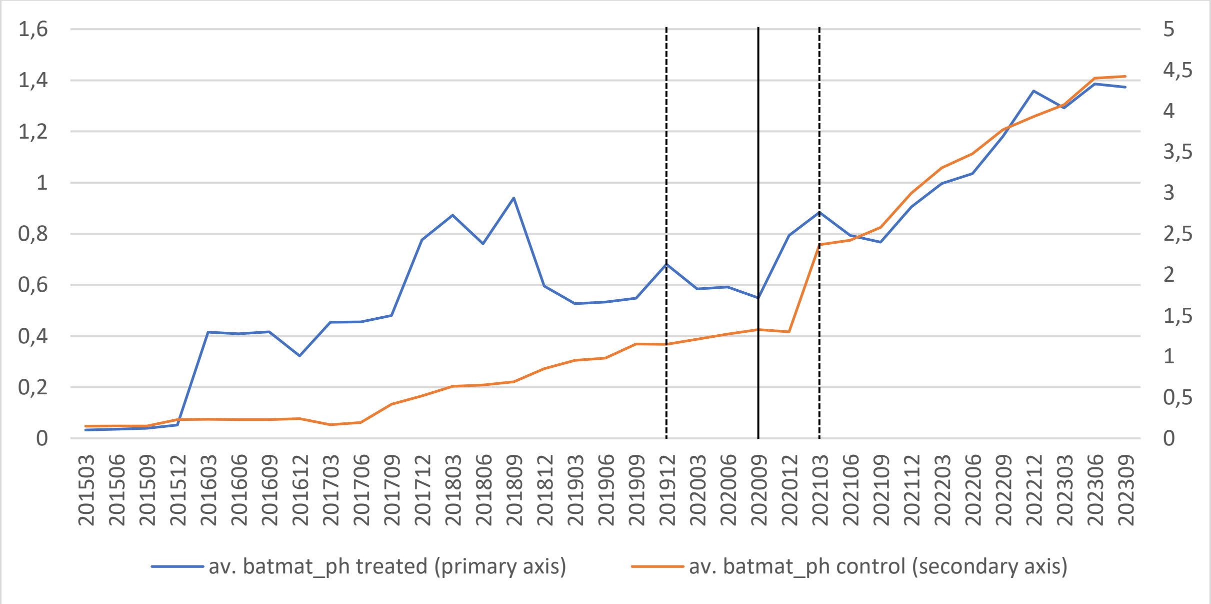
B.3 Parallel Trends

B.3.2 Parallel Trends: ESG Regulation—Public Holdings Battery Raw Materials



Note: dotted horizontal lines indicate introduction (Q4/2019) and entering into force (Q1/2021) of the SFDR, solid line indicates introduction of the Taxonomy (Q3/2020). batmat_ph, per-bank average, M EUR.

Figure B.18: Public Holdings Battery Raw Materials—Parallel Trends



Note: dotted horizontal lines indicate introduction (Q4/2019) and entering into force (Q1/2021) of the SFDR, solid line indicates introduction of the Taxonomy (Q3/2020). batmat_ph, per-bank average, M EUR.

Figure B.19: Public Holdings Battery Raw Materials—Parallel Trends

Table B.11: Public Holdings Battery Raw Materials—Parallel Trends Normalized Differences

	Treated		Control		Norm. Diff.
VARIABLES	Mean	Std. Dev.	Mean	Std. Dev.	
batmat_ph_s	0.05	0.41	0.05	0.54	0.00
all_ph_s	8.43	20.79	2.79	11.00	0.33
co_share_pr_s	1.08	2.59	1.22	2.13	0.06
co_div	0.04	0.22	0.05	0.12	0.01
co_credit_risk	0.16	0.28	0.20	0.30	0.15
co_rev_s	1.76	5.91	0.93	2.95	0.18
co_E_rtg	1.39	2.07	1.24	2.00	0.08
co_E_disc	0.18	0.28	0.16	0.27	0.08
co_S_rtg	1.13	1.82	1.21	2.00	0.04
co_S_disc	0.16	0.43	0.15	0.51	0.01
co_G_rtg	2.35	3.13	2.37	3.14	0.01
co_G_disc	0.36	0.47	0.36	0.47	0.00
co_hq_co2_pr	17.16	21.86	8.91	17.34	0.42
yy_gdp_chg	0.03	0.00	0.03	0.00	0.00
yy_infl	0.03	0.00	0.03	0.00	0.00
li_price_s	1.13	5.34	1.13	5.34	0.00
cob_price	17.92	6.66	17.92	6.66	0.00
mn_price	4.52	0.91	4.52	0.91	0.00
ni_price	4.81	0.84	4.81	0.84	0.00
bnk_esg_nbm	0.00	0.00	0.01	0.08	0.11
bnk_esg_breg	0.00	0.00	0.03	0.18	0.27
bnk_anti_esg_breg	0.00	0.00	0.00	0.00	n.a.

Statistics of relevant co-variates over the pre-shock period (Q1/2015 to Q3/2019) of treated (EU headquartered banks) and control groups (non-EU headquartered banks). Last column: normalized differences between treatment and control groups (differences in averages by treatment status, scaled by the square root of the sum of the variances). Absolute difference < 0.25 indicates no significant difference between the groups. See Table B.8 for detailed variable definitions incl. units. Rounded values shown.

Table B.12: batmat_ph—Parallel Trends

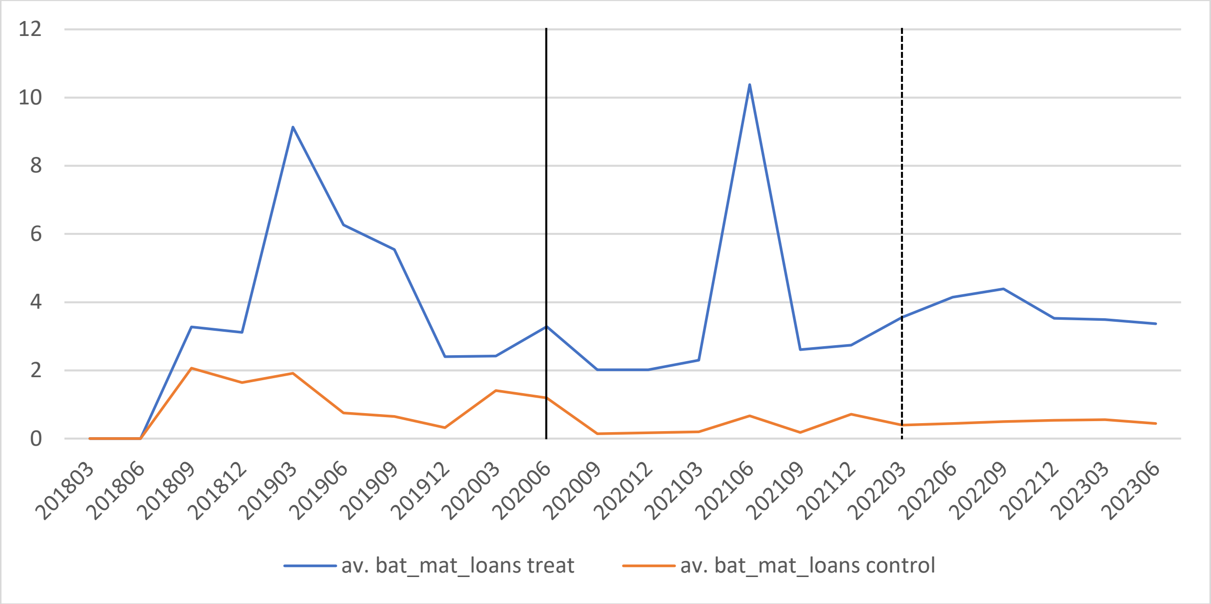
VARIABLES	(1) batmat_ph Parallel Trends
treat	-14.32**
	(6.289)
afterPT	0
	(1.74e-07)
treat_afterPT	-1.755
	(2.671)
all_ph_s	0.00361**
	(0.00137)
co_hq_loc_au	-7.808*
	(4.350)
co_hq_loc_br	-9.092**
	(4.171)
co_hq_loc_ca	-10.43**
	(4.439)
co_hq_loc_ch	-37.72**
	(16.27)
co_hq_loc_cn	-9.614**
	(4.205)
co_hq_loc_fr	-28.21***
	(6.755)
co_hq_loc_de	-25.04**
	(9.525)
co_hq_loc_es	-43.50***
	(10.39)
co_hq_loc_hk	-11.38**
	(4.341)
co_hq_loc_id	53.89
	(48.96)
co_hq_loc_im	-8.749*
	(4.312)
co_hq_loc_in	-29.13***
	(7.899)
co_hq_loc_jp	-16.33***
	(4.717)
co_hq_loc_ke	-11.08**
	(4.765)
co_hq_loc_kr	-16.13
	(10.70)
co_hq_loc_kz	-4.144
	(4.328)
co_hq_loc_lu	-27.39***
	(6.557)
co_hq_loc_mx	-8.918*
	(4.679)
co_hq_loc_nl	-31.15***
	(8.609)
co_hq_loc_pe	-7.094*
	(3.536)
co_hq_loc_ph	213.3*
	(108.5)
co_hq_loc_pl	-16.45**
	(6.434)
co_hq_loc_ru	-7.233
	(4.302)
co_hq_loc_se	2.018
	(11.32)
co_hq_loc_tw	-33.34***
	(9.226)
co_hq_loc_uk	-31.36***
	(7.150)
co_hq_loc_us	-9.976**
	(4.185)

co_hq_loc_vg	-11.11**
	(4.767)
co_hq_loc_za	0
	(5.14e-07)
co_share_pr_s	-0.239
	(0.156)
co_div	-4.629***
	(1.550)
co_credit_risk	9.245**
	(4.042)
co_fd_yr	0.00316***
	(0.00105)
co_rev	-0.000906***
	(0.000288)
co_E	2.070
	(1.459)
co_S	0.150
	(1.137)
co_G	5.423
	(3.545)
bnk_hq_loc_ae	-24.31
	(14.32)
bnk_hq_loc_at	-0.839
	(2.608)
bnk_hq_loc_au	-10.99
	(6.782)
bnk_hq_loc_be	1.767
	(1.792)
bnk_hq_loc_br	-13.61**
	(6.332)
bnk_hq_loc_ca	-12.09*
	(6.139)
bnk_hq_loc_ch	-14.76**
	(6.385)
bnk_hq_loc_cn	7.916
	(17.39)
bnk_hq_loc_co	-11.68*
	(5.676)
bnk_hq_loc_cy	8.135*
	(4.623)
bnk_hq_loc_cz	2.260
	(2.075)
bnk_hq_loc_de	1.008
	(1.331)
bnk_hq_loc_dk	-6.368
	(5.331)
bnk_hq_loc_es	-4.380**
	(1.929)
bnk_hq_loc_fr	-0.0187
	(1.880)
bnk_hq_loc_hk	-12.46*
	(6.780)
bnk_hq_loc_ie	-1.183
	(1.770)
bnk_hq_loc_il	-14.45**
	(6.408)
bnk_hq_loc_im	-16.48**
	(6.774)
bnk_hq_loc_in	-20.83***
	(7.068)
bnk_hq_loc_it	-1.912
	(1.678)
bnk_hq_loc_jp	-9.234
	(6.104)
bnk_hq_loc_kr	-0.484
	(10.83)
bnk_hq_loc_kz	-14.39*
	(7.251)
bnk_hq_loc_li	-1.676

	(2.132)
bnk_hq_loc_lu	-5.020
	(4.767)
bnk_hq_loc_mt	1.940
	(1.809)
bnk_hq_loc_nl	-1.472
	(1.718)
bnk_hq_loc_no	0.968
	(12.97)
bnk_hq_loc_nz	-14.33**
	(6.279)
bnk_hq_loc_om	183.6**
	(66.68)
bnk_hq_loc_ph	-147.9
	(109.0)
bnk_hq_loc_pt	0.479
	(2.072)
bnk_hq_loc_ru	-15.02**
	(6.671)
bnk_hq_loc_sa	-9.872
	(10.90)
bnk_hq_loc_se	8.482
	(10.18)
bnk_hq_loc_sg	-18.99**
	(7.601)
bnk_hq_loc_uk	-4.921
	(5.952)
bnk_hq_loc_us	-13.36**
	(6.191)
bnk_hq_loc_za	-16.69**
	(6.357)
co_hq_co2_pr	0.687***
	(0.178)
yy_gdp_chg	0
	(1.41e-07)
yy_infl	0
	(1.30e-07)
li_price_s	0
	(0)
cob_price	0
	(7.62e-11)
mn_price	0
	(4.39e-10)
ni_price	0
	(1.44e-10)
bnk_esg_nbm	8.553
	(7.542)
bnk_esg_breg	-2.112
	(2.389)
bnk_anti_esg_breg	0
	(6.57e-07)
Constant	15.76**
	(6.701)
Observations	65,056
R-squared	0.069

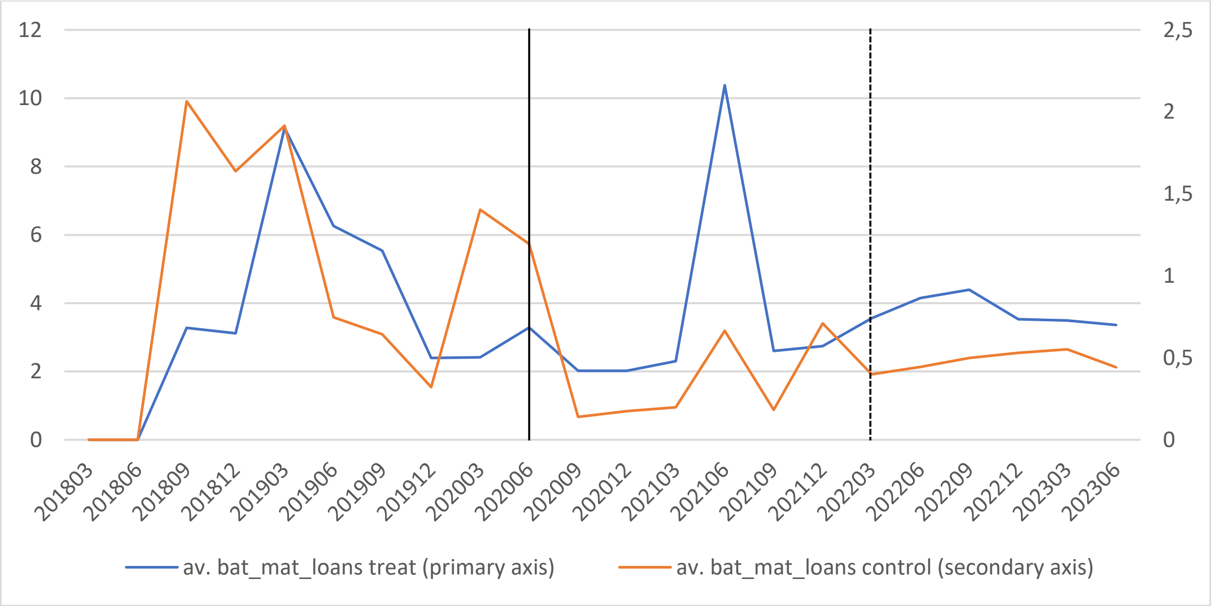
Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1
Results based on stata's reghdfe OLS estimation method.
Time fixed effects treated by means of 'absorbing' (Correia, 2016).

B.3.2 Parallel Trends: ESG Supervision—Loans All Battery Raw Materials



Note: solid horizontal line indicates the introduction of the Guide (Q2/2020), dotted line indicates first supervisory revision based on the Guide. bat_mat_loans, per-bank average, M EUR.

Figure B.20: Loans All Battery Materials Companies—Parallel Trends



Note: dotted horizontal lines indicate introduction (Q4/2019) and entering into force (Q1/2021) of the SFDR, solid line indicates introduction of the Taxonomy (Q3/2020). bat_mat_loans, per-bank average, M EUR.

Figure B.21: Loans All Battery Materials Companies—Parallel Trends

Table B.13: Loans All Battery Raw Materials—Parallel Trends Normalized Differences

	Treated		Control		Norm. Diff.
VARIABLES	Mean	Std. Dev.	Mean	Std. Dev.	
bat_mat_loans_s	3.57	25.58	0.97	6.77	0.14
all_loans_s	24.38	37.65	1.52	4.62	0.85
co_rev_s	0.40	1.04	0.48	0.73	0.09
co_credit_risk	0.04	0.15	0.03	0.14	0.04
co_E_rtg	0.74	1.64	1.11	1.70	0.22
co_E_disc	0.10	0.22	0.14	0.22	0.18
co_S_rtg	0.49	1.24	0.70	1.29	0.17
co_S_disc	0.06	0.15	0.08	0.15	0.12
co_G_rtg	1.00	2.18	1.72	2.59	0.30
co_G_disc	0.16	0.35	0.27	0.39	0.28
yy_gdp_chg	0.03	0.02	0.03	0.02	0.00
yy_infl	0.04	0.00	0.04	0.00	0.00
li_price_s	1.08	0.44	1.08	0.44	0.00
mn_price	4.87	0.43	4.87	0.43	0.00
ni_price	5.43	0.62	5.43	0.62	0.00
cob_price	21.84	5.96	21.84	5.96	0.00
cop_price	2.49	0.07	2.49	0.07	0.00
al_price	0.78	0.04	0.78	0.04	0.00
tin_price	7.63	0.38	7.63	0.38	0.00

This table reports statistics of relevant co-variates over the pre-shock period (Q1/2015 to Q3/2019) dividing the sample between treated (EU headquartered banks) and control group (non-EU headquartered banks). The last column reports normalized differences between treatment and control groups (differences in averages by treatment status, scaled by the square root of the sum of the variances). An absolute difference smaller than 0.25 indicates that there is no significant difference between the groups. See Table B.8 for detailed variable definitions incl. units.
Rounded values shown.

B.4 Regression Results

B.4.1 Regression Results—Public Holdings Battery Raw Materials

Table B.14: batmat_ph—2019 & 2021 Sequential Regressions

VARIABLES	(1) batmat_ph_s	(2) batmat_ph_s	(3) batmat_ph_s	(4) batmat_ph_s	(5) batmat_ph_s	(6) batmat_ph_s	(7) batmat_ph_s	(8) batmat_ph_s	(9) batmat_ph_s	(10) batmat_ph_s	(11) batmat_ph_s	(12) batmat_ph_s	(13) batmat_ph_s	(14) batmat_ph_s	(15) batmat_ph_s	(16) batmat_ph_s	(17) batmat_ph_s	(18) batmat_ph_s
treat	-8.548**	-0.0533	-2.654	-7.884***	-7.884***	-7.833***	-7.582***	-7.924***	-7.621***	-7.495***	-7.459***	-7.313***	-11.61	-16.17	-16.17	-14.18	-14.92	-14.84
	(3.878)	(2.059)	(1.958)	(2.447)	(2.446)	(2.440)	(2.417)	(2.462)	(2.444)	(2.384)	(2.380)	(2.437)	(10.96)	(10.66)	(10.66)	(10.90)	(10.81)	(10.78)
after19_21		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		(0)	(6.00e-08)	(3.55e-08)	(9.88e-08)	(1.85e-07)	(8.40e-08)	(7.79e-08)	(2.63e-07)	(1.03e-07)	(2.13e-07)	(7.66e-07)	(5.70e-08)	(1.26e-06)	(1.26e-06)	(0)	(0)	(1.11e-07)
treat_after19_21	2.503	-5.991***	-6.741***	-6.733***	-6.731***	-6.589***	-6.596***	-6.596***	-6.865***	-6.846***	-6.825***	-7.013***	-6.797***	-7.330***	-7.330***	-7.168***	-6.725***	-6.737***
	(2.699)	(1.047)	(1.066)	(1.141)	(1.142)	(1.117)	(1.145)	(1.111)	(1.175)	(1.267)	(1.304)	(1.244)	(1.337)	(1.458)	(1.458)	(1.491)	(1.505)	(1.494)
after21		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		(0)	(1.93e-08)	(9.76e-08)	(8.17e-08)	(1.52e-08)	(1.23e-07)	(2.59e-08)	(4.64e-08)	(1.27e-07)	(1.32e-07)	(2.12e-07)	(3.53e-07)	(2.40e-08)	(2.40e-08)	(0)	(0)	(2.35e-07)
treat_after21		-23.17***	-24.45***	-24.44***	-24.43***	-24.07***	-24.09***	-24.09***	-23.90***	-23.68***	-23.75***	-22.60***	-22.26***	-27.38***	-27.38***	-25.12***	-23.38***	-23.84***
		(5.357)	(5.326)	(5.359)	(5.331)	(5.283)	(5.290)	(5.290)	(5.263)	(5.114)	(5.135)	(4.747)	(4.875)	(6.167)	(6.167)	(5.759)	(5.284)	(5.350)
all_ph_s			0.00463***	0.00459***	0.00458***	0.00464***	0.00459***	0.00459***	0.00456***	0.00453***	0.00451***	0.00400***	0.00299	0.00294	0.00294	0.00295	0.00295	0.00293
			(0.00137)	(0.00119)	(0.00119)	(0.00119)	(0.00121)	(0.00121)	(0.00121)	(0.00123)	(0.00123)	(0.00134)	(0.00181)	(0.00180)	(0.00180)	(0.00180)	(0.00180)	(0.00180)
co_hq_loc_au				9.703	9.700	9.191	6.898	7.943	13.23	11.16	9.671	8.185	-0.627	-0.0835	-0.0835	-0.213	-0.598	-0.572
				(8.864)	(8.858)	(8.752)	(7.909)	(8.037)	(8.940)	(9.899)	(8.759)	(9.129)	(6.622)	(6.721)	(6.721)	(6.706)	(6.667)	(6.666)
co_hq_loc_br				-12.39***	-12.39***	-11.43***	-11.11***	-10.49***	-1.535	1.878	1.222	-21.49**	-22.02**	-19.45*	-19.45*	-19.66*	-20.42*	-20.47*
				(3.846)	(3.847)	(3.822)	(3.840)	(3.829)	(4.507)	(6.248)	(5.518)	(10.53)	(10.35)	(10.61)	(10.61)	(10.57)	(10.56)	(10.56)
co_hq_loc_ca				-13.48***	-13.48***	-14.43***	-16.33***	-15.58***	-12.63***	-10.64**	-12.71**	-14.37**	-13.29**	-16.59**	-16.59**	-16.59**	-16.60**	-16.54**
				(3.837)	(3.837)	(3.847)	(4.276)	(4.206)	(4.095)	(4.381)	(4.817)	(5.882)	(5.772)	(6.226)	(6.226)	(6.177)	(6.169)	(6.157)
co_hq_loc_ch				-7.943*	-7.948*	-9.311**	-7.704*	-7.445	93.18***	87.26***	87.15***	72.66***	47.91***	0.906	0.906	2.908	4.387	4.467
				(4.451)	(4.450)	(4.393)	(4.543)	(4.569)	(25.33)	(24.12)	(23.70)	(18.57)	(17.35)	(19.27)	(19.27)	(18.86)	(18.70)	(18.63)
co_hq_loc_cn				-6.487	-6.350	-7.821*	-10.43**	-10.19**	-4.476	-4.887	-6.357	-14.05*	-16.84**	-17.26**	-17.26**	-17.34**	-17.42**	-17.40**
				(4.679)	(4.255)	(4.177)	(4.520)	(4.502)	(4.610)	(4.965)	(5.070)	(6.985)	(7.104)	(7.215)	(7.215)	(7.191)	(7.201)	(7.192)
co_hq_loc_fr				-17.90***	-17.89***	-19.27***	-18.36***	-18.47***	-19.00***	-17.61***	-21.08***	-28.12***	-29.04***	-43.84***	-43.84***	-42.90***	-42.32***	-42.30***
				(4.313)	(4.315)	(4.375)	(4.443)	(4.401)	(4.319)	(4.641)	(5.049)	(6.653)	(7.085)	(9.803)	(9.803)	(9.607)	(9.398)	(9.391)
co_hq_loc_de				-19.23	-19.19	-15.90	-19.19	-17.01	-7.100	0.616	-1.098	-13.18	-17.41	-32.58**	-32.58**	-31.75**	-31.19**	-31.14**
				(12.47)	(12.49)	(12.74)	(12.56)	(12.59)	(12.66)	(13.18)	(13.13)	(12.06)	(13.60)	(14.12)	(14.12)	(14.01)	(13.99)	(13.96)
co_hq_loc_es				-48.54***	-48.53***	-50.16***	-52.68***	-51.84***	-47.37***	-47.76***	-50.37***	-51.88***	-56.41***	-69.97***	-69.97***	-69.29***	-68.65***	-68.50***
				(9.672)	(9.687)	(9.759)	(9.555)	(9.481)	(9.343)	(9.930)	(10.33)	(11.39)	(12.56)	(14.98)	(14.98)	(14.74)	(14.57)	(14.55)
co_hq_loc_hk				-3.063	-3.067	-4.397	-7.237	-6.954	-2.580	-4.058	-5.490	-5.807	0.383	1.903	1.903	1.755	2.782	3.142
				(5.194)	(5.201)	(5.112)	(4.866)	(4.847)	(5.054)	(5.163)	(5.103)	(5.993)	(6.669)	(6.891)	(6.891)	(6.868)	(7.081)	(7.143)
co_hq_loc_id				82.64	82.64	81.20	79.63	80.07	82.10	79.61	78.21	78.58	84.00	88.86	88.86	88.61	88.65	88.70
				(68.94)	(68.94)	(68.88)	(69.65)	(69.64)	(68.92)	(68.06)	(68.05)	(68.04)	(67.74)	(68.50)	(68.50)	(68.49)	(68.43)	(68.45)
co_hq_loc_im				24.82**	24.81**	23.50**	20.65**	20.82**	24.83**	23.37**	21.94**	21.52**	27.50*	30.09**	30.09**	29.89**	26.89**	26.78**
				(10.27)	(10.28)	(10.07)	(9.202)	(8.660)	(9.228)	(9.087)	(8.200)	(8.900)	(14.23)	(14.03)	(14.03)	(14.23)	(12.69)	(12.70)
co_hq_loc_in				-18.44***	-18.44***	-19.65***	-22.03***	-21.29***	-15.77***	-18.11***	-19.93***	-25.34***	-28.03**	-36.14***	-36.14***	-34.77***	-34.53***	-34.46***
				(4.917)	(4.915)	(4.952)	(5.241)	(5.177)	(5.094)	(5.346)	(5.967)	(8.512)	(11.02)	(10.55)	(10.55)	(10.54)	(10.50)	(10.47)
co_hq_loc_jp				-19.76***	-19.75***	-18.68***	-21.73***	-19.59***	-14.26***	-14.57***	-16.47***	-26.77***	-34.37***	-33.08***	-33.08***	-33.13***	-33.12***	-33.07***
				(4.509)	(4.520)	(4.502)	(4.873)	(4.727)	(4.687)	(5.099)	(5.301)	(9.137)	(11.04)	(10.76)	(10.76)	(10.75)	(10.81)	(10.78)
co_hq_loc_ke				-14.09***	-14.09***	-15.41***	-18.26***	-17.98***	-13.98***	-15.43***	-16.86***	-17.28***	-28.56**	-25.91**	-25.91**	-26.13**	-26.54**	-26.55**
				(3.864)	(3.865)	(3.914)	(4.800)	(4.759)	(4.514)	(4.835)	(5.446)	(6.138)	(11.46)	(11.45)	(11.45)	(11.42)	(11.45)	(11.44)
co_hq_loc_kr				-10.40	-10.29	9.064	4.048	4.823	4.479	2.822	1.123	-12.04	-23.18	-40.68**	-40.68**	-39.44**	-39.01**	-38.98**

	(8.608)	(8.762)	(10.16)	(8.658)	(8.680)	(7.726)	(7.554)	(7.309)	(11.68)	(19.18)	(18.77)	(18.77)	(18.84)	(18.73)	(18.72)
co_hq_loc_kz	-3.066	-3.060	-4.512	-7.524	1.895	5.575	4.240	2.890	2.045	5.584	7.238	7.238	7.024	6.987	7.014
	(6.179)	(6.172)	(6.050)	(6.171)	(5.940)	(6.185)	(6.413)	(6.176)	(6.596)	(8.181)	(8.400)	(8.400)	(8.376)	(8.428)	(8.430)
co_hq_loc_lu	-16.64***	-16.64***	-17.16***	-16.10***	-15.63***	-19.24***	-21.84***	-23.95***	-36.80***	-34.66***	-47.60***	-47.60***	-46.78***	-45.68***	-45.66***
	(4.067)	(4.067)	(4.038)	(4.088)	(4.068)	(4.152)	(4.448)	(4.945)	(10.42)	(10.51)	(12.18)	(12.18)	(12.07)	(11.81)	(11.80)
co_hq_loc_mx	-15.82***	-15.82***	-17.16***	-20.00***	-18.82***	-13.73***	-16.38***	-19.26***	-76.46**	-71.66*	-71.13*	-71.13*	-70.94*	-70.40*	-70.47*
	(3.894)	(3.895)	(3.956)	(4.782)	(4.642)	(4.395)	(4.615)	(5.482)	(37.05)	(36.85)	(37.14)	(37.14)	(37.17)	(37.15)	(37.16)
co_hq_loc_nl	-18.38*	-18.37*	-17.94*	-16.92	-17.07	-21.61**	-26.66**	-28.04**	-39.72***	-42.07***	-56.14***	-56.14***	-55.12***	-53.70***	-53.70***
	(10.19)	(10.19)	(10.22)	(10.22)	(10.26)	(10.17)	(10.33)	(10.35)	(12.50)	(13.91)	(15.04)	(15.04)	(14.99)	(14.78)	(14.75)
co_hq_loc_pe	-14.37***	-14.37***	-15.44***	-18.31***	-17.39***	-12.95***	-13.80***	-14.99***	-51.15**	-50.87**	-48.92**	-48.92**	-48.77**	-49.48**	-49.46**
	(3.854)	(3.855)	(3.886)	(4.747)	(4.638)	(4.419)	(4.508)	(4.945)	(22.91)	(23.73)	(23.94)	(23.94)	(23.97)	(24.01)	(24.00)
co_hq_loc_ph	131.1*	131.1*	129.7*	126.8*	127.6*	131.6*	130.2*	128.8*	129.0*	260.7*	263.7*	263.7*	263.4*	260.9*	260.9*
	(66.76)	(66.76)	(66.69)	(66.70)	(66.71)	(66.77)	(66.67)	(66.67)	(67.15)	(138.9)	(138.8)	(138.8)	(138.8)	(139.8)	(139.8)
co_hq_loc_pl	-13.60	-13.59	-14.11	-17.02*	-16.08*	-9.089	-5.771	-9.166	-31.96**	-32.57*	-48.02***	-48.02***	-46.99**	-46.47**	-46.36**
	(8.827)	(8.832)	(8.877)	(8.785)	(8.809)	(8.737)	(8.816)	(8.806)	(14.70)	(17.11)	(17.39)	(17.39)	(17.32)	(17.24)	(17.21)
co_hq_loc_ru	-14.14***	-14.15***	-15.43***	-18.28***	-17.99***	-8.274*	-11.10*	-13.63*	-33.86*	-31.04	-29.32	-29.32	-29.36	-29.79	-29.70
	(3.863)	(3.864)	(3.914)	(4.798)	(4.755)	(4.545)	(6.328)	(7.584)	(17.63)	(19.43)	(19.81)	(19.81)	(19.72)	(19.73)	(19.69)
co_hq_loc_se	20.54	20.55	20.67	17.57	18.68	23.61*	24.98*	24.15*	17.79	12.49	-2.046	-2.046	-1.431	-0.997	-0.976
	(13.56)	(13.56)	(13.47)	(13.35)	(13.33)	(13.41)	(13.50)	(13.41)	(13.88)	(11.96)	(12.69)	(12.69)	(12.61)	(12.61)	(12.61)
co_hq_loc_tw	-48.54***	-48.53***	-50.22***	-52.73***	-52.09***	-46.72***	-47.37***	-48.71***	-56.32***	-60.78***	-57.59***	-57.59***	-57.87***	-58.46***	-58.30***
	(9.672)	(9.685)	(9.758)	(9.555)	(9.497)	(9.340)	(10.23)	(10.22)	(12.98)	(15.22)	(14.92)	(14.92)	(14.93)	(15.06)	(15.02)
co_hq_loc_uk	19.25**	19.25**	18.46**	15.93**	17.27**	21.72**	20.39**	19.12**	19.11**	9.148	-12.70	-12.70	-11.75	-10.23	-10.20
	(8.076)	(8.072)	(7.905)	(7.359)	(7.564)	(7.983)	(7.525)	(7.035)	(7.181)	(6.218)	(7.856)	(7.856)	(7.777)	(7.464)	(7.463)
co_hq_loc_us	-13.60***	-13.58***	-11.98***	-12.36***	-11.51***	-11.80***	-14.83***	-15.82***	-19.59***	-19.16**	-17.57**	-17.57**	-17.76**	-17.84**	-17.76**
	(3.847)	(3.864)	(3.868)	(3.927)	(3.897)	(3.871)	(4.128)	(4.902)	(7.043)	(7.049)	(7.010)	(7.010)	(6.983)	(6.996)	(6.981)
co_hq_loc_vg	-10.10**	-10.11**	-11.42***	-14.27***	-14.07***	-10.07**	-11.53**	-12.96**	-13.38**	-24.64**	-22.00*	-22.00*	-22.22*	-22.63**	-22.64**
	(4.027)	(4.029)	(4.011)	(4.614)	(4.594)	(4.437)	(4.654)	(5.065)	(5.825)	(10.93)	(11.08)	(11.08)	(11.05)	(11.06)	(11.07)
co_hq_loc_za		0	0	0	0	0	0	0	0	0	0	0	0	0	0
		(0)	(1.62e-09)	(0)	(2.74e-09)	(0)	(4.37e-09)	(1.06e-08)	(1.60e-08)	(2.11e-09)	(7.22e-08)	(7.25e-08)	(1.70e-10)	(3.96e-08)	(2.77e-08)
co_share_pr_s		-0.00619	-0.000456	-0.00135	-0.00136	-0.00495	0.00354	0.00323	0.0407	0.0298	0.101	0.101	0.0974	0.0895	0.0901
		(0.0910)	(0.0907)	(0.0908)	(0.0908)	(0.0909)	(0.0896)	(0.0898)	(0.0884)	(0.0867)	(0.0878)	(0.0878)	(0.0877)	(0.0870)	(0.0869)
co_div			-19.79***	-17.83***	-17.71***	-12.00***	-11.31**	-11.51**	-11.08**	-8.922**	-8.779**	-8.779**	-8.888**	-8.662**	-8.653**
			(6.571)	(5.945)	(5.896)	(4.090)	(4.193)	(4.259)	(4.227)	(3.897)	(3.739)	(3.739)	(3.746)	(3.698)	(3.692)
co_credit_risk				-6.324	-5.612	7.938*	13.71***	13.82***	15.92***	16.60***	14.09***	14.09***	14.05***	14.01***	13.98***
				(4.454)	(4.350)	(4.040)	(4.822)	(4.941)	(5.287)	(5.083)	(4.961)	(4.961)	(4.961)	(4.956)	(4.957)
co_fd_yr					0.0134***	0.0132***	0.0136***	0.0137***	0.0137***	0.0128***	0.0126***	0.0126***	0.0126***	0.0129***	0.0129***
					(0.00326)	(0.00323)	(0.00331)	(0.00340)	(0.00335)	(0.00337)	(0.00333)	(0.00333)	(0.00333)	(0.00335)	(0.00336)
co_rev						-0.00249***	-0.00228***	-0.00222***	-0.00192***	-0.00136***	-0.00121***	-0.00121***	-0.00121***	-0.00117***	-0.00116***
						(0.000562)	(0.000518)	(0.000492)	(0.000401)	(0.000364)	(0.000357)	(0.000357)	(0.000356)	(0.000345)	(0.000344)
co_E							-4.317	-7.326**	4.933	4.221	4.369	4.369	4.726	4.767	4.810
							(2.617)	(3.261)	(5.980)	(5.625)	(5.636)	(5.636)	(5.555)	(5.557)	(5.559)
co_E_rtg							-2.168**	-0.631	-7.332	-7.108	-7.425	-7.425	-7.569	-7.558	-7.564
							(1.000)	(1.107)	(5.537)	(5.412)	(5.411)	(5.411)	(5.394)	(5.400)	(5.400)
co_E_disc							28.87	39.32*	-1.746	1.135	8.124	8.124	6.468	5.939	5.858
							(19.73)	(19.79)	(13.31)	(12.55)	(13.94)	(13.94)	(13.53)	(13.45)	(13.45)
co_S								3.240**	4.749**	4.215**	5.631**	5.631**	5.469**	5.466**	5.453**
								(1.373)	(2.059)	(2.070)	(2.161)	(2.161)	(2.149)	(2.140)	(2.136)
co_S_rtg								-0.785	-1.800**	-1.851**	-2.587***	-2.587***	-2.459***	-2.412***	-2.405***
								(0.724)	(0.726)	(0.739)	(0.840)	(0.840)	(0.821)	(0.807)	(0.805)
co_S_disc								-19.51**	-31.37**	-27.67*	-37.12**	-37.12**	-36.13**	-36.15**	-36.09**
								(8.730)	(14.09)	(14.12)	(14.51)	(14.51)	(14.48)	(14.44)	(14.42)
co_G									-21.48*	-21.70*	-22.33*	-22.33*	-22.21*	-22.32*	-22.30*
									(12.36)	(12.72)	(12.75)	(12.75)	(12.78)	(12.78)	(12.77)
co_G_rtg									8.920	9.354	10.53*	10.53*	10.46*	10.40*	10.39*
									(5.631)	(5.776)	(5.746)	(5.746)	(5.763)	(5.757)	(5.754)
co_G_disc									110.6	110.8	110.0	110.0	109.7	110.8	110.6
									(65.55)	(67.23)	(67.75)	(67.75)	(67.82)	(67.84)	(67.81)
bnk_hq_loc_ae										-32.64	-38.56*	-38.56*	-35.91*	-36.20*	-36.34*

	(20.68)	(20.37)	(20.37)	(20.43)	(20.36)	(20.34)
bnk_hq_loc_at	-14.15	-15.35	-15.35	-15.17	-15.33	-15.31
	(10.52)	(10.78)	(10.78)	(10.73)	(10.73)	(10.71)
bnk_hq_loc_au	5.941	-0.192	-0.192	2.453	2.468	2.442
	(12.42)	(13.02)	(13.02)	(12.94)	(12.75)	(12.71)
bnk_hq_loc_be	6.462	6.382	6.382	6.363	6.479	6.489
	(8.271)	(8.200)	(8.200)	(8.206)	(8.218)	(8.215)
bnk_hq_loc_br	-31.60	-37.88**	-37.88**	-35.20*	-35.34*	-35.31*
	(18.70)	(18.13)	(18.13)	(18.42)	(18.34)	(18.31)
bnk_hq_loc_ca	-3.286	-9.210	-9.210	-6.558	-6.687	-6.756
	(11.02)	(10.90)	(10.90)	(11.04)	(10.86)	(10.82)
bnk_hq_loc_ch	-16.82	-22.82**	-22.82**	-23.68**	-22.67**	-22.55**
	(9.993)	(9.875)	(9.875)	(10.58)	(10.11)	(10.07)
bnk_hq_loc_cn	11.66	6.846	6.846	-4.170	-10.43	-9.534
	(22.98)	(22.94)	(22.94)	(23.95)	(24.49)	(24.45)
bnk_hq_loc_co	-1.697	-6.973	-6.973	-5.262	-5.377	-5.485
	(8.958)	(7.629)	(7.629)	(8.099)	(7.925)	(7.869)
bnk_hq_loc_cy	6.733	9.486	9.486	8.564	8.792	8.842
	(9.056)	(7.812)	(7.812)	(8.214)	(8.129)	(8.092)
bnk_hq_loc_cz	19.30**	18.74**	18.74**	18.62**	18.51**	18.45**
	(9.039)	(8.978)	(8.978)	(8.955)	(8.930)	(8.908)
bnk_hq_loc_de	4.541	4.560	4.560	4.513	4.488	4.499
	(5.720)	(5.721)	(5.721)	(5.705)	(5.694)	(5.686)
bnk_hq_loc_dk	0.522	-0.412	-0.412	-0.467	-0.328	-0.354
	(8.567)	(8.643)	(8.643)	(8.611)	(8.610)	(8.604)
bnk_hq_loc_es	-3.933	-4.083	-4.083	-4.106	-4.286	-4.295
	(8.670)	(8.482)	(8.482)	(8.492)	(8.462)	(8.447)
bnk_hq_loc_fr	1.847	1.612	1.612	1.546	1.491	1.499
	(6.106)	(6.097)	(6.097)	(6.088)	(6.083)	(6.074)
bnk_hq_loc_hk	-23.57	-29.07*	-29.07*	-37.86**	-43.20***	-42.46***
	(14.86)	(14.45)	(14.45)	(14.47)	(15.48)	(15.41)
bnk_hq_loc_ie	-0.0209	0.255	0.255	0.215	0.196	0.196
	(7.014)	(6.992)	(6.992)	(6.986)	(6.984)	(6.976)
bnk_hq_loc_il	-5.640	-12.55	-12.55	-9.882	-10.15	-10.27
	(12.58)	(11.87)	(11.87)	(11.95)	(11.80)	(11.74)
bnk_hq_loc_im	-16.93	-23.33*	-23.33*	-20.65*	-20.83*	-20.89*
	(11.05)	(11.55)	(11.55)	(11.39)	(11.24)	(11.21)
bnk_hq_loc_in	8.892	-7.819	-7.819	-5.756	-5.132	-5.210
	(7.822)	(11.47)	(11.47)	(11.18)	(10.81)	(10.79)
bnk_hq_loc_it	-2.032	-1.603	-1.603	-1.660	-1.756	-1.749
	(6.580)	(6.564)	(6.564)	(6.556)	(6.554)	(6.547)
bnk_hq_loc_jp	6.869	0.751	0.751	0.403	0.0575	0.175
	(12.03)	(11.95)	(11.95)	(12.39)	(12.28)	(12.25)
bnk_hq_loc_kr	20.52	25.52	25.52	24.74	25.12	25.12
	(20.51)	(19.94)	(19.94)	(20.07)	(20.01)	(20.00)
bnk_hq_loc_kz	-15.78	-22.05	-22.05	-19.36	-19.38	-19.43
	(13.94)	(14.16)	(14.16)	(14.11)	(14.08)	(14.05)
bnk_hq_loc_li	2.659	2.407	2.407	2.403	2.336	2.339
	(8.291)	(8.249)	(8.249)	(8.253)	(8.274)	(8.270)
bnk_hq_loc_lu	-1.613	-1.047	-1.047	-1.138	-1.048	-1.046
	(7.903)	(7.774)	(7.774)	(7.765)	(7.772)	(7.765)
bnk_hq_loc_mt	11.31	10.86	10.86	10.78	10.64	10.63
	(7.111)	(6.900)	(6.900)	(6.870)	(6.844)	(6.831)
bnk_hq_loc_nl	-5.037	-4.791	-4.791	-4.836	-4.838	-4.834
	(6.659)	(6.616)	(6.616)	(6.608)	(6.612)	(6.603)
bnk_hq_loc_no	3.974	4.564	4.564	4.477	4.359	4.527
	(17.73)	(17.69)	(17.69)	(17.68)	(17.71)	(17.71)
bnk_hq_loc_nz	-22.23*	-28.30**	-28.30**	-25.64**	-25.52**	-25.58**

													(11.49)	(11.09)	(11.09)	(11.04)	(10.84)	(10.82)
bnk_hq_loc_om													850.7***	844.1***	844.1***	846.6***	846.7***	846.7***
													(135.1)	(135.5)	(135.5)	(136.1)	(136.0)	(136.1)
bnk_hq_loc_ph													-201.7	-208.4	-208.4	-205.6	-203.8	-203.8
													(134.5)	(134.1)	(134.1)	(134.1)	(134.7)	(134.7)
bnk_hq_loc_pt													6.463	6.413	6.413	6.296	6.055	5.942
													(6.094)	(6.037)	(6.037)	(6.001)	(5.984)	(5.966)
bnk_hq_loc_ru													-11.77	-20.41	-20.41	-17.65	-17.89	-18.00
													(16.33)	(16.35)	(16.35)	(16.46)	(16.33)	(16.28)
bnk_hq_loc_sa													-18.42	-24.46*	-24.46*	-21.78	-21.97	-22.03
													(13.40)	(13.95)	(13.95)	(13.80)	(13.71)	(13.69)
bnk_hq_loc_se													18.86	19.76	19.76	19.68	19.73	19.70
													(16.82)	(16.95)	(16.95)	(16.93)	(16.98)	(16.98)
bnk_hq_loc_sg													-2.697	-10.46	-10.46	-13.86	-11.88	-11.63
													(19.73)	(18.44)	(18.44)	(18.56)	(18.29)	(18.27)
bnk_hq_loc_uk													16.99	10.85	10.85	12.02	10.04	10.10
													(10.86)	(10.03)	(10.03)	(10.44)	(10.21)	(10.17)
bnk_hq_loc_us													-11.31	-17.39*	-17.39*	-14.77	-16.12	-15.96
													(9.666)	(9.485)	(9.485)	(9.676)	(9.631)	(9.603)
bnk_hq_loc_za													-14.22	-19.64	-19.64	-21.45	-20.21	-20.02
													(15.52)	(15.47)	(15.47)	(15.42)	(15.42)	(15.40)
co_hq_co2_pr														0.381**	0.381**	0.362**	0.336**	0.335**
														(0.154)	(0.154)	(0.151)	(0.143)	(0.143)
yy_gdp_chg															0	0	0	0
															(4.05e-08)	(9.01e-08)	(3.87e-08)	(8.76e-08)
yy_infl																0	0	0
																(3.93e-08)	(1.58e-07)	(8.30e-08)
li_price_s																0	0	0
																(1.13e-10)	(1.91e-10)	(1.04e-10)
cob_price																0	0	0
																(3.11e-10)	(2.98e-10)	(3.47e-10)
mn_price																0	0	0
																(4.04e-09)	(1.20e-09)	(5.07e-09)
ni_price																0	0	0
																(1.33e-10)	(5.16e-11)	(6.55e-10)
bnk_esg_nbm																17.76*	11.61	10.73
																(9.950)	(7.836)	(7.747)
bnk_esg_breg																	13.85**	13.56**
																	(6.096)	(6.083)
bnk_anti_esg_breg																		-19.34***
																		(5.313)
Constant	15.00***	15.00***	13.28***	14.07***	14.07***	15.39***	18.24***	-8.766	-12.42	-11.78	-10.62	-10.08	-3.019	0.737	0.737	-1.675	-1.711	-1.708
	(1.860)	(1.853)	(1.856)	(4.082)	(4.089)	(3.995)	(4.296)	(7.296)	(7.825)	(8.040)	(7.211)	(7.390)	(11.39)	(10.95)	(10.95)	(11.41)	(11.17)	(11.15)
Observations	119,840	119,840	119,840	119,840	119,840	119,840	119,840	119,840	119,840	119,840	119,840	119,840	119,840	119,526	119,526	119,526	119,526	119,526
R-squared	0.006	0.006	0.008	0.016	0.016	0.016	0.017	0.017	0.017	0.018	0.018	0.021	0.039	0.040	0.040	0.040	0.041	0.041

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1
Results based on stata’s reghdfe OLS estimation method.
Time fixed effects treated by means of ‘absorbing’ (Correia, 2016).

Table B.15: batmat_ph—2020 Sequential Regressions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
VARIABLES	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s
treat	-8.969	-3.537	-8.766***	-8.766***	-8.719***	-8.467***	-8.808***	-8.525***	-8.395***	-8.354***	-8.232***	-12.47	-17.02	-14.98	-15.69	-15.61
	(8.364)	(2.121)	(2.650)	(2.649)	(2.645)	(2.621)	(2.667)	(2.654)	(2.594)	(2.589)	(2.640)	(10.96)	(10.64)	(10.89)	(10.80)	(10.76)
after20	25.24***	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	(4.336)	(0)	(0)	(1.44e-07)	(0)	(4.26e-08)	(3.98e-08)	(3.28e-09)	(0)	(0)	(3.70e-07)	(0)	(6.34e-07)	(1.27e-06)	(4.49e-08)	(0)
treat_after20	-19.78***	-20.89***	-20.88***	-20.87***	-20.50***	-20.53***	-20.53***	-20.41***	-20.24***	-20.30***	-19.34***	-19.04***	-23.31***	-21.35***	-19.85***	-20.23***
	(4.633)	(4.854)	(4.882)	(4.860)	(4.807)	(4.816)	(4.815)	(4.779)	(4.642)	(4.668)	(4.284)	(4.265)	(5.540)	(5.126)	(4.604)	(4.653)
all_ph_s		0.00463***	0.00458***	0.00458***	0.00463***	0.00459***	0.00458***	0.00456***	0.00453***	0.00450***	0.00400***	0.00298	0.00293	0.00294	0.00294	0.00293
		(0.00137)	(0.00119)	(0.00119)	(0.00119)	(0.00121)	(0.00121)	(0.00121)	(0.00123)	(0.00123)	(0.00134)	(0.00181)	(0.00180)	(0.00180)	(0.00180)	(0.00180)
co_hq_loc_au			9.700	9.698	9.188	6.895	7.940	13.24	11.18	9.700	8.221	-0.595	-0.0520	-0.187	-0.577	-0.551
			(8.864)	(8.858)	(8.752)	(7.909)	(8.037)	(8.942)	(9.901)	(8.760)	(9.131)	(6.626)	(6.723)	(6.709)	(6.671)	(6.671)
co_hq_loc_br			-12.40***	-12.40***	-11.43***	-11.11***	-10.50***	-1.519	1.921	1.267	-21.44**	-21.98**	-19.43*	-19.65*	-20.42*	-20.47*
			(3.847)	(3.847)	(3.822)	(3.841)	(3.829)	(4.509)	(6.252)	(5.522)	(10.53)	(10.34)	(10.61)	(10.57)	(10.56)	(10.57)
co_hq_loc_ca			-13.49***	-13.49***	-14.43***	-16.33***	-15.58***	-12.63***	-10.62**	-12.69**	-14.34**	-13.27**	-16.52**	-16.52**	-16.54**	-16.48**
			(3.837)	(3.838)	(3.848)	(4.276)	(4.207)	(4.095)	(4.382)	(4.818)	(5.882)	(5.772)	(6.221)	(6.173)	(6.167)	(6.154)
co_hq_loc_ch			-7.950*	-7.954*	-9.317**	-7.709*	-7.451	93.40***	87.48***	87.36***	72.85***	48.09***	1.785	3.736	5.171	5.270
			(4.450)	(4.449)	(4.392)	(4.542)	(4.567)	(25.38)	(24.16)	(23.74)	(18.60)	(17.36)	(19.25)	(18.85)	(18.69)	(18.62)
co_hq_loc_cn			-6.489	-6.348	-7.819*	-10.43**	-10.19**	-4.462	-4.860	-6.327	-14.01*	-16.81**	-17.21**	-17.31**	-17.38**	-17.37**
			(4.679)	(4.256)	(4.177)	(4.520)	(4.502)	(4.611)	(4.967)	(5.072)	(6.986)	(7.105)	(7.217)	(7.192)	(7.202)	(7.194)
co_hq_loc_fr			-17.89***	-17.89***	-19.27***	-18.36***	-18.47***	-19.00***	-17.59***	-21.04***	-28.09***	-29.02***	-43.61***	-42.67***	-42.10***	-42.08***
			(4.312)	(4.314)	(4.375)	(4.443)	(4.401)	(4.319)	(4.641)	(5.052)	(6.652)	(7.084)	(9.788)	(9.594)	(9.388)	(9.383)
co_hq_loc_de			-19.22	-19.18	-15.89	-19.19	-17.00	-7.071	0.659	-1.048	-13.14	-17.36	-32.31**	-31.48**	-30.94**	-30.88**
			(12.45)	(12.47)	(12.72)	(12.54)	(12.57)	(12.64)	(13.18)	(13.12)	(12.05)	(13.59)	(14.10)	(13.99)	(13.98)	(13.94)
co_hq_loc_es			-48.50***	-48.49***	-50.12***	-52.64***	-51.80***	-47.32***	-47.70***	-50.30***	-51.81***	-56.34***	-69.69***	-69.02***	-68.40***	-68.24***
			(9.674)	(9.689)	(9.762)	(9.557)	(9.484)	(9.346)	(9.932)	(10.33)	(11.39)	(12.56)	(14.96)	(14.73)	(14.57)	(14.55)
co_hq_loc_hk			-3.066	-3.071	-4.400	-7.242	-6.958	-2.575	-4.035	-5.466	-5.775	0.417	1.923	1.771	2.807	3.160
			(5.091)	(5.094)	(4.997)	(4.766)	(4.818)	(5.009)	(5.163)	(5.102)	(6.002)	(6.704)	(6.907)	(6.871)	(7.088)	(7.179)
co_hq_loc_id			82.65	82.65	81.21	79.64	80.08	82.11	79.64	78.25	78.63	84.05	88.87	88.62	88.65	88.71
			(68.94)	(68.94)	(68.88)	(69.66)	(69.64)	(68.92)	(68.06)	(68.06)	(68.04)	(67.74)	(68.51)	(68.49)	(68.43)	(68.45)
co_hq_loc_im			24.81**	24.81**	23.50**	20.64**	20.82**	24.83***	23.39**	21.96**	21.55**	27.53*	30.09**	29.89**	26.86**	26.75**
			(10.35)	(10.36)	(10.16)	(9.291)	(8.374)	(9.093)	(9.049)	(8.185)	(8.796)	(14.28)	(14.07)	(14.29)	(12.85)	(12.96)
co_hq_loc_in			-18.44***	-18.44***	-19.65***	-22.03***	-21.29***	-15.76***	-18.08***	-19.90***	-25.28***	-27.96**	-35.93***	-34.56***	-34.32***	-34.25***
			(4.915)	(4.914)	(4.950)	(5.240)	(5.176)	(5.093)	(5.346)	(5.968)	(8.515)	(11.03)	(10.55)	(10.53)	(10.50)	(10.47)
co_hq_loc_jp			-19.76***	-19.75***	-18.67***	-21.73***	-19.59***	-14.24***	-14.54***	-16.44***	-26.73***	-34.33***	-33.05***	-33.11***	-33.09***	-33.05***
			(4.509)	(4.520)	(4.502)	(4.873)	(4.727)	(4.688)	(5.101)	(5.303)	(9.138)	(11.05)	(10.77)	(10.76)	(10.82)	(10.80)
co_hq_loc_ke			-14.09***	-14.10***	-15.41***	-18.27***	-17.99***	-13.97***	-15.41***	-16.84***	-17.25***	-28.54**	-25.92**	-26.15**	-26.56**	-26.57**
			(3.865)	(3.865)	(3.915)	(4.800)	(4.759)	(4.514)	(4.835)	(5.447)	(6.139)	(11.45)	(11.46)	(11.43)	(11.45)	(11.45)
co_hq_loc_kr			-10.40	-10.29	9.065	4.047	4.821	4.476	2.815	1.120	-12.04	-23.22	-40.48**	-39.23**	-38.82**	-38.78**
			(8.594)	(8.747)	(10.16)	(8.655)	(8.676)	(7.719)	(7.544)	(7.302)	(11.68)	(19.19)	(18.78)	(18.85)	(18.73)	(18.72)
co_hq_loc_kz			-3.074	-3.067	-4.519	-7.532	1.887	5.575	4.258	2.910	2.072	5.610	7.235	7.017	6.981	7.007
			(6.169)	(6.161)	(6.039)	(6.160)	(5.930)	(6.174)	(6.404)	(6.166)	(6.587)	(8.171)	(8.398)	(8.375)	(8.427)	(8.429)
co_hq_loc_lu			-16.64***	-16.64***	-17.16***	-16.10***	-15.63***	-19.25***	-21.84***	-23.94***	-36.79***	-34.65***	-47.42***	-46.60***	-45.49***	-45.48***
			(4.067)	(4.067)	(4.037)	(4.088)	(4.068)	(4.151)	(4.450)	(4.947)	(10.42)	(10.51)	(12.16)	(12.05)	(11.79)	(11.79)
co_hq_loc_mx			-15.83***	-15.82***	-17.16***	-20.00***	-18.82***	-13.73***	-16.36***	-19.24***	-76.47**	-71.68*	-71.17*	-70.97*	-70.42*	-70.49*
			(3.894)	(3.896)	(3.957)	(4.782)	(4.642)	(4.395)	(4.615)	(5.481)	(37.05)	(36.85)	(37.15)	(37.17)	(37.16)	(37.17)
co_hq_loc_nl			-18.37*	-18.36*	-17.93*	-16.91	-17.06	-21.61**	-26.67**	-28.05**	-39.74***	-42.08***	-55.96***	-54.93***	-53.52***	-53.51***
			(10.18)	(10.18)	(10.21)	(10.21)	(10.25)	(10.16)	(10.32)	(10.34)	(12.49)	(13.91)	(15.02)	(14.96)	(14.76)	(14.74)
co_hq_loc_pe			-14.37***	-14.37***	-15.45***	-18.32***	-17.40***	-12.95***	-13.79***	-14.98***	-51.16**	-50.88**	-48.96**	-48.80**	-49.52**	-49.50**
			(3.854)	(3.855)	(3.887)	(4.748)	(4.639)	(4.419)	(4.509)	(4.946)	(22.91)	(23.73)	(23.95)	(23.97)	(24.01)	(24.01)
co_hq_loc_ph			131.1*	131.1*	129.7*	126.8*	127.6*	131.6*	130.2*	128.8*	129.0*	260.8*	263.8*	263.4*	260.9*	260.9*
			(66.77)	(66.77)	(66.69)	(66.70)	(66.71)	(66.77)	(66.68)	(66.67)	(67.15)	(138.9)	(138.8)	(138.9)	(139.8)	(139.8)
co_hq_loc_pl			-13.59	-13.58	-14.10	-17.02*	-16.07*	-9.065	-5.744	-9.128	-31.94**	-32.54*	-47.77***	-46.75**	-46.24**	-46.13**
			(8.816)	(8.821)	(8.865)	(8.773)	(8.797)	(8.726)	(8.806)	(8.796)	(14.69)	(17.10)	(17.36)	(17.29)	(17.21)	(17.18)

co_hq_loc_ru	-14.15***	-14.15***	-15.43***	-18.29***	-18.00***	-8.258*	-11.13*	-13.65*	-33.88*	-31.03	-29.34	-29.37	-29.80	-29.72
	(3.864)	(3.864)	(3.914)	(4.798)	(4.756)	(4.545)	(6.327)	(7.586)	(17.63)	(19.45)	(19.82)	(19.73)	(19.74)	(19.70)
co_hq_loc_se	20.54	20.55	20.67	17.56	18.67	23.62*	24.99*	24.17*	17.81	12.51	-1.828	-1.222	-0.798	-0.773
	(13.56)	(13.56)	(13.47)	(13.35)	(13.33)	(13.41)	(13.50)	(13.41)	(13.88)	(11.97)	(12.67)	(12.60)	(12.60)	(12.60)
co_hq_loc_tw	-48.50***	-48.49***	-50.18***	-52.69***	-52.05***	-46.67***	-47.29***	-48.64***	-56.24***	-60.70***	-57.54***	-57.82***	-58.42***	-58.27***
	(9.674)	(9.687)	(9.760)	(9.557)	(9.500)	(9.343)	(10.23)	(10.22)	(12.97)	(15.23)	(14.94)	(14.94)	(15.08)	(15.05)
co_hq_loc_uk	19.25**	19.24**	18.46**	15.92**	17.26**	21.73**	20.41**	19.14**	19.14**	9.177	-12.36	-11.43	-9.914	-9.877
	(8.076)	(8.072)	(7.905)	(7.359)	(7.564)	(7.984)	(7.528)	(7.038)	(7.184)	(6.221)	(7.854)	(7.779)	(7.472)	(7.473)
co_hq_loc_us	-13.60***	-13.58***	-11.99***	-12.36***	-11.51***	-11.80***	-14.83***	-15.82***	-19.59***	-19.16**	-17.60**	-17.79**	-17.86**	-17.79**
	(3.847)	(3.864)	(3.868)	(3.927)	(3.897)	(3.871)	(4.129)	(4.905)	(7.047)	(7.052)	(7.016)	(6.989)	(7.002)	(6.988)
co_hq_loc_vg	-10.11**	-10.11**	-11.42***	-14.28***	-14.08***	-10.06**	-11.51**	-12.94**	-13.35**	-24.62**	-22.01*	-22.23*	-22.65**	-22.66**
	(4.028)	(4.030)	(4.011)	(4.613)	(4.599)	(4.441)	(4.659)	(5.069)	(5.828)	(10.93)	(11.09)	(11.05)	(11.06)	(11.07)
co_hq_loc_za	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	(4.29e-07)	(5.00e-09)	(0)	(5.95e-08)	(2.79e-07)	(7.63e-08)	(0)	(0)	(1.21e-06)	(0)	(3.51e-07)	(3.07e-07)	(5.07e-07)	(0)
co_share_pr_s		-0.00640	-0.000672	-0.00157	-0.00158	-0.00516	0.00338	0.00306	0.0405	0.0297	0.0996	0.0963	0.0884	0.0890
		(0.0910)	(0.0908)	(0.0908)	(0.0908)	(0.0909)	(0.0896)	(0.0898)	(0.0884)	(0.0867)	(0.0878)	(0.0878)	(0.0871)	(0.0870)
co_div			-19.79***	-17.82***	-17.70***	-11.98***	-11.28**	-11.48**	-11.05**	-8.896**	-8.751**	-8.865**	-8.638**	-8.629**
			(6.576)	(5.950)	(5.902)	(4.090)	(4.190)	(4.256)	(4.225)	(3.900)	(3.745)	(3.751)	(3.702)	(3.696)
co_credit_risk				-6.327	-5.615	7.966*	13.72***	13.83***	15.92***	16.60***	14.12***	14.08***	14.03***	14.00***
				(4.454)	(4.350)	(4.041)	(4.822)	(4.942)	(5.288)	(5.085)	(4.964)	(4.965)	(4.959)	(4.960)
co_fd_yr					0.0134***	0.0132***	0.0136***	0.0137***	0.0137***	0.0128***	0.0126***	0.0126***	0.0129***	0.0129***
					(0.00326)	(0.00323)	(0.00331)	(0.00340)	(0.00335)	(0.00337)	(0.00333)	(0.00332)	(0.00335)	(0.00336)
co_rev						-0.00249***	-0.00229***	-0.00223***	-0.00193***	-0.00136***	-0.00122***	-0.00122***	-0.00117***	-0.00117***
						(0.000563)	(0.000519)	(0.000493)	(0.000402)	(0.000365)	(0.000358)	(0.000356)	(0.000346)	(0.000345)
co_E							-4.332	-7.336**	4.940	4.228	4.380	4.743	4.783	4.825
							(2.619)	(3.260)	(5.984)	(5.629)	(5.640)	(5.559)	(5.561)	(5.564)
co_E_rtg							-2.177**	-0.644	-7.355	-7.131	-7.453	-7.597	-7.584	-7.590
							(1.000)	(1.108)	(5.540)	(5.416)	(5.414)	(5.398)	(5.404)	(5.404)
co_E_disc							29.04	39.47*	-1.648	1.233	8.128	6.444	5.913	5.830
							(19.74)	(19.79)	(13.31)	(12.55)	(13.95)	(13.54)	(13.46)	(13.47)
co_S								3.230**	4.744**	4.210**	5.604**	5.442**	5.441**	5.427**
								(1.372)	(2.058)	(2.069)	(2.158)	(2.146)	(2.137)	(2.134)
co_S_rtg								-0.783	-1.801**	-1.852**	-2.577***	-2.449***	-2.402***	-2.394***
								(0.725)	(0.725)	(0.738)	(0.838)	(0.820)	(0.805)	(0.804)
co_S_disc								-19.43**	-31.33**	-27.63*	-36.93**	-35.95**	-35.98**	-35.91**
								(8.722)	(14.08)	(14.11)	(14.49)	(14.46)	(14.42)	(14.40)
co_G									-21.50*	-21.72*	-22.35*	-22.23*	-22.34*	-22.32*
									(12.36)	(12.73)	(12.75)	(12.78)	(12.78)	(12.78)
co_G_rtg									8.945	9.380	10.55*	10.47*	10.41*	10.40*
									(5.633)	(5.778)	(5.746)	(5.764)	(5.758)	(5.755)
co_G_disc									110.6	110.8	110.1	109.7	110.9	110.7
									(65.56)	(67.24)	(67.75)	(67.82)	(67.85)	(67.82)
bnk_hq_loc_ae										-32.60	-38.41*	-35.72*	-36.02*	-36.15*
										(20.68)	(20.36)	(20.43)	(20.36)	(20.34)
bnk_hq_loc_at										-14.15	-15.34	-15.16	-15.32	-15.30
										(10.51)	(10.77)	(10.72)	(10.72)	(10.70)
bnk_hq_loc_au										5.986	-0.0288	2.656	2.658	2.636
										(12.42)	(13.01)	(12.95)	(12.75)	(12.72)
bnk_hq_loc_be										6.470	6.411	6.389	6.503	6.514
										(8.260)	(8.192)	(8.200)	(8.213)	(8.209)
bnk_hq_loc_br										-31.60	-37.77**	-35.05*	-35.20*	-35.16*
										(18.71)	(18.13)	(18.42)	(18.33)	(18.31)
bnk_hq_loc_ca										-3.251	-9.061	-6.367	-6.511	-6.574
										(11.03)	(10.90)	(11.05)	(10.86)	(10.83)
bnk_hq_loc_ch										-16.79	-22.68**	-23.56**	-22.55**	-22.43**
										(9.998)	(9.864)	(10.58)	(10.12)	(10.07)
bnk_hq_loc_cn										11.69	6.979	-4.284	-10.59	-9.721
										(22.99)	(22.94)	(23.96)	(24.50)	(24.46)

bnk_hq_loc_co	-1.683	-6.864	-5.129	-5.254	-5.357
	(8.959)	(7.644)	(8.129)	(7.953)	(7.900)
bnk_hq_loc_cy	6.735	9.443	8.506	8.740	8.788
	(9.036)	(7.809)	(8.224)	(8.138)	(8.101)
bnk_hq_loc_cz	19.31**	18.75**	18.63**	18.52**	18.46**
	(9.034)	(8.974)	(8.954)	(8.930)	(8.908)
bnk_hq_loc_de	4.548	4.576	4.527	4.500	4.511
	(5.715)	(5.714)	(5.699)	(5.688)	(5.681)
bnk_hq_loc_dk	0.512	-0.397	-0.455	-0.316	-0.340
	(8.561)	(8.634)	(8.604)	(8.605)	(8.598)
bnk_hq_loc_es	-3.927	-4.072	-4.097	-4.279	-4.288
	(8.657)	(8.447)	(8.463)	(8.436)	(8.421)
bnk_hq_loc_fr	1.857	1.636	1.566	1.509	1.517
	(6.097)	(6.088)	(6.080)	(6.075)	(6.067)
bnk_hq_loc_hk	-23.56	-28.97*	-37.95**	-43.34***	-42.61***
	(14.87)	(14.45)	(14.48)	(15.48)	(15.42)
bnk_hq_loc_ie	-0.0119	0.263	0.221	0.201	0.201
	(7.011)	(6.984)	(6.979)	(6.977)	(6.969)
bnk_hq_loc_il	-5.593	-12.37	-9.664	-9.949	-10.06
	(12.57)	(11.86)	(11.95)	(11.80)	(11.75)
bnk_hq_loc_im	-16.90	-23.18*	-20.46*	-20.65*	-20.71*
	(11.05)	(11.53)	(11.38)	(11.23)	(11.20)
bnk_hq_loc_in	8.944	-7.510	-5.435	-4.827	-4.896
	(7.827)	(11.46)	(11.17)	(10.81)	(10.78)
bnk_hq_loc_it	-2.019	-1.579	-1.640	-1.738	-1.730
	(6.573)	(6.555)	(6.549)	(6.547)	(6.541)
bnk_hq_loc_jp	6.901	0.900	0.530	0.172	0.290
	(12.03)	(11.95)	(12.40)	(12.29)	(12.25)
bnk_hq_loc_kr	20.59	25.54	24.74	25.13	25.13
	(20.51)	(19.93)	(20.06)	(20.01)	(20.00)
bnk_hq_loc_kz	-15.75	-21.89	-19.16	-19.19	-19.24
	(13.94)	(14.16)	(14.12)	(14.08)	(14.06)
bnk_hq_loc_li	2.665	2.434	2.426	2.357	2.360
	(8.285)	(8.239)	(8.246)	(8.269)	(8.264)
bnk_hq_loc_lu	-1.604	-1.032	-1.126	-1.036	-1.034
	(7.895)	(7.763)	(7.756)	(7.765)	(7.757)
bnk_hq_loc_mt	11.33	10.88	10.80	10.66	10.65
	(7.105)	(6.898)	(6.869)	(6.844)	(6.831)
bnk_hq_loc_nl	-5.025	-4.780	-4.827	-4.830	-4.825
	(6.648)	(6.601)	(6.596)	(6.602)	(6.592)
bnk_hq_loc_no	4.028	4.621	4.529	4.407	4.572
	(17.72)	(17.68)	(17.68)	(17.70)	(17.71)
bnk_hq_loc_nz	-22.20*	-28.15**	-25.45**	-25.34**	-25.40**
	(11.49)	(11.08)	(11.04)	(10.85)	(10.82)
bnk_hq_loc_om	850.7***	844.2***	846.7***	846.8***	846.8***
	(135.0)	(135.4)	(135.9)	(135.8)	(135.9)
bnk_hq_loc_ph	-201.7	-208.2	-205.5	-203.6	-203.6
	(134.5)	(134.2)	(134.1)	(134.7)	(134.7)
bnk_hq_loc_pt	6.473	6.428	6.307	6.062	5.952
	(6.086)	(6.016)	(5.986)	(5.967)	(5.950)
bnk_hq_loc_ru	-11.77	-20.26	-17.46	-17.72	-17.82
	(16.35)	(16.36)	(16.46)	(16.34)	(16.29)
bnk_hq_loc_sa	-18.38	-24.31*	-21.59	-21.79	-21.84
	(13.40)	(13.94)	(13.79)	(13.71)	(13.68)
bnk_hq_loc_se	18.87	19.76	19.68	19.74	19.71
	(16.83)	(16.95)	(16.94)	(16.99)	(16.98)
bnk_hq_loc_sg	-2.660	-10.31	-13.79	-11.80	-11.55
	(19.74)	(18.44)	(18.56)	(18.29)	(18.27)

bnk_hq_loc_uk												17.02	11.00	12.19	10.17	10.24
												(10.87)	(10.03)	(10.45)	(10.22)	(10.18)
bnk_hq_loc_us												-11.28	-17.24*	-14.58	-15.96	-15.80
												(9.672)	(9.476)	(9.674)	(9.630)	(9.604)
bnk_hq_loc_za												-14.20	-19.51	-21.38	-20.13	-19.94
												(15.52)	(15.46)	(15.42)	(15.42)	(15.40)
co_hq_co2_pr													0.376**	0.357**	0.331**	0.330**
													(0.153)	(0.150)	(0.143)	(0.142)
yy_gdp_chg														0	0	0
														(0)	(6.47e-08)	(1.20e-07)
yy_infl														0	0	0
														(0)	(9.38e-08)	(1.10e-07)
li_price_s														0	0	0
														(0)	(6.26e-11)	(1.51e-10)
cob_price														0	0	0
														(0)	(2.60e-10)	(2.64e-10)
mn_price														0	0	0
														(0)	(1.18e-09)	(2.81e-09)
ni_price														0	0	0
														(0)	(1.64e-09)	(2.68e-10)
bnk_esg_nbm														18.13*	11.90	11.05
														(9.996)	(7.876)	(7.794)
bnk_esg_breg															13.98**	13.71**
															(6.116)	(6.104)
bnk_anti_esg_breg																-18.98***
																(5.104)
Constant	6.368***	13.28***	14.07***	14.08***	15.39***	18.25***	-8.761	-12.42	-11.80	-10.64	-10.11	-3.082	0.585	-1.863	-1.887	-1.888
	(1.088)	(1.858)	(4.073)	(4.080)	(3.987)	(4.294)	(7.281)	(7.810)	(8.027)	(7.200)	(7.380)	(11.40)	(10.94)	(11.41)	(11.17)	(11.15)
Observations	119,840	119,840	119,840	119,840	119,840	119,840	119,840	119,840	119,840	119,840	119,840	119,840	119,526	119,526	119,526	119,526
R-squared	0.033	0.007	0.016	0.016	0.016	0.017	0.017	0.017	0.018	0.018	0.021	0.039	0.040	0.040	0.041	0.041

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1
Results based on stata’s reghdfe OLS estimation method.
Time fixed effects treated by means of ‘absorbing’ (Correia, 2016).

Table B.16: batmat_ph—2019, 2020 & 2021 Sequential Regressions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
VARIABLES	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s	batmat_ph_s
treat	-16.54*	-0.0533	-0.0533	-2.654	-7.884***	-7.884***	-7.833***	-7.582***	-7.924***	-7.621***	-7.495***	-7.459***	-7.313***	-11.61	-16.17	-14.18	-14.92	-14.84
	(8.444)	(2.059)	(2.059)	(1.958)	(2.447)	(2.446)	(2.440)	(2.417)	(2.462)	(2.445)	(2.384)	(2.380)	(2.437)	(10.96)	(10.66)	(10.90)	(10.81)	(10.78)
after19_20	-3.240*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	(1.968)	(0)	(0)	(4.81e-08)	(5.52e-08)	(9.01e-08)	(1.34e-07)	(1.12e-08)	(2.97e-07)	(4.13e-07)	(2.28e-07)	(4.06e-08)	(4.20e-07)	(2.79e-08)	(6.91e-08)	(1.30e-06)	(7.65e-07)	(1.63e-06)
treat_after19_20	2.562	2.467	-5.794***	-6.500***	-6.493***	-6.493***	-6.521***	-6.512***	-6.511***	-6.659***	-6.619***	-6.578***	-6.756***	-6.546***	-7.073***	-6.938***	-6.548***	-6.557***
	(2.142)	(2.820)	(1.069)	(1.088)	(1.147)	(1.148)	(1.141)	(1.159)	(1.118)	(1.184)	(1.283)	(1.320)	(1.256)	(1.337)	(1.460)	(1.494)	(1.505)	(1.495)
after20_21		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		(0)	(0)	(3.57e-08)	(2.23e-07)	(2.13e-07)	(7.62e-08)	(1.53e-07)	(2.71e-07)	(2.92e-08)	(2.82e-07)	(3.14e-07)	(5.75e-07)	(5.05e-08)	(2.15e-07)	(3.01e-07)	(7.41e-07)	(6.06e-07)
treat_after20_21		1.867	-6.287***	-7.102***	-7.094***	-7.089***	-6.691***	-6.723***	-6.724***	-7.173***	-7.187***	-7.195***	-7.400***	-7.173***	-7.715***	-7.512***	-6.992***	-7.007***
		(2.820)	(1.017)	(1.032)	(1.132)	(1.133)	(1.122)	(1.162)	(1.139)	(1.191)	(1.270)	(1.306)	(1.243)	(1.366)	(1.483)	(1.514)	(1.535)	(1.522)
after21			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			(0)	(1.63e-09)	(3.45e-08)	(1.12e-07)	(7.47e-08)	(1.37e-07)	(7.26e-08)	(1.39e-07)	(5.60e-08)	(5.05e-08)	(2.32e-07)	(3.60e-07)	(5.39e-08)	(9.61e-08)	(1.48e-07)	(1.74e-08)
treat_after21			-23.17***	-24.45***	-24.44***	-24.43***	-24.07***	-24.09***	-24.09***	-23.90***	-23.68***	-23.75***	-22.60***	-22.26***	-27.38***	-25.12***	-23.38***	-23.84***
			(5.357)	(5.326)	(5.359)	(5.331)	(5.283)	(5.290)	(5.290)	(5.263)	(5.114)	(5.135)	(4.747)	(4.875)	(6.167)	(5.759)	(5.284)	(5.350)
all_ph_s				0.00463***	0.00459***	0.00458***	0.00464***	0.00459***	0.00459***	0.00456***	0.00453***	0.00451***	0.00400***	0.00299	0.00294	0.00295	0.00295	0.00293
				(0.00137)	(0.00119)	(0.00119)	(0.00119)	(0.00121)	(0.00121)	(0.00121)	(0.00123)	(0.00123)	(0.00134)	(0.00181)	(0.00180)	(0.00180)	(0.00180)	(0.00180)
co_hq_loc_au					9.703	9.700	9.191	6.898	7.943	13.23	11.16	9.671	8.185	-0.627	-0.0833	-0.212	-0.598	-0.572
					(8.864)	(8.858)	(8.752)	(7.909)	(8.037)	(8.940)	(9.899)	(8.759)	(9.129)	(6.622)	(6.721)	(6.706)	(6.667)	(6.666)
co_hq_loc_br					-12.39***	-12.39***	-11.43***	-11.11***	-10.49***	-1.535	1.878	1.222	-21.49**	-22.02**	-19.45*	-19.66*	-20.42*	-20.47*
					(3.847)	(3.847)	(3.822)	(3.840)	(3.829)	(4.507)	(6.248)	(5.518)	(10.53)	(10.35)	(10.61)	(10.57)	(10.56)	(10.56)
co_hq_loc_ca					-13.48***	-13.48***	-14.43***	-16.33***	-15.58***	-12.63***	-10.64**	-12.71**	-14.37**	-13.29**	-16.59**	-16.59**	-16.60**	-16.54**
					(3.837)	(3.837)	(3.847)	(4.276)	(4.206)	(4.095)	(4.381)	(4.817)	(5.882)	(5.772)	(6.226)	(6.177)	(6.170)	(6.157)
co_hq_loc_ch					-7.943*	-7.948*	-9.311**	-7.704*	-7.445	93.18***	87.27***	87.16***	72.67***	47.92***	0.910	2.911	4.389	4.469
					(4.451)	(4.450)	(4.393)	(4.543)	(4.569)	(25.33)	(24.12)	(23.70)	(18.58)	(17.35)	(19.27)	(18.86)	(18.70)	(18.63)
co_hq_loc_cn					-6.487	-6.350	-7.821*	-10.43**	-10.19**	-4.476	-4.887	-6.357	-14.05*	-16.84**	-17.26**	-17.34**	-17.42**	-17.40**
					(4.679)	(4.255)	(4.177)	(4.520)	(4.502)	(4.610)	(4.965)	(5.070)	(6.985)	(7.104)	(7.215)	(7.191)	(7.201)	(7.192)
co_hq_loc_fr					-17.90***	-17.89***	-19.27***	-18.36***	-18.47***	-19.00***	-17.61***	-21.08***	-28.12***	-29.04***	-43.84***	-42.90***	-42.32***	-42.30***
					(4.313)	(4.315)	(4.375)	(4.443)	(4.401)	(4.319)	(4.641)	(5.049)	(6.653)	(7.085)	(9.803)	(9.607)	(9.398)	(9.391)
co_hq_loc_de					-19.23	-19.19	-15.90	-19.19	-17.01	-7.100	0.616	-1.098	-13.18	-17.41	-32.58**	-31.75**	-31.19**	-31.14**
					(12.47)	(12.49)	(12.74)	(12.56)	(12.59)	(12.66)	(13.19)	(13.13)	(12.06)	(13.60)	(14.12)	(14.01)	(13.99)	(13.96)
co_hq_loc_es					-48.54***	-48.53***	-50.16***	-52.68***	-51.84***	-47.37***	-47.76***	-50.37***	-51.88***	-56.41***	-69.97***	-69.29***	-68.65***	-68.50***
					(9.672)	(9.687)	(9.759)	(9.555)	(9.481)	(9.343)	(9.930)	(10.33)	(11.39)	(12.56)	(14.98)	(14.74)	(14.57)	(14.55)
co_hq_loc_hk					-3.063	-3.067	-4.397	-7.237	-6.954	-2.580	-4.058	-5.490	-5.807	0.383	1.903	1.755	2.782	3.142
					(5.198)	(5.204)	(5.114)	(4.868)	(4.848)	(5.055)	(5.163)	(5.103)	(5.993)	(6.670)	(6.891)	(6.868)	(7.082)	(7.143)
co_hq_loc_id					82.64	82.64	81.20	79.63	80.07	82.10	79.61	78.21	78.58	84.00	88.86	88.61	88.65	88.70
					(68.94)	(68.94)	(68.88)	(69.65)	(69.64)	(68.92)	(68.06)	(68.05)	(68.04)	(67.74)	(68.50)	(68.49)	(68.43)	(68.45)
co_hq_loc_im					24.82**	24.81**	23.50**	20.65**	20.82**	24.83**	23.37**	21.94**	21.52**	27.50*	30.09**	29.89**	26.89**	26.78**
					(10.27)	(10.28)	(10.07)	(9.202)	(8.660)	(9.227)	(9.086)	(8.199)	(8.900)	(14.23)	(14.03)	(14.23)	(12.69)	(12.70)
co_hq_loc_in					-18.44***	-18.44***	-19.65***	-22.03***	-21.29***	-15.77***	-18.11***	-19.93***	-25.34***	-28.03**	-36.14***	-34.77***	-34.53***	-34.46***
					(4.917)	(4.915)	(4.952)	(5.241)	(5.177)	(5.094)	(5.346)	(5.967)	(8.512)	(11.02)	(10.55)	(10.54)	(10.50)	(10.47)
co_hq_loc_jp					-19.76***	-19.75***	-18.68***	-21.73***	-19.59***	-14.26***	-14.57***	-16.47***	-26.77***	-34.37***	-33.08***	-33.13***	-33.12***	-33.07***
					(4.509)	(4.520)	(4.502)	(4.873)	(4.727)	(4.687)	(5.099)	(5.301)	(9.137)	(11.04)	(10.76)	(10.75)	(10.81)	(10.78)
co_hq_loc_ke					-14.09***	-14.09***	-15.41***	-18.26***	-17.98***	-13.98***	-15.43***	-16.86***	-17.28***	-28.56**	-25.91**	-26.13**	-26.54**	-26.55**
					(3.864)	(3.865)	(3.914)	(4.800)	(4.759)	(4.514)	(4.835)	(5.446)	(6.138)	(11.46)	(11.45)	(11.42)	(11.45)	(11.44)
co_hq_loc_kr					-10.40	-10.29	9.064	4.048	4.822	4.478	2.821	1.121	-12.05	-23.19	-40.69**	-39.44**	-39.02**	-38.98**
					(8.608)	(8.762)	(10.16)	(8.664)	(8.687)	(7.733)	(7.560)	(7.316)	(11.68)	(19.18)	(18.77)	(18.84)	(18.73)	(18.72)
co_hq_loc_kz					-3.066	-3.060	-4.512	-7.524	1.895	5.575	4.240	2.890	2.045	5.584	7.238	7.024	6.987	7.014
					(6.179)	(6.172)	(6.050)	(6.171)	(5.940)	(6.185)	(6.413)	(6.176)	(6.596)	(8.181)	(8.400)	(8.376)	(8.428)	(8.430)
co_hq_loc_lu					-16.64***	-16.64***	-17.16***	-16.10***	-15.63***	-19.24***	-21.84***	-23.95***	-36.80***	-34.66***	-47.60***	-46.78***	-45.68***	-45.66***
					(4.067)	(4.067)	(4.038)	(4.088)	(4.068)	(4.152)	(4.448)	(4.945)	(10.42)	(10.51)	(12.18)	(12.07)	(11.81)	(11.80)
co_hq_loc_mx					-15.82***	-15.82***	-17.16***	-20.00***	-18.82***	-13.73***	-16.38***	-19.26***	-76.46**	-71.66*	-71.13*	-70.94*	-70.40*	-70.47*
					(3.894)	(3.895)	(3.956)	(4.782)	(4.642)	(4.395)	(4.615)	(5.482)	(37.05)	(36.85)	(37.14)	(37.17)	(37.15)	(37.16)

co_hq_loc_nl	-18.38*	-18.37*	-17.94*	-16.92	-17.07	-21.61**	-26.66**	-28.04**	-39.72***	-42.07***	-56.14***	-55.12***	-53.70***	-53.70***
	(10.19)	(10.19)	(10.22)	(10.22)	(10.26)	(10.17)	(10.33)	(10.35)	(12.50)	(13.91)	(15.04)	(14.99)	(14.78)	(14.75)
co_hq_loc_pe	-14.37***	-14.37***	-15.44***	-18.31***	-17.39***	-12.95***	-13.80***	-14.99***	-51.15**	-50.87**	-48.92**	-48.77**	-49.48**	-49.46**
	(3.854)	(3.854)	(3.886)	(4.747)	(4.638)	(4.419)	(4.508)	(4.945)	(22.91)	(23.73)	(23.94)	(23.97)	(24.01)	(24.00)
co_hq_loc_ph	131.1*	131.1*	129.7*	126.8*	127.6*	131.6*	130.2*	128.8*	129.0*	260.7*	263.7*	263.4*	260.9*	260.9*
	(66.76)	(66.76)	(66.69)	(66.70)	(66.71)	(66.77)	(66.67)	(66.67)	(67.15)	(138.9)	(138.8)	(138.8)	(139.8)	(139.8)
co_hq_loc_pl	-13.60	-13.59	-14.11	-17.02*	-16.08*	-9.089	-5.771	-9.166	-31.96**	-32.57*	-48.01***	-46.99**	-46.47**	-46.36**
	(8.827)	(8.832)	(8.877)	(8.785)	(8.809)	(8.737)	(8.816)	(8.806)	(14.70)	(17.11)	(17.39)	(17.32)	(17.24)	(17.21)
co_hq_loc_ru	-14.14***	-14.15***	-15.43***	-18.28***	-17.99***	-8.274*	-11.10*	-13.63*	-33.86*	-31.04	-29.32	-29.36	-29.79	-29.70
	(3.863)	(3.864)	(3.914)	(4.798)	(4.755)	(4.545)	(6.328)	(7.584)	(17.63)	(19.43)	(19.81)	(19.72)	(19.73)	(19.69)
co_hq_loc_se	20.54	20.55	20.67	17.57	18.68	23.61*	24.98*	24.15*	17.79	12.49	-2.046	-1.431	-0.997	-0.976
	(13.56)	(13.56)	(13.47)	(13.35)	(13.33)	(13.41)	(13.50)	(13.41)	(13.88)	(11.96)	(12.69)	(12.61)	(12.61)	(12.61)
co_hq_loc_tw	-48.54***	-48.53***	-50.22***	-52.73***	-52.09***	-46.72***	-47.37***	-48.71***	-56.32***	-60.78***	-57.59***	-57.87***	-58.46***	-58.30***
	(9.672)	(9.685)	(9.758)	(9.555)	(9.497)	(9.340)	(10.23)	(10.22)	(12.98)	(15.22)	(14.92)	(14.93)	(15.06)	(15.02)
co_hq_loc_uk	19.25**	19.25**	18.46**	15.93**	17.27**	21.72**	20.39**	19.12**	19.11**	9.148	-12.70	-11.75	-10.23	-10.20
	(8.076)	(8.072)	(7.905)	(7.359)	(7.564)	(7.983)	(7.525)	(7.035)	(7.181)	(6.218)	(7.856)	(7.777)	(7.464)	(7.463)
co_hq_loc_us	-13.60***	-13.58***	-11.98***	-12.36***	-11.51***	-11.80***	-14.83***	-15.82***	-19.59***	-19.16**	-17.57**	-17.76**	-17.84**	-17.76**
	(3.847)	(3.864)	(3.868)	(3.927)	(3.897)	(3.871)	(4.128)	(4.902)	(7.043)	(7.049)	(7.010)	(6.983)	(6.996)	(6.982)
co_hq_loc_vg	-10.10**	-10.11**	-11.42***	-14.27***	-14.07***	-10.07**	-11.53**	-12.96**	-13.38**	-24.64**	-22.00*	-22.22*	-22.63**	-22.64**
	(4.027)	(4.029)	(4.011)	(4.614)	(4.594)	(4.437)	(4.655)	(5.065)	(5.825)	(10.93)	(11.08)	(11.05)	(11.06)	(11.07)
co_hq_loc_za		0	0	0	0	0	0	0	0	0	0	0	0	0
		(0)	(0)	(2.38e-09)	(0)	(0)	(0)	(0)	(8.86e-09)	(2.16e-10)	(1.49e-09)	(3.84e-08)	(1.14e-09)	(2.44e-08)
co_share_pr_s		-0.00618	-0.000455	-0.00135	-0.00136	-0.00494	0.00354	0.00323	0.0407	0.0298	0.101	0.0974	0.0895	0.0902
		(0.0910)	(0.0907)	(0.0908)	(0.0908)	(0.0909)	(0.0896)	(0.0898)	(0.0884)	(0.0867)	(0.0878)	(0.0877)	(0.0870)	(0.0869)
co_div			-19.79***	-17.83***	-17.71***	-12.00***	-11.31**	-11.51**	-11.07**	-8.921**	-8.778**	-8.887**	-8.661**	-8.652**
			(6.572)	(5.945)	(5.897)	(4.091)	(4.194)	(4.259)	(4.228)	(3.898)	(3.740)	(3.746)	(3.698)	(3.692)
co_credit_risk				-6.324	-5.612	7.938*	13.71***	13.82***	15.92***	16.60***	14.09***	14.05***	14.01***	13.98***
				(4.454)	(4.350)	(4.040)	(4.822)	(4.941)	(5.287)	(5.083)	(4.961)	(4.961)	(4.956)	(4.957)
co_fd_yr					0.0134***	0.0132***	0.0136***	0.0137***	0.0137***	0.0128***	0.0126***	0.0126***	0.0129***	0.0129***
					(0.00326)	(0.00323)	(0.00331)	(0.00340)	(0.00335)	(0.00337)	(0.00333)	(0.00333)	(0.00335)	(0.00336)
co_rev						-0.00249***	-0.00228***	-0.00222***	-0.00192***	-0.00136***	-0.00121***	-0.00121***	-0.00117***	-0.00116***
						(0.000562)	(0.000518)	(0.000492)	(0.000401)	(0.000364)	(0.000357)	(0.000356)	(0.000345)	(0.000344)
co_E							-4.317	-7.327**	4.933	4.221	4.369	4.726	4.767	4.810
							(2.617)	(3.261)	(5.980)	(5.625)	(5.636)	(5.555)	(5.557)	(5.559)
co_E_rtg							-2.168**	-0.631	-7.332	-7.108	-7.425	-7.569	-7.558	-7.564
							(1.000)	(1.107)	(5.537)	(5.412)	(5.411)	(5.394)	(5.400)	(5.400)
co_E_disc							28.87	39.32*	-1.745	1.136	8.125	6.469	5.940	5.858
							(19.73)	(19.79)	(13.31)	(12.55)	(13.94)	(13.53)	(13.45)	(13.45)
co_S								3.240**	4.749**	4.215**	5.631**	5.469**	5.466**	5.453**
								(1.373)	(2.059)	(2.070)	(2.161)	(2.149)	(2.140)	(2.136)
co_S_rtg								-0.785	-1.800**	-1.851**	-2.587***	-2.459***	-2.412***	-2.405***
								(0.724)	(0.726)	(0.739)	(0.840)	(0.821)	(0.807)	(0.805)
co_S_disc								-19.51**	-31.37**	-27.67*	-37.12**	-36.13**	-36.15**	-36.09**
								(8.730)	(14.09)	(14.12)	(14.51)	(14.48)	(14.44)	(14.42)
co_G									-21.48*	-21.70*	-22.33*	-22.21*	-22.32*	-22.30*
									(12.36)	(12.72)	(12.75)	(12.78)	(12.78)	(12.77)
co_G_rtg									8.920	9.354	10.53*	10.46*	10.40*	10.39*
									(5.631)	(5.776)	(5.746)	(5.763)	(5.757)	(5.754)
co_G_disc									110.6	110.8	110.0	109.7	110.8	110.6
									(65.55)	(67.23)	(67.75)	(67.82)	(67.84)	(67.81)
bnk_hq_loc_ae										-32.64	-38.56*	-35.91*	-36.20*	-36.34*
										(20.68)	(20.37)	(20.43)	(20.36)	(20.34)
bnk_hq_loc_at										-14.15	-15.35	-15.17	-15.33	-15.31
										(10.52)	(10.78)	(10.73)	(10.73)	(10.71)
bnk_hq_loc_au										5.941	-0.192	2.453	2.468	2.442
										(12.42)	(13.02)	(12.94)	(12.75)	(12.71)
bnk_hq_loc_be										6.462	6.382	6.363	6.479	6.489
										(8.271)	(8.200)	(8.206)	(8.218)	(8.215)

bnk_hq_loc_br	-31.60	-37.88**	-35.20*	-35.34*	-35.31*
	(18.70)	(18.13)	(18.42)	(18.34)	(18.31)
bnk_hq_loc_ca	-3.286	-9.210	-6.558	-6.687	-6.756
	(11.02)	(10.90)	(11.04)	(10.86)	(10.82)
bnk_hq_loc_ch	-16.82	-22.82**	-23.68**	-22.67**	-22.55**
	(9.993)	(9.875)	(10.58)	(10.11)	(10.07)
bnk_hq_loc_cn	11.66	6.846	-4.170	-10.43	-9.534
	(22.98)	(22.94)	(23.95)	(24.49)	(24.45)
bnk_hq_loc_co	-1.697	-6.972	-5.262	-5.377	-5.485
	(8.959)	(7.629)	(8.099)	(7.925)	(7.870)
bnk_hq_loc_cy	6.733	9.486	8.564	8.792	8.842
	(9.056)	(7.812)	(8.214)	(8.129)	(8.092)
bnk_hq_loc_cz	19.30**	18.74**	18.62**	18.51**	18.45**
	(9.039)	(8.978)	(8.955)	(8.930)	(8.908)
bnk_hq_loc_de	4.541	4.560	4.513	4.488	4.499
	(5.720)	(5.721)	(5.705)	(5.694)	(5.686)
bnk_hq_loc_dk	0.522	-0.412	-0.467	-0.328	-0.354
	(8.567)	(8.643)	(8.611)	(8.610)	(8.604)
bnk_hq_loc_es	-3.933	-4.083	-4.106	-4.285	-4.295
	(8.670)	(8.483)	(8.492)	(8.462)	(8.447)
bnk_hq_loc_fr	1.847	1.612	1.546	1.491	1.499
	(6.106)	(6.098)	(6.088)	(6.083)	(6.074)
bnk_hq_loc_hk	-23.57	-29.07*	-37.86**	-43.20***	-42.46***
	(14.86)	(14.45)	(14.47)	(15.48)	(15.41)
bnk_hq_loc_ie	-0.0209	0.255	0.215	0.196	0.196
	(7.014)	(6.992)	(6.986)	(6.984)	(6.976)
bnk_hq_loc_il	-5.639	-12.55	-9.882	-10.15	-10.27
	(12.58)	(11.87)	(11.95)	(11.80)	(11.74)
bnk_hq_loc_im	-16.93	-23.33*	-20.65*	-20.83*	-20.89*
	(11.05)	(11.55)	(11.39)	(11.24)	(11.21)
bnk_hq_loc_in	8.892	-7.819	-5.756	-5.132	-5.210
	(7.822)	(11.47)	(11.18)	(10.81)	(10.79)
bnk_hq_loc_it	-2.031	-1.603	-1.660	-1.756	-1.749
	(6.580)	(6.564)	(6.556)	(6.554)	(6.548)
bnk_hq_loc_jp	6.869	0.751	0.403	0.0575	0.175
	(12.03)	(11.95)	(12.39)	(12.28)	(12.25)
bnk_hq_loc_kr	20.52	25.53	24.74	25.13	25.12
	(20.51)	(19.94)	(20.07)	(20.01)	(20.00)
bnk_hq_loc_kz	-15.78	-22.05	-19.36	-19.38	-19.43
	(13.94)	(14.16)	(14.11)	(14.08)	(14.05)
bnk_hq_loc_li	2.659	2.407	2.403	2.336	2.339
	(8.291)	(8.249)	(8.253)	(8.274)	(8.270)
bnk_hq_loc_lu	-1.612	-1.047	-1.138	-1.048	-1.046
	(7.903)	(7.774)	(7.765)	(7.772)	(7.765)
bnk_hq_loc_mt	11.31	10.86	10.78	10.64	10.63
	(7.111)	(6.900)	(6.870)	(6.844)	(6.831)
bnk_hq_loc_nl	-5.037	-4.791	-4.836	-4.838	-4.834
	(6.659)	(6.616)	(6.608)	(6.612)	(6.603)
bnk_hq_loc_no	3.974	4.564	4.477	4.359	4.527
	(17.73)	(17.69)	(17.68)	(17.71)	(17.71)
bnk_hq_loc_nz	-22.23*	-28.30**	-25.64**	-25.52**	-25.58**
	(11.49)	(11.09)	(11.04)	(10.84)	(10.82)
bnk_hq_loc_om	850.7***	844.1***	846.6***	846.7***	846.7***
	(135.1)	(135.5)	(136.1)	(136.0)	(136.1)
bnk_hq_loc_ph	-201.7	-208.4	-205.6	-203.8	-203.8
	(134.5)	(134.1)	(134.1)	(134.7)	(134.7)
bnk_hq_loc_pt	6.463	6.413	6.296	6.055	5.942
	(6.094)	(6.038)	(6.000)	(5.983)	(5.966)

bnk_hq_loc_ru														-11.77	-20.41	-17.65	-17.89	-18.00
														(16.33)	(16.35)	(16.46)	(16.33)	(16.28)
bnk_hq_loc_sa														-18.42	-24.46*	-21.78	-21.97	-22.03
														(13.40)	(13.95)	(13.80)	(13.71)	(13.69)
bnk_hq_loc_se														18.86	19.76	19.68	19.73	19.70
														(16.82)	(16.95)	(16.93)	(16.98)	(16.98)
bnk_hq_loc_sg														-2.697	-10.46	-13.86	-11.88	-11.63
														(19.74)	(18.44)	(18.56)	(18.29)	(18.27)
bnk_hq_loc_uk														16.99	10.85	12.02	10.04	10.10
														(10.86)	(10.03)	(10.44)	(10.21)	(10.17)
bnk_hq_loc_us														-11.31	-17.39*	-14.77	-16.12	-15.96
														(9.666)	(9.485)	(9.676)	(9.631)	(9.603)
bnk_hq_loc_za														-14.22	-19.64	-21.45	-20.21	-20.02
														(15.52)	(15.47)	(15.42)	(15.42)	(15.40)
co_hq_co2_pr															0.381**	0.362**	0.336**	0.335**
															(0.154)	(0.151)	(0.143)	(0.143)
yy_gdp_chg																0	0	0
																(8.06e-08)	(8.33e-08)	(6.75e-08)
yy_infl																0	0	0
																(3.36e-08)	(8.79e-08)	(3.00e-08)
li_price_s																0	0	0
																(0)	(1.09e-10)	(1.04e-10)
cob_price																0	0	0
																(1.35e-10)	(2.40e-10)	(0)
mn_price																0	0	0
																(2.04e-09)	(2.92e-09)	(6.35e-10)
ni_price																0	0	0
																(0)	(0)	(0)
bnk_esg_nbm																17.76*	11.61	10.73
																(9.950)	(7.836)	(7.747)
bnk_esg_breg																	13.85**	13.56**
																	(6.096)	(6.083)
bnk_anti_esg_breg																		-19.34***
																		(5.313)
Constant	16.02***	13.30***	15.00***	13.28***	14.07***	14.07***	15.39***	18.24***	-8.766	-12.42	-11.78	-10.62	-10.08	-3.019	0.737	-1.675	-1.712	-1.708
	(2.029)	(1.867)	(1.853)	(1.856)	(4.082)	(4.089)	(3.995)	(4.296)	(7.296)	(7.825)	(8.040)	(7.211)	(7.390)	(11.39)	(10.95)	(11.41)	(11.17)	(11.15)
Observations	119,840	119,840	119,840	119,840	119,840	119,840	119,840	119,840	119,840	119,840	119,840	119,840	119,840	119,840	119,526	119,526	119,526	119,526
R-squared	0.029	0.007	0.006	0.008	0.016	0.016	0.016	0.017	0.017	0.017	0.018	0.018	0.021	0.039	0.040	0.040	0.041	0.041

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1
Results based on stata’s reghdfe OLS estimation method.
Time fixed effects treated by means of ‘absorbing’ (Correia, 2016).

Table B.17: batmat_ph—2019 & 2021 Baseline Regression

VARIABLES	(1) batmat_ph Contemporaneous	(2) batmat_ph Lagged 1Q	(3) batmat_ph Lagged 2Q	(4) batmat_ph Lagged 3Q
treat	-14.84	-15.30	-15.86	-16.50
	(10.78)	(11.10)	(11.45)	(11.83)
after19_21	0			
	(1.81e-06)			
after21	0			
	(1.53e-06)			
treat_after19_21	-6.737***			
	(1.494)			
treat_after21	-23.84***			
	(5.350)			
all_ph_s	0.00293	0.00293	0.00292	0.00292
	(0.00180)	(0.00183)	(0.00187)	(0.00190)
co_hq_loc_au	-0.572	-1.341	-2.198	-3.189
	(6.666)	(6.734)	(6.801)	(6.873)
co_hq_loc_br	-20.47*	-21.82*	-23.28*	-24.89*
	(10.56)	(11.09)	(11.70)	(12.36)
co_hq_loc_ca	-16.54**	-17.74***	-19.02***	-20.44***
	(6.157)	(6.319)	(6.508)	(6.717)
co_hq_loc_ch	4.467	3.383	1.536	-0.608
	(18.63)	(18.95)	(19.34)	(19.88)
co_hq_loc_cn	-17.40**	-18.68**	-20.10**	-21.72**
	(7.192)	(7.554)	(7.986)	(8.469)
co_hq_loc_fr	-42.30***	-43.49***	-44.76***	-46.00***
	(9.391)	(9.628)	(9.889)	(10.19)
co_hq_loc_de	-31.14**	-32.14**	-33.31**	-34.46**
	(13.96)	(14.28)	(14.63)	(15.01)
co_hq_loc_es	-68.50***	-70.75***	-73.21***	-75.86***
	(14.55)	(14.87)	(15.23)	(15.63)
co_hq_loc_hk	3.142	2.560	1.922	1.155
	(7.143)	(7.300)	(7.465)	(7.670)
co_hq_loc_id	88.70	90.61	92.65	94.74
	(68.45)	(70.39)	(72.48)	(74.70)
co_hq_loc_im	26.78**	26.85**	26.90*	26.88*
	(12.70)	(13.10)	(13.65)	(14.03)
co_hq_loc_in	-34.46***	-35.86***	-37.43***	-39.20***
	(10.47)	(10.91)	(11.42)	(12.00)
co_hq_loc_jp	-33.07***	-34.89***	-36.89***	-39.10***
	(10.78)	(11.31)	(11.92)	(12.59)
co_hq_loc_ke	-26.55**	-28.03**	-29.64**	-31.42**
	(11.44)	(11.93)	(12.49)	(13.09)
co_hq_loc_kr	-38.98**	-39.62**	-40.56*	-41.69*
	(18.72)	(19.42)	(20.20)	(20.98)
co_hq_loc_kz	7.014	6.579	6.097	5.492
	(8.430)	(8.680)	(8.965)	(9.283)
co_hq_loc_lu	-45.66***	-47.81***	-50.15***	-52.75***
	(11.80)	(12.45)	(13.21)	(14.08)
co_hq_loc_mx	-70.47*	-73.26*	-76.32*	-79.76*
	(37.16)	(38.63)	(40.28)	(42.11)
co_hq_loc_nl	-53.70***	-54.86***	-56.32***	-58.02***
	(14.75)	(15.15)	(15.61)	(16.16)
co_hq_loc_pe	-49.46**	-51.47**	-53.66**	-56.08**
	(24.00)	(24.92)	(25.95)	(27.07)
co_hq_loc_ph	260.9*	266.6*	272.5*	278.7*
	(139.8)	(144.1)	(148.7)	(153.6)
co_hq_loc_pl	-46.36**	-48.09**	-50.05**	-52.10**
	(17.21)	(17.87)	(18.61)	(19.43)
co_hq_loc_ru	-29.70	-31.41	-33.40	-35.64
	(19.69)	(20.49)	(21.47)	(22.57)
co_hq_loc_se	-0.976	-1.831	-2.821	-3.992
	(12.61)	(12.94)	(13.35)	(13.82)
co_hq_loc_tw	-58.30***	-60.74***	-63.33***	-66.22***
	(15.02)	(15.64)	(16.34)	(17.12)

co_hq_loc_uk	-10.20	-10.55	-10.98	-11.51
	(7.463)	(7.501)	(7.552)	(7.641)
co_hq_loc_us	-17.76**	-18.85**	-20.01**	-21.42**
	(6.981)	(7.316)	(7.710)	(8.156)
co_hq_loc_vg	-22.64**	-24.01**	-25.49**	-27.14**
	(11.07)	(11.55)	(12.11)	(12.72)
co_hq_loc_za	0	0	0	0
	(9.71e-08)	(1.03e-07)	(8.71e-08)	(7.89e-08)
co_share_pr_s	0.0901	0.0926	0.0958	0.0999
	(0.0869)	(0.0868)	(0.0867)	(0.0866)
co_div	-8.653**	-8.923**	-9.122**	-9.290**
	(3.692)	(3.809)	(3.905)	(3.966)
co_credit_risk	13.98***	14.10***	14.08**	14.02**
	(4.957)	(5.079)	(5.215)	(5.369)
co_fd_yr	0.0129***	0.0133***	0.0137***	0.0142***
	(0.00336)	(0.00344)	(0.00353)	(0.00362)
co_rev	-0.00116***	-0.00115***	-0.00113***	-0.00110***
	(0.000344)	(0.000352)	(0.000361)	(0.000370)
co_E	4.810	4.974	5.170	5.463
	(5.559)	(5.740)	(5.927)	(6.170)
co_E_rtg	-7.564	-7.682	-7.847	-8.140
	(5.400)	(5.571)	(5.759)	(6.011)
co_E_disc	5.858	4.926	4.391	3.894
	(13.45)	(14.05)	(14.64)	(15.24)
co_S	5.453**	5.643**	5.867**	6.060**
	(2.136)	(2.185)	(2.247)	(2.315)
co_S_rtg	-2.405***	-2.410***	-2.440***	-2.429***
	(0.805)	(0.825)	(0.849)	(0.877)
co_S_disc	-36.09**	-37.33**	-38.83**	-40.14**
	(14.42)	(14.77)	(15.23)	(15.74)
co_G	-22.30*	-22.97*	-23.70*	-24.53*
	(12.77)	(13.22)	(13.72)	(14.27)
co_G_rtg	10.39*	10.70*	11.04*	11.42*
	(5.754)	(5.980)	(6.221)	(6.488)
co_G_disc	110.6	114.1	117.8	122.1
	(67.81)	(70.09)	(72.62)	(75.43)
bnk_hq_loc_ae	-36.34*	-37.16*	-38.06*	-39.00*
	(20.34)	(20.92)	(21.55)	(22.23)
bnk_hq_loc_at	-15.31	-15.82	-16.40	-16.98
	(10.71)	(11.04)	(11.40)	(11.78)
bnk_hq_loc_au	2.442	2.740	3.041	3.390
	(12.71)	(13.05)	(13.42)	(13.83)
bnk_hq_loc_be	6.489	6.659	6.896	7.217
	(8.215)	(8.452)	(8.714)	(9.010)
bnk_hq_loc_br	-35.31*	-36.12*	-37.01*	-38.00*
	(18.31)	(18.94)	(19.63)	(20.41)
bnk_hq_loc_ca	-6.756	-6.722	-6.716	-6.674
	(10.82)	(11.17)	(11.55)	(11.98)
bnk_hq_loc_ch	-22.55**	-22.98**	-23.46**	-23.92**
	(10.07)	(10.38)	(10.73)	(11.12)
bnk_hq_loc_cn	-9.534	-9.432	-9.342	-9.186
	(24.45)	(25.24)	(26.10)	(27.04)
bnk_hq_loc_co	-5.485	-5.281	-5.012	-4.756
	(7.869)	(8.189)	(8.548)	(8.937)
bnk_hq_loc_cy	8.842	8.883	8.946	9.057
	(8.092)	(8.366)	(8.668)	(8.978)
bnk_hq_loc_cz	18.45**	18.90**	19.41**	19.88*
	(8.908)	(9.198)	(9.495)	(9.789)
bnk_hq_loc_de	4.499	4.587	4.720	4.897
	(5.686)	(5.830)	(5.975)	(6.117)
bnk_hq_loc_dk	-0.354	-0.297	-0.253	-0.187
	(8.604)	(8.812)	(9.046)	(9.291)
bnk_hq_loc_es	-4.295	-4.534	-4.753	-4.901
	(8.447)	(8.653)	(8.881)	(9.153)
bnk_hq_loc_fr	1.499	1.453	1.439	1.457
	(6.074)	(6.221)	(6.373)	(6.527)
bnk_hq_loc_hk	-42.46***	-43.51***	-44.67**	-45.88**
	(15.41)	(15.91)	(16.46)	(17.06)
bnk_hq_loc_ie	0.196	0.126	0.0858	0.0657

	(6.976)	(7.158)	(7.347)	(7.539)
bnk_hq_loc_il	-10.27	-10.27	-10.27	-10.27
	(11.74)	(12.20)	(12.73)	(13.30)
bnk_hq_loc_im	-20.89*	-21.30*	-21.75*	-22.20*
	(11.21)	(11.53)	(11.89)	(12.28)
bnk_hq_loc_in	-5.210	-4.779	-4.349	-3.814
	(10.79)	(11.06)	(11.36)	(11.71)
bnk_hq_loc_it	-1.749	-1.884	-1.993	-2.062
	(6.547)	(6.704)	(6.870)	(7.044)
bnk_hq_loc_jp	0.175	0.327	0.451	0.604
	(12.25)	(12.63)	(13.06)	(13.53)
bnk_hq_loc_kr	25.12	24.83	24.78	24.82
	(20.00)	(20.49)	(21.03)	(21.57)
bnk_hq_loc_kz	-19.43	-19.77	-20.16	-20.53
	(14.05)	(14.48)	(14.94)	(15.46)
bnk_hq_loc_li	2.339	2.335	2.378	2.524
	(8.270)	(8.502)	(8.764)	(9.068)
bnk_hq_loc_lu	-1.046	-1.106	-1.125	-1.109
	(7.765)	(7.934)	(8.114)	(8.301)
bnk_hq_loc_mt	10.63	10.86	11.14	11.49
	(6.831)	(7.034)	(7.252)	(7.462)
bnk_hq_loc_nl	-4.834	-5.045	-5.231	-5.405
	(6.603)	(6.767)	(6.936)	(7.108)
bnk_hq_loc_no	4.527	5.071	5.709	6.416
	(17.71)	(18.23)	(18.78)	(19.37)
bnk_hq_loc_nz	-25.58**	-26.03**	-26.52**	-27.01**
	(10.82)	(11.16)	(11.54)	(11.97)
bnk_hq_loc_om	846.7***	871.3***	897.3***	925.0***
	(136.1)	(138.7)	(141.4)	(144.0)
bnk_hq_loc_ph	-203.8	-214.4	-225.6	-237.6
	(134.7)	(138.5)	(142.6)	(147.2)
bnk_hq_loc_pt	5.942	5.978	6.047	6.141
	(5.966)	(6.150)	(6.323)	(6.453)
bnk_hq_loc_ru	-18.00	-18.07	-18.19	-18.41
	(16.28)	(16.79)	(17.42)	(18.14)
bnk_hq_loc_sa	-22.03	-22.86	-23.78*	-24.72*
	(13.69)	(13.84)	(14.02)	(14.24)
bnk_hq_loc_se	19.70	20.37	21.13	21.98
	(16.98)	(17.47)	(17.99)	(18.55)
bnk_hq_loc_sg	-11.63	-11.68	-11.76	-11.81
	(18.27)	(18.80)	(19.37)	(20.00)
bnk_hq_loc_uk	10.10	10.63	11.15	11.75
	(10.17)	(10.49)	(10.85)	(11.25)
bnk_hq_loc_us	-15.96	-16.19	-16.47	-16.73
	(9.603)	(9.907)	(10.25)	(10.63)
bnk_hq_loc_za	-20.02	-20.48	-21.03	-21.67
	(15.40)	(15.95)	(16.58)	(17.29)
co_hq_co2_pr	0.335**	0.332**	0.328**	0.325**
	(0.143)	(0.142)	(0.142)	(0.142)
yy_gdp_chg	0	0	0	0
	(3.34e-08)	(9.86e-08)	(5.44e-08)	(7.93e-08)
yy_infl	0	0	0	0
	(4.78e-08)	(1.22e-07)	(5.55e-08)	(1.26e-07)
li_price_s	0	0	0	0
	(1.40e-10)	(5.90e-11)	(5.70e-11)	(1.15e-10)
cob_price	0	0	0	0
	(4.81e-10)	(9.02e-11)	(1.19e-10)	(3.87e-10)
mn_price	0	0	0	0
	(3.28e-09)	(2.57e-09)	(1.17e-09)	(2.67e-09)
ni_price	0	0	0	0
	(3.29e-10)	(2.32e-09)	(2.59e-09)	(1.08e-09)
bnk_esg_nbm	10.73	10.61	10.46	10.30
	(7.747)	(7.628)	(7.494)	(7.349)
bnk_esg_breg	13.56**	13.59**	13.62**	13.63**
	(6.083)	(6.079)	(6.071)	(6.057)
bnk_anti_esg_breg	-19.34***	-19.13***	-18.91***	-18.68***
	(5.313)	(5.288)	(5.267)	(5.222)
L.after19_21		0		
		(1.86e-06)		

L.after21		0		
		(1.57e-06)		
L.treat_after19_21		-8.397***		
		(1.977)		
L.treat_after21		-24.33***		
		(5.510)		
L2.after19_21			0	
			(1.02e-06)	
L2.after21			0	
			(2.28e-06)	
L2.treat_after19_21			-10.09***	
			(2.438)	
L2.treat_after21			-24.83***	
			(5.806)	
L3.after19_21				0
				(1.21e-10)
L3.after21				0
				(5.94e-11)
L3.treat_after19_21				-11.79***
				(2.906)
L3.treat_after21				-25.32***
				(6.039)
Constant	-1.708	-1.325	-0.896	-0.405
	(11.15)	(11.41)	(11.71)	(12.06)
Observations	119,526	116,102	112,678	109,254
R-squared	0.041	0.041	0.042	0.043

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1
Results based on stata’s reghdfe OLS estimation method.
Time fixed effects treated by means of ‘absorbing’ (Correia, 2016).

Table B.18: batmat_ph—2020 Baseline Regression

VARIABLES	(1) batmat_ph Contemporaneous	(2) batmat_ph Lagged 1Q	(3) batmat_ph Lagged 2Q	(4) batmat_ph Lagged 3Q
treat	-15.61	-16.19	-16.74	-17.64
	(10.76)	(11.08)	(11.43)	(11.84)
after20	0			
	(0)			
treat_after20	-20.23***			
	(4.653)			
all_ph_s	0.00293	0.00292	0.00292	0.00291
	(0.00180)	(0.00183)	(0.00187)	(0.00190)
co_hq_loc_au	-0.551	-1.343	-2.215	-3.198
	(6.671)	(6.738)	(6.804)	(6.875)
co_hq_loc_br	-20.47*	-21.84*	-23.31*	-24.91*
	(10.57)	(11.10)	(11.71)	(12.36)
co_hq_loc_ca	-16.48**	-17.70***	-19.02***	-20.41***
	(6.154)	(6.317)	(6.508)	(6.712)
co_hq_loc_ch	5.270	3.692	1.487	-0.420
	(18.62)	(18.91)	(19.30)	(19.79)
co_hq_loc_cn	-17.37**	-18.68**	-20.11**	-21.72**
	(7.194)	(7.556)	(7.987)	(8.469)
co_hq_loc_fr	-42.08***	-43.36***	-44.74***	-45.90***
	(9.383)	(9.621)	(9.877)	(10.16)
co_hq_loc_de	-30.88**	-32.00**	-33.30**	-34.37**
	(13.94)	(14.27)	(14.62)	(14.98)
co_hq_loc_es	-68.24***	-70.59***	-73.16***	-75.73***
	(14.55)	(14.87)	(15.23)	(15.60)
co_hq_loc_hk	3.160	2.564	1.913	1.153
	(7.179)	(7.325)	(7.486)	(7.677)
co_hq_loc_id	88.71	90.60	92.64	94.74
	(68.45)	(70.40)	(72.48)	(74.70)
co_hq_loc_im	26.75**	26.81*	26.87*	26.84*
	(12.96)	(13.30)	(13.57)	(14.04)
co_hq_loc_in	-34.25***	-35.75***	-37.42***	-39.12***
	(10.47)	(10.91)	(11.42)	(11.99)
co_hq_loc_jp	-33.05***	-34.89***	-36.90***	-39.10***
	(10.80)	(11.33)	(11.93)	(12.59)
co_hq_loc_ke	-26.57**	-28.06**	-29.67**	-31.45**
	(11.45)	(11.93)	(12.49)	(13.10)
co_hq_loc_kr	-38.78**	-39.41**	-40.49*	-41.61*
	(18.72)	(19.37)	(20.15)	(20.98)
co_hq_loc_kz	7.007	6.563	6.080	5.477
	(8.429)	(8.678)	(8.962)	(9.281)
co_hq_loc_lu	-45.48***	-47.69***	-50.12***	-52.66***
	(11.79)	(12.45)	(13.20)	(14.06)
co_hq_loc_mx	-70.49*	-73.26*	-76.30*	-79.75*
	(37.17)	(38.63)	(40.27)	(42.11)
co_hq_loc_fnl	-53.51***	-54.72***	-56.27***	-57.92***
	(14.74)	(15.14)	(15.60)	(16.13)
co_hq_loc_pe	-49.50**	-51.50**	-53.66**	-56.10**
	(24.01)	(24.92)	(25.95)	(27.07)
co_hq_loc_ph	260.9*	266.5*	272.5*	278.7*
	(139.8)	(144.1)	(148.7)	(153.6)
co_hq_loc_pl	-46.13**	-47.95**	-50.02**	-52.00**
	(17.18)	(17.85)	(18.60)	(19.40)
co_hq_loc_ru	-29.72	-31.43	-33.41	-35.66
	(19.70)	(20.50)	(21.46)	(22.57)
co_hq_loc_se	-0.773	-1.709	-2.795	-3.909
	(12.60)	(12.93)	(13.34)	(13.80)
co_hq_loc_tw	-58.27***	-60.72***	-63.31***	-66.19***
	(15.05)	(15.66)	(16.35)	(17.13)
co_hq_loc_uk	-9.877	-10.36	-10.94	-11.37
	(7.473)	(7.497)	(7.532)	(7.600)
co_hq_loc_us	-17.79**	-18.86**	-20.00**	-21.42**
	(6.988)	(7.319)	(7.710)	(8.159)

co_hq_loc_vg	-22.66**	-24.03**	-25.52**	-27.18**
	(11.07)	(11.56)	(12.12)	(12.73)
co_hq_loc_za	0	0	0	0
	(0)	(5.68e-07)	(9.29e-07)	(0)
co_share_pr_s	0.0890	0.0921	0.0957	0.0993
	(0.0870)	(0.0869)	(0.0867)	(0.0865)
co_div	-8.629**	-8.954**	-9.145**	-9.283**
	(3.696)	(3.792)	(3.882)	(3.970)
co_credit_risk	14.00***	14.10***	14.07**	14.02**
	(4.960)	(5.079)	(5.215)	(5.370)
co_fd_yr	0.0129***	0.0133***	0.0137***	0.0142***
	(0.00336)	(0.00344)	(0.00353)	(0.00362)
co_rev	-0.00117***	-0.00115***	-0.00112***	-0.00110***
	(0.000345)	(0.000351)	(0.000361)	(0.000370)
co_E	4.825	4.976	5.161	5.462
	(5.564)	(5.741)	(5.926)	(6.171)
co_E_rtg	-7.590	-7.688	-7.831	-8.136
	(5.404)	(5.571)	(5.756)	(6.011)
co_E_disc	5.830	4.919	4.397	3.903
	(13.47)	(14.05)	(14.63)	(15.24)
co_S	5.427**	5.628**	5.867**	6.051**
	(2.134)	(2.183)	(2.247)	(2.313)
co_S_rtg	-2.394***	-2.405***	-2.444***	-2.428***
	(0.804)	(0.824)	(0.849)	(0.876)
co_S_disc	-35.91**	-37.24**	-38.84**	-40.09**
	(14.40)	(14.76)	(15.23)	(15.73)
co_G	-22.32*	-22.97*	-23.68*	-24.53*
	(12.78)	(13.22)	(13.72)	(14.27)
co_G_rtg	10.40*	10.70*	11.02*	11.41*
	(5.755)	(5.979)	(6.218)	(6.487)
co_G_disc	110.7	114.1	117.8	122.1
	(67.82)	(70.09)	(72.61)	(75.43)
bnk_hq_loc_ae	-36.15*	-37.04*	-38.03*	-38.91*
	(20.34)	(20.92)	(21.55)	(22.23)
bnk_hq_loc_at	-15.30	-15.82	-16.41	-16.98
	(10.70)	(11.04)	(11.40)	(11.78)
bnk_hq_loc_au	2.636	2.867	3.086	3.491
	(12.72)	(13.05)	(13.41)	(13.83)
bnk_hq_loc_be	6.514	6.674	6.901	7.228
	(8.209)	(8.449)	(8.713)	(9.008)
bnk_hq_loc_br	-35.16*	-36.01*	-36.95*	-37.91*
	(18.31)	(18.94)	(19.62)	(20.40)
bnk_hq_loc_ca	-6.574	-6.609	-6.682	-6.589
	(10.83)	(11.17)	(11.55)	(11.98)
bnk_hq_loc_ch	-22.43**	-22.92**	-23.46**	-23.88**
	(10.07)	(10.38)	(10.73)	(11.12)
bnk_hq_loc_cn	-9.721	-9.635	-9.526	-9.379
	(24.46)	(25.25)	(26.11)	(27.05)
bnk_hq_loc_co	-5.357	-5.209	-4.995	-4.704
	(7.900)	(8.204)	(8.547)	(8.949)
bnk_hq_loc_cy	8.788	8.849	8.933	9.031
	(8.101)	(8.370)	(8.661)	(8.972)
bnk_hq_loc_cz	18.46**	18.90**	19.40**	19.88*
	(8.908)	(9.199)	(9.496)	(9.793)
bnk_hq_loc_de	4.511	4.591	4.719	4.899
	(5.681)	(5.827)	(5.977)	(6.118)
bnk_hq_loc_dk	-0.340	-0.286	-0.247	-0.181
	(8.598)	(8.811)	(9.051)	(9.295)
bnk_hq_loc_es	-4.288	-4.537	-4.760	-4.906
	(8.421)	(8.633)	(8.871)	(9.136)
bnk_hq_loc_fr	1.517	1.459	1.436	1.461
	(6.067)	(6.216)	(6.372)	(6.525)
bnk_hq_loc_hk	-42.61***	-43.68***	-44.82**	-46.03**
	(15.42)	(15.91)	(16.46)	(17.07)
bnk_hq_loc_ie	0.201	0.124	0.0788	0.0619
	(6.969)	(7.155)	(7.348)	(7.538)
bnk_hq_loc_il	-10.06	-10.15	-10.25	-10.19
	(11.75)	(12.20)	(12.73)	(13.30)
bnk_hq_loc_im	-20.71*	-21.18*	-21.72*	-22.11*

	(11.20)	(11.53)	(11.88)	(12.28)
bnk_hq_loc_in	-4.896	-4.593	-4.325	-3.690
	(10.78)	(11.05)	(11.34)	(11.69)
bnk_hq_loc_it	-1.730	-1.878	-1.995	-2.059
	(6.541)	(6.700)	(6.871)	(7.043)
bnk_hq_loc_jp	0.290	0.384	0.444	0.639
	(12.25)	(12.64)	(13.06)	(13.53)
bnk_hq_loc_kr	25.13	24.75	24.73	24.82
	(20.00)	(20.44)	(20.98)	(21.57)
bnk_hq_loc_kz	-19.24	-19.65	-20.12	-20.44
	(14.06)	(14.48)	(14.94)	(15.47)
bnk_hq_loc_li	2.360	2.345	2.379	2.531
	(8.264)	(8.499)	(8.764)	(9.067)
bnk_hq_loc_lu	-1.034	-1.101	-1.126	-1.106
	(7.757)	(7.930)	(8.115)	(8.299)
bnk_hq_loc_mt	10.65	10.86	11.13	11.48
	(6.831)	(7.037)	(7.255)	(7.464)
bnk_hq_loc_nl	-4.825	-5.044	-5.237	-5.406
	(6.592)	(6.760)	(6.934)	(7.104)
bnk_hq_loc_no	4.572	5.112	5.751	6.466
	(17.71)	(18.22)	(18.78)	(19.37)
bnk_hq_loc_nz	-25.40**	-25.91**	-26.48**	-26.92**
	(10.82)	(11.17)	(11.54)	(11.97)
bnk_hq_loc_om	846.8***	871.4***	897.4***	925.0***
	(135.9)	(138.5)	(141.2)	(143.9)
bnk_hq_loc_ph	-203.6	-214.3	-225.6	-237.5
	(134.7)	(138.5)	(142.6)	(147.2)
bnk_hq_loc_pt	5.952	5.979	6.042	6.139
	(5.950)	(6.114)	(6.285)	(6.443)
bnk_hq_loc_ru	-17.82	-17.96	-18.16	-18.33
	(16.29)	(16.79)	(17.41)	(18.13)
bnk_hq_loc_sa	-21.84	-22.75	-23.74	-24.63*
	(13.68)	(13.84)	(14.02)	(14.24)
bnk_hq_loc_se	19.71	20.37	21.13	21.98
	(16.98)	(17.47)	(17.99)	(18.55)
bnk_hq_loc_sg	-11.55	-11.66	-11.79	-11.80
	(18.27)	(18.80)	(19.38)	(20.01)
bnk_hq_loc_uk	10.24	10.70	11.16	11.80
	(10.18)	(10.50)	(10.85)	(11.26)
bnk_hq_loc_us	-15.80	-16.10	-16.45	-16.65
	(9.604)	(9.906)	(10.24)	(10.63)
bnk_hq_loc_za	-19.94	-20.45	-21.04	-21.65
	(15.40)	(15.95)	(16.57)	(17.29)
co_hq_co2_pr	0.330**	0.328**	0.327**	0.322**
	(0.142)	(0.142)	(0.142)	(0.141)
yy_gdp_chg	0	0	0	0
	(1.20e-07)	(1.47e-07)	(1.29e-07)	(1.57e-07)
yy_infl	0	0	0	0
	(1.10e-07)	(7.50e-08)	(1.31e-07)	(1.31e-07)
li_price_s	0	0	0	0
	(1.51e-10)	(8.52e-11)	(1.94e-10)	(1.26e-10)
cob_price	0	0	0	0
	(2.64e-10)	(2.78e-10)	(4.61e-10)	(3.27e-10)
mn_price	0	0	0	0
	(2.81e-09)	(5.75e-09)	(4.84e-09)	(2.94e-09)
ni_price	0	0	0	0
	(2.68e-10)	(8.87e-10)	(1.29e-09)	(1.38e-09)
bnk_esg_nbm	11.05	10.87	10.64	10.52
	(7.794)	(7.668)	(7.526)	(7.389)
bnk_esg_breg	13.71**	13.72**	13.71**	13.74**
	(6.104)	(6.095)	(6.084)	(6.073)
bnk_anti_esg_breg	-18.98***	-18.81***	-18.67***	-18.42***
	(5.104)	(5.135)	(5.216)	(5.171)
L.after20		0		
		(5.95e-07)		
L.treat_after20		-20.91***		
		(4.880)		
L2.after20			0	
			(1.37e-06)	

L2.treat_after20			-22.15***	
			(5.127)	
L3.after20				0
				(0)
L3.treat_after20				-22.21***
				(5.226)
Constant	-1.888	-1.429	-0.918	-0.480
	(11.15)	(11.41)	(11.70)	(12.06)
Observations	119,526	116,102	112,678	109,254
R-squared	0.041	0.041	0.042	0.043

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1
Results based on stata’s reghdfe OLS estimation method.
Time fixed effects treated by means of ‘absorbing’ (Correia, 2016).

Table B.19: batmat_ph—2019, 2020 & 2021 Baseline Regression

VARIABLES	(1) batmat_ph Contemporaneous	(2) batmat_ph Lagged 1Q	(3) batmat_ph Lagged 2Q	(4) batmat_ph Lagged 3Q
treat	-14.84	-15.30	-15.89	
	(10.78)	(11.10)	(11.45)	
after19_20	0			
	(1.63e-06)			
treat_after19_20	-6.557***			
	(1.495)			
after20_21	0			
	(6.06e-07)			
treat_after20_21	-7.007***			
	(1.522)			
after21	0			
	(1.74e-08)			
treat_after21	-23.84***			
	(5.350)			
all_ph_s	0.00293	0.00293	0.00292	0.00291
	(0.00180)	(0.00183)	(0.00187)	(0.00190)
co_hq_loc_au	-0.572	-1.343	-2.207	-3.372
	(6.666)	(6.734)	(6.800)	(6.855)
co_hq_loc_br	-20.47*	-21.82*	-23.29*	-25.03*
	(10.56)	(11.09)	(11.71)	(12.37)
co_hq_loc_ca	-16.54**	-17.74***	-19.03***	-20.57***
	(6.157)	(6.319)	(6.509)	(6.717)
co_hq_loc_ch	4.469	3.340	1.347	-0.600
	(18.63)	(18.96)	(19.36)	(19.87)
co_hq_loc_cn	-17.40**	-18.68**	-20.11**	-21.87**
	(7.192)	(7.555)	(7.986)	(8.471)
co_hq_loc_fr	-42.30***	-43.50***	-44.81***	-46.02***
	(9.391)	(9.630)	(9.895)	(10.19)
co_hq_loc_de	-31.14**	-32.15**	-33.37**	-34.48**
	(13.96)	(14.29)	(14.64)	(15.00)
co_hq_loc_es	-68.50***	-70.76***	-73.26***	-75.92***
	(14.55)	(14.87)	(15.23)	(15.62)
co_hq_loc_hk	3.142	2.559	1.915	0.982
	(7.143)	(7.298)	(7.456)	(7.656)
co_hq_loc_id	88.70	90.61	92.64	94.59
	(68.45)	(70.39)	(72.48)	(74.70)
co_hq_loc_im	26.78**	26.85**	26.90*	26.70*
	(12.70)	(13.11)	(13.57)	(14.02)
co_hq_loc_in	-34.46***	-35.87***	-37.48***	-35.85***
	(10.47)	(10.91)	(11.42)	(11.10)
co_hq_loc_jp	-33.07***	-34.89***	-36.90***	-39.21***
	(10.78)	(11.31)	(11.92)	(12.59)
co_hq_loc_ke	-26.55**	-28.03**	-29.64**	-31.60**
	(11.44)	(11.93)	(12.49)	(13.10)
co_hq_loc_kr	-38.98**	-39.63**	-40.61*	-41.74*
	(18.72)	(19.42)	(20.20)	(20.98)
co_hq_loc_kz	7.014	6.578	6.094	5.305
	(8.430)	(8.680)	(8.964)	(9.267)
co_hq_loc_lu	-45.66***	-47.82***	-50.19***	-52.81***
	(11.80)	(12.46)	(13.22)	(14.09)
co_hq_loc_mx	-70.47*	-73.26*	-76.31*	-79.87*
	(37.16)	(38.63)	(40.27)	(42.11)
co_hq_loc_nl	-53.70***	-54.86***	-56.36***	-58.04***
	(14.75)	(15.15)	(15.61)	(16.16)
co_hq_loc_pe	-49.46**	-51.47**	-53.65**	-56.19**
	(24.00)	(24.92)	(25.94)	(27.08)
co_hq_loc_ph	260.9*	266.6*	272.5*	278.6*
	(139.8)	(144.1)	(148.7)	(153.6)
co_hq_loc_pl	-46.36**	-48.10**	-50.10**	-52.14**
	(17.21)	(17.87)	(18.62)	(19.42)
co_hq_loc_ru	-29.70	-31.41	-33.40	-35.78
	(19.69)	(20.49)	(21.46)	(22.56)

co_hq_loc_se	-0.976	-1.840	-2.865	-4.093
	(12.61)	(12.94)	(13.35)	(13.82)
co_hq_loc_tw	-58.30***	-60.74***	-63.33***	-66.32***
	(15.02)	(15.64)	(16.33)	(17.13)
co_hq_loc_uk	-10.20	-10.57	-11.05	-11.63
	(7.463)	(7.502)	(7.553)	(7.630)
co_hq_loc_us	-17.76**	-18.85**	-20.00**	-21.54**
	(6.982)	(7.315)	(7.708)	(8.158)
co_hq_loc_vg	-22.64**	-24.01**	-25.49**	-27.32**
	(11.07)	(11.55)	(12.11)	(12.73)
co_hq_loc_za	0	0	0	0
	(2.44e-08)	(3.67e-08)	(3.98e-08)	(2.70e-08)
co_share_pr_s	0.0902	0.0927	0.0961	0.0996
	(0.0869)	(0.0868)	(0.0867)	(0.0866)
co_div	-8.652**	-8.923**	-9.123**	-9.245**
	(3.692)	(3.806)	(3.897)	(3.960)
co_credit_risk	13.98***	14.09***	14.07**	13.99**
	(4.957)	(5.079)	(5.215)	(5.365)
co_fd_yr	0.0129***	0.0133***	0.0137***	0.0142***
	(0.00336)	(0.00344)	(0.00353)	(0.00362)
co_rev	-0.00116***	-0.00115***	-0.00113***	-0.00110***
	(0.000344)	(0.000352)	(0.000361)	(0.000370)
co_E	4.810	4.972	5.163	5.499
	(5.559)	(5.739)	(5.925)	(6.170)
co_E_rtg	-7.564	-7.680	-7.836	-8.178
	(5.400)	(5.570)	(5.756)	(6.012)
co_E_disc	5.858	4.932	4.404	3.876
	(13.45)	(14.05)	(14.64)	(15.24)
co_S	5.453**	5.644**	5.874**	6.042**
	(2.136)	(2.185)	(2.248)	(2.313)
co_S_rtg	-2.405***	-2.411***	-2.444***	-2.419***
	(0.805)	(0.825)	(0.850)	(0.875)
co_S_disc	-36.09**	-37.34**	-38.88**	-40.01**
	(14.42)	(14.77)	(15.24)	(15.72)
co_G	-22.30*	-22.96*	-23.69*	-24.60*
	(12.77)	(13.22)	(13.72)	(14.28)
co_G_rtg	10.39*	10.70*	11.03*	11.50*
	(5.754)	(5.979)	(6.219)	(6.495)
co_G_disc	110.6	114.0	117.8	122.0
	(67.81)	(70.09)	(72.61)	(75.42)
bnk_hq_loc_ae	-36.34*	-37.16*	-38.10*	-31.46
	(20.34)	(20.92)	(21.55)	(20.51)
bnk_hq_loc_at	-15.31	-15.82	-16.40	-25.76**
	(10.71)	(11.04)	(11.40)	(12.49)
bnk_hq_loc_au	2.442	2.733	3.006	10.92
	(12.71)	(13.05)	(13.41)	(11.63)
bnk_hq_loc_be	6.489	6.658	6.891	-1.620
	(8.215)	(8.452)	(8.715)	(8.978)
bnk_hq_loc_br	-35.31*	-36.13*	-37.03*	-30.47
	(18.31)	(18.94)	(19.63)	(18.27)
bnk_hq_loc_ca	-6.756	-6.729	-6.751	0.852
	(10.82)	(11.17)	(11.55)	(8.811)
bnk_hq_loc_ch	-22.55**	-22.99**	-23.49**	-16.44**
	(10.07)	(10.38)	(10.73)	(7.258)
bnk_hq_loc_cn	-9.534	-9.432	-9.352	-1.703
	(24.45)	(25.24)	(26.10)	(26.13)
bnk_hq_loc_co	-5.485	-5.286	-5.036	0.272
	(7.870)	(8.188)	(8.539)	(8.739)
bnk_hq_loc_cy	8.842	8.885	8.954	-2.310
	(8.092)	(8.367)	(8.665)	(8.589)
bnk_hq_loc_cz	18.45**	18.90**	19.40**	11.07
	(8.908)	(9.197)	(9.494)	(9.482)
bnk_hq_loc_de	4.499	4.586	4.717	-3.938
	(5.686)	(5.830)	(5.976)	(6.305)
bnk_hq_loc_dk	-0.354	-0.298	-0.255	-9.013
	(8.604)	(8.812)	(9.048)	(9.431)
bnk_hq_loc_es	-4.295	-4.535	-4.757	-13.70
	(8.447)	(8.653)	(8.884)	(9.500)
bnk_hq_loc_fr	1.499	1.452	1.434	-7.432

	(6.074)	(6.221)	(6.375)	(6.812)
bnk_hq_loc_hk	-42.46***	-43.51***	-44.68**	-38.39**
	(15.41)	(15.91)	(16.46)	(14.21)
bnk_hq_loc_ie	0.196	0.125	0.0825	-8.782
	(6.976)	(7.158)	(7.348)	(7.911)
bnk_hq_loc_il	-10.27	-10.28	-10.31	-2.730
	(11.74)	(12.20)	(12.73)	(10.59)
bnk_hq_loc_im	-20.89*	-21.30*	-21.79*	-14.66
	(11.21)	(11.53)	(11.89)	(8.987)
bnk_hq_loc_in	-5.210	-4.792	-4.422	0.666
	(10.79)	(11.06)	(11.35)	(11.28)
bnk_hq_loc_it	-1.749	-1.885	-1.998	-10.90
	(6.548)	(6.704)	(6.871)	(7.343)
bnk_hq_loc_jp	0.175	0.321	0.420	8.120
	(12.25)	(12.63)	(13.06)	(10.73)
bnk_hq_loc_kr	25.12	24.83	24.79	15.88
	(20.00)	(20.49)	(21.03)	(21.33)
bnk_hq_loc_kz	-19.43	-19.78	-20.20	-13.00
	(14.05)	(14.48)	(14.94)	(13.07)
bnk_hq_loc_li	2.339	2.334	2.373	-6.282
	(8.270)	(8.502)	(8.765)	(9.161)
bnk_hq_loc_lu	-1.046	-1.107	-1.128	-9.965
	(7.765)	(7.934)	(8.116)	(8.375)
bnk_hq_loc_mt	10.63	10.86	11.14	2.645
	(6.831)	(7.035)	(7.252)	(7.443)
bnk_hq_loc_nl	-4.834	-5.045	-5.235	-14.25*
	(6.603)	(6.767)	(6.938)	(7.497)
bnk_hq_loc_no	4.527	5.070	5.709	-2.484
	(17.71)	(18.23)	(18.78)	(18.97)
bnk_hq_loc_nz	-25.58**	-26.03**	-26.55**	-19.47**
	(10.82)	(11.16)	(11.54)	(8.276)
bnk_hq_loc_om	846.7***	871.3***	897.3***	932.5***
	(136.1)	(138.7)	(141.4)	(144.7)
bnk_hq_loc_ph	-203.8	-214.4	-225.7	-230.1
	(134.7)	(138.5)	(142.6)	(146.8)
bnk_hq_loc_pt	5.942	5.977	6.043	-2.685
	(5.966)	(6.140)	(6.285)	(6.721)
bnk_hq_loc_ru	-18.00	-18.07	-18.23	-10.86
	(16.28)	(16.79)	(17.42)	(16.08)
bnk_hq_loc_sa	-22.03	-22.87	-23.81*	-17.19
	(13.69)	(13.84)	(14.02)	(11.51)
bnk_hq_loc_se	19.70	20.37	21.13	13.12
	(16.98)	(17.47)	(17.99)	(18.42)
bnk_hq_loc_sg	-11.63	-11.69	-11.79	-4.303
	(18.27)	(18.80)	(19.37)	(18.19)
bnk_hq_loc_uk	10.10	10.62	11.12	19.28**
	(10.17)	(10.49)	(10.85)	(8.077)
bnk_hq_loc_us	-15.96	-16.20	-16.50	-9.197
	(9.603)	(9.907)	(10.24)	(6.616)
bnk_hq_loc_za	-20.02	-20.49	-21.06	-14.22
	(15.40)	(15.95)	(16.58)	(15.39)
co_hq_co2_pr	0.335**	0.332**	0.329**	0.324**
	(0.143)	(0.142)	(0.142)	(0.142)
yy_gdp_chg	0	0	0	0
	(6.75e-08)	(4.15e-08)	(5.43e-08)	(6.33e-08)
yy_infl	0	0	0	0
	(3.00e-08)	(6.30e-08)	(5.43e-08)	(8.79e-08)
li_price_s	0	0	0	0
	(1.04e-10)	(1.09e-10)	(1.15e-10)	(7.15e-11)
cob_price	0	0	0	0
	(0)	(3.27e-10)	(4.93e-10)	(3.56e-10)
mn_price	0	0	0	0
	(6.35e-10)	(1.17e-09)	(1.40e-09)	(1.63e-09)
ni_price	0	0	0	0
	(0)	(0)	(0)	(1.06e-10)
bnk_esg_nbm	10.73	10.60	10.44	10.38
	(7.747)	(7.628)	(7.492)	(7.339)
bnk_esg_breg	13.56**	13.58**	13.61**	13.61**
	(6.083)	(6.079)	(6.071)	(6.056)

bnk_anti_esg_breg	-19.34***	-19.13***	-18.91***	-18.69***
	(5.313)	(5.291)	(5.297)	(5.249)
L.after19_20		0		
		(2.26e-06)		
L.treat_after19_20		-7.133***		
		(1.435)		
L.after20_21		0		
		(3.92e-07)		
L.treat_after20_21		-10.29***		
		(3.209)		
L.after21		0		
		(1.96e-07)		
L.treat_after21		-24.33***		
		(5.512)		
L2.after19_20			0	
			(1.56e-06)	
L2.treat_after19_20			-6.587***	
			(1.291)	
L2.after20_21			0	
			(4.93e-07)	
L2.treat_after20_21			-15.36***	
			(3.424)	
L2.after21			0	
			(3.42e-07)	
L2.treat_after21			-24.85***	
			(5.817)	
oL3.after19_20				0
				(0)
L3.treat_after19_20				-9.123***
				(2.326)
L3.after20_21				0
				(0)
L3.treat_after20_21				-16.55***
				(3.409)
L3.after21				0
				(0)
L3.treat_after21				-25.61***
				(6.048)
Constant	-1.708	-1.317	-0.859	-7.742
	(11.15)	(11.41)	(11.70)	(9.643)
Observations	119,526	116,102	112,678	109,254
R-squared	0.041	0.041	0.042	0.043

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1
Results based on stata’s reghdfe OLS estimation method.
Time fixed effects treated by means of ‘absorbing’ (Correia, 2016).

Table B.20: batmat_ph—2019 & 2021 Fixed Effects

VARIABLES	(1) batmat_ph No Fixed Effects	(2) batmat_ph Time Fixed Effects	(3) batmat_ph Time & Entity Fixed Effects
treat	-14.92	-14.84	
	(10.78)	(10.78)	
after19_21	6.066***	0	
	(2.075)	(1.81e-06)	
after21	16.78***	0	
	(5.794)	(1.53e-06)	
treat_after19_21	-6.717***	-6.737***	-7.383***
	(1.618)	(1.494)	(1.867)
treat_after21	-23.60***	-23.84***	-20.83***
	(5.259)	(5.350)	(4.809)
all_ph_s	0.00301	0.00293	0.00618
	(0.00179)	(0.00180)	(0.00414)
co_hq_loc_au	-0.462	-0.572	0
	(6.706)	(6.666)	(1.97e-06)
co_hq_loc_br	-20.19*	-20.47*	0
	(10.48)	(10.56)	(3.20e-06)
co_hq_loc_ca	-16.81***	-16.54**	0
	(6.131)	(6.157)	(1.25e-06)
co_hq_loc_ch	2.494	4.467	0
	(18.23)	(18.63)	(1.06e-05)
co_hq_loc_cn	-17.25**	-17.40**	0
	(7.125)	(7.192)	(1.96e-06)
co_hq_loc_fr	-42.60***	-42.30***	0
	(9.414)	(9.391)	(9.28e-06)
co_hq_loc_de	-31.90**	-31.14**	0
	(14.06)	(13.96)	(2.49e-05)
co_hq_loc_es	-69.17***	-68.50***	0
	(14.60)	(14.55)	(2.22e-05)
co_hq_loc_hk	3.117	3.142	0
	(7.249)	(7.143)	(1.22e-05)
co_hq_loc_id	88.69	88.70	0
	(68.47)	(68.45)	(6.72e-06)
co_hq_loc_im	26.91*	26.78**	0
	(14.51)	(12.70)	(3.83e-05)
co_hq_loc_in	-34.40***	-34.46***	0
	(10.44)	(10.47)	(7.53e-06)
co_hq_loc_jp	-32.98***	-33.07***	0
	(10.67)	(10.78)	(3.92e-06)
co_hq_loc_ke	-26.32**	-26.55**	0
	(11.40)	(11.44)	(3.40e-05)
co_hq_loc_kr	-38.73**	-38.98**	0
	(18.60)	(18.72)	(2.24e-05)
co_hq_loc_kz	7.072	7.014	0
	(8.488)	(8.430)	(1.08e-05)
co_hq_loc_lu	-45.42***	-45.66***	0
	(11.75)	(11.80)	(9.93e-06)
co_hq_loc_mx	-69.38*	-70.47*	0
	(36.90)	(37.16)	(3.94e-05)
co_hq_loc_nl	-53.53***	-53.70***	0
	(14.77)	(14.75)	(1.23e-05)
co_hq_loc_pe	-48.80**	-49.46**	0
	(23.85)	(24.00)	(7.53e-06)
co_hq_loc_ph	261.0*	260.9*	0
	(139.7)	(139.8)	(1.74e-05)
co_hq_loc_pl	-46.75**	-46.36**	0
	(17.33)	(17.21)	(3.59e-05)
co_hq_loc_ru	-29.33	-29.70	0
	(19.43)	(19.69)	(2.34e-05)
co_hq_loc_se	-1.274	-0.976	0
	(12.60)	(12.61)	(9.08e-06)
co_hq_loc_tw	-58.41***	-58.30***	0
	(14.94)	(15.02)	(2.85e-05)

co_hq_loc_uk	-10.56	-10.20	0
	(7.438)	(7.463)	(1.47e-06)
co_hq_loc_us	-17.47**	-17.76**	0
	(6.895)	(6.981)	(2.40e-06)
co_hq_loc_vg	-22.41*	-22.64**	0
	(11.07)	(11.07)	(0)
co_hq_loc_za	0	0	0
	(0)	(9.71e-08)	(0)
co_share_pr_s	0.0863	0.0901	0.00494
	(0.0861)	(0.0869)	(0.0941)
co_div	-8.758**	-8.653**	-1.479
	(3.747)	(3.692)	(1.955)
co_credit_risk	13.27**	13.98***	0
	(4.887)	(4.957)	(0)
co_fd_yr	0.0128***	0.0129***	0
	(0.00348)	(0.00336)	(0)
co_rev	-0.00113***	-0.00116***	-0.000870**
	(0.000338)	(0.000344)	(0.000420)
co_E	4.555	4.810	13.22
	(5.487)	(5.559)	(11.55)
co_E_rtg	-7.220	-7.564	-12.03*
	(5.315)	(5.400)	(6.205)
co_E_disc	6.166	5.858	-38.99
	(13.30)	(13.45)	(39.37)
co_S	5.666**	5.453**	10.84**
	(2.167)	(2.136)	(4.108)
co_S_rtg	-2.530***	-2.405***	-5.279***
	(0.815)	(0.805)	(1.702)
co_S_disc	-36.85**	-36.09**	-75.17**
	(14.50)	(14.42)	(29.55)
co_G	-21.86*	-22.30*	-51.48*
	(12.68)	(12.77)	(30.08)
co_G_rtg	10.23*	10.39*	24.90*
	(5.720)	(5.754)	(13.70)
co_G_disc	108.5	110.6	262.5*
	(67.32)	(67.81)	(155.0)
bnk_hq_loc_ae	-36.21*	-36.34*	0
	(20.35)	(20.34)	(0)
bnk_hq_loc_at	-15.17	-15.31	0
	(10.64)	(10.71)	(0)
bnk_hq_loc_au	2.400	2.442	0
	(12.75)	(12.71)	(0)
bnk_hq_loc_be	6.494	6.489	0
	(8.171)	(8.215)	(0)
bnk_hq_loc_br	-34.78*	-35.31*	0
	(18.15)	(18.31)	(0)
bnk_hq_loc_ca	-6.623	-6.756	0
	(10.84)	(10.82)	(0)
bnk_hq_loc_ch	-22.89**	-22.55**	0
	(10.10)	(10.07)	(0)
bnk_hq_loc_cn	-11.32	-9.534	0
	(24.37)	(24.45)	(0)
bnk_hq_loc_co	-5.747	-5.485	0
	(7.834)	(7.869)	(0)
bnk_hq_loc_cy	9.065	8.842	0
	(8.041)	(8.092)	(0)
bnk_hq_loc_cz	18.31**	18.45**	0
	(8.866)	(8.908)	(0)
bnk_hq_loc_de	4.553	4.499	0
	(5.662)	(5.686)	(0)
bnk_hq_loc_dk	-0.332	-0.354	0
	(8.600)	(8.604)	(0)
bnk_hq_loc_es	-4.302	-4.295	0
	(8.381)	(8.447)	(0)
bnk_hq_loc_fr	1.541	1.499	0
	(6.046)	(6.074)	(0)
bnk_hq_loc_hk	-43.70***	-42.46***	0
	(15.68)	(15.41)	(0)
bnk_hq_loc_ie	0.344	0.196	0

	(6.969)	(6.976)	(0)
bnk_hq_loc_il	-10.29	-10.27	0
	(11.62)	(11.74)	(0)
bnk_hq_loc_im	-20.81*	-20.89*	0
	(11.24)	(11.21)	(0)
bnk_hq_loc_in	-5.593	-5.210	0
	(10.72)	(10.79)	(0)
bnk_hq_loc_it	-1.639	-1.749	0
	(6.535)	(6.547)	(0)
bnk_hq_loc_jp	-0.133	0.175	0
	(12.30)	(12.25)	(0)
bnk_hq_loc_kr	24.81	25.12	0
	(19.92)	(20.00)	(0)
bnk_hq_loc_kz	-19.32	-19.43	0
	(14.04)	(14.05)	(0)
bnk_hq_loc_li	2.285	2.339	0
	(8.216)	(8.270)	(0)
bnk_hq_loc_lu	-0.890	-1.046	0
	(7.755)	(7.765)	(0)
bnk_hq_loc_mt	10.60	10.63	0
	(6.811)	(6.831)	(0)
bnk_hq_loc_nl	-4.713	-4.834	0
	(6.593)	(6.603)	(0)
bnk_hq_loc_no	4.172	4.527	0
	(17.68)	(17.71)	(0)
bnk_hq_loc_nz	-25.53**	-25.58**	0
	(10.81)	(10.82)	(0)
bnk_hq_loc_om	847.0***	846.7***	0
	(137.8)	(136.1)	(0)
bnk_hq_loc_ph	-203.8	-203.8	0
	(134.6)	(134.7)	(0)
bnk_hq_loc_pt	6.000	5.942	0
	(5.966)	(5.966)	(0)
bnk_hq_loc_ru	-17.97	-18.00	0
	(16.08)	(16.28)	(0)
bnk_hq_loc_sa	-21.90	-22.03	0
	(13.71)	(13.69)	(0)
bnk_hq_loc_se	19.89	19.70	0
	(16.98)	(16.98)	(0)
bnk_hq_loc_sg	-12.37	-11.63	0
	(18.25)	(18.27)	(0)
bnk_hq_loc_uk	9.987	10.10	0
	(10.22)	(10.17)	(0)
bnk_hq_loc_us	-15.95	-15.96	0
	(9.594)	(9.603)	(0)
bnk_hq_loc_za	-20.29	-20.02	0
	(15.43)	(15.40)	(0)
co_hq_co2_pr	0.342**	0.335**	0.302**
	(0.143)	(0.143)	(0.140)
yy_gdp_chg	-47.01**	0	0
	(19.48)	(3.34e-08)	(0)
yy_infl	262.7*	0	0
	(145.7)	(4.78e-08)	(0)
li_price_s	-0.173*	0	0
	(0.0995)	(1.40e-10)	(0)
cob_price	0.200*	0	0
	(0.115)	(4.81e-10)	(0)
mn_price	0.930	0	0
	(0.671)	(3.28e-09)	(0)
ni_price	-0.433	0	0
	(0.372)	(3.29e-10)	(0)
bnk_esg_nbm	12.96*	10.73	2.283
	(7.626)	(7.747)	(6.232)
bnk_esg_breg	13.72**	13.56**	29.62**
	(6.336)	(6.083)	(10.96)
bnk_anti_esg_breg	-13.92***	-19.34***	-18.63***
	(4.286)	(5.313)	(4.506)
o.treat			-

o.after19_21			-
o.after21			-
Constant	-19.47	-1.708	-5.899
	(13.51)	(11.15)	(10.60)
Observations	119,526	119,526	119,526
R-squared	0.040	0.041	0.352

Robust standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

Results based on stata’s reghdfe OLS estimation method.

Both time and entity fixed effects treated by means of ‘absorbing’ (Correia, 2016).

Table B.21: batmat_ph—2020 Fixed Effects

	(1)	(2)	(3)
	batmat_ph	batmat_ph	batmat_ph
VARIABLES	No Fixed Effects	Time Fixed Effects	Time & Entity Fixed Effects
treat	-16.04	-15.61	
	(10.79)	(10.76)	
after20	10.39**	0	
	(3.970)	(0)	
treat_after20	-20.30***	-20.23***	-17.70***
	(4.670)	(4.653)	(4.293)
all_ph_s	0.00303	0.00293	0.00614
	(0.00179)	(0.00180)	(0.00413)
co_hq_loc_au	-0.416	-0.551	0
	(6.701)	(6.671)	(2.08e-06)
co_hq_loc_br	-20.11*	-20.47*	0
	(10.44)	(10.57)	(2.75e-06)
co_hq_loc_ca	-17.03***	-16.48**	0
	(6.113)	(6.154)	(1.49e-06)
co_hq_loc_ch	0.102	5.270	0
	(18.02)	(18.62)	(1.14e-05)
co_hq_loc_cn	-17.37**	-17.37**	0
	(7.116)	(7.194)	(1.60e-06)
co_hq_loc_fr	-42.85***	-42.08***	0
	(9.414)	(9.383)	(7.98e-06)
co_hq_loc_de	-32.65**	-30.88**	0
	(14.11)	(13.94)	(3.25e-05)
co_hq_loc_es	-69.70***	-68.24***	0
	(14.62)	(14.55)	(4.42e-05)
co_hq_loc_hk	3.180	3.160	0
	(7.295)	(7.179)	(1.53e-05)
co_hq_loc_id	88.87	88.71	0
	(68.52)	(68.45)	(7.78e-06)
co_hq_loc_im	26.99**	26.75**	0
	(12.50)	(12.96)	(4.08e-05)
co_hq_loc_in	-34.71***	-34.25***	0
	(10.47)	(10.47)	(3.50e-06)
co_hq_loc_jp	-32.98***	-33.05***	0
	(10.64)	(10.80)	(2.51e-06)
co_hq_loc_ke	-26.20**	-26.57**	0
	(11.33)	(11.45)	(3.32e-05)
co_hq_loc_kr	-40.15**	-38.78**	0
	(18.80)	(18.72)	(1.04e-05)
co_hq_loc_kz	7.071	7.007	0
	(8.475)	(8.429)	(1.45e-05)
co_hq_loc_lu	-45.51***	-45.48***	0
	(11.76)	(11.79)	(6.69e-06)
co_hq_loc_mx	-69.09*	-70.49*	0
	(36.81)	(37.17)	(1.42e-05)
co_hq_loc_nl	-53.67***	-53.51***	0
	(14.84)	(14.74)	(3.72e-05)
co_hq_loc_pe	-48.48**	-49.50**	0
	(23.74)	(24.01)	(7.59e-06)
co_hq_loc_ph	261.1*	260.9*	0
	(139.7)	(139.8)	(1.62e-05)
co_hq_loc_pl	-47.26**	-46.13**	0
	(17.44)	(17.18)	(2.52e-05)
co_hq_loc_ru	-29.31	-29.72	0
	(19.42)	(19.70)	(3.60e-05)
co_hq_loc_se	-1.939	-0.773	0
	(12.61)	(12.60)	(7.74e-06)
co_hq_loc_tw	-58.43***	-58.27***	0
	(14.90)	(15.05)	(2.66e-05)
co_hq_loc_uk	-11.20	-9.877	0
	(7.288)	(7.473)	(2.27e-06)
co_hq_loc_us	-17.47**	-17.79**	0
	(6.870)	(6.988)	(2.02e-06)

co_hq_loc_vg	-22.28**	-22.66**	0
	(10.95)	(11.07)	(2.13e-05)
co_hq_loc_za	0	0	0
	(1.59e-06)	(0)	(6.18e-06)
co_share_pr_s	0.0922	0.0890	0.00380
	(0.0859)	(0.0870)	(0.0941)
co_div	-8.372**	-8.629**	-1.453
	(3.605)	(3.696)	(1.951)
co_credit_risk	12.56**	14.00***	0
	(4.852)	(4.960)	(0)
co_fd_yr	0.0128***	0.0129***	0
	(0.00347)	(0.00336)	(0)
co_rev	-0.00110***	-0.00117***	-0.000881**
	(0.000340)	(0.000345)	(0.000421)
co_E	4.721	4.825	13.24
	(5.531)	(5.564)	(11.55)
co_E_rtg	-7.290	-7.590	-12.06*
	(5.338)	(5.404)	(6.209)
co_E_disc	6.381	5.830	-38.96
	(13.16)	(13.47)	(39.37)
co_S	5.738**	5.427**	10.82**
	(2.177)	(2.134)	(4.106)
co_S_rtg	-2.504***	-2.394***	-5.272***
	(0.812)	(0.804)	(1.698)
co_S_disc	-37.44**	-35.91**	-75.04**
	(14.59)	(14.40)	(29.54)
co_G	-21.74*	-22.32*	-51.52*
	(12.65)	(12.78)	(30.09)
co_G_rtg	10.22*	10.40*	24.93*
	(5.717)	(5.755)	(13.70)
co_G_disc	107.9	110.7	262.7*
	(67.17)	(67.82)	(155.0)
bnk_hq_loc_ae	-36.46*	-36.15*	0
	(20.40)	(20.34)	(0)
bnk_hq_loc_at	-15.27	-15.30	0
	(10.65)	(10.70)	(0)
bnk_hq_loc_au	2.116	2.636	0
	(12.70)	(12.72)	(0)
bnk_hq_loc_be	6.545	6.514	0
	(8.144)	(8.209)	(0)
bnk_hq_loc_br	-34.95*	-35.16*	0
	(18.22)	(18.31)	(0)
bnk_hq_loc_ca	-6.837	-6.574	0
	(10.85)	(10.83)	(0)
bnk_hq_loc_ch	-23.09**	-22.43**	0
	(10.14)	(10.07)	(0)
bnk_hq_loc_cn	-11.32	-9.721	0
	(24.37)	(24.46)	(0)
bnk_hq_loc_co	-6.139	-5.357	0
	(7.711)	(7.900)	(0)
bnk_hq_loc_cy	9.273	8.788	0
	(7.932)	(8.101)	(0)
bnk_hq_loc_cz	18.11**	18.46**	0
	(8.823)	(8.908)	(0)
bnk_hq_loc_de	4.571	4.511	0
	(5.626)	(5.681)	(0)
bnk_hq_loc_dk	-0.405	-0.340	0
	(8.602)	(8.598)	(0)
bnk_hq_loc_es	-4.338	-4.288	0
	(8.287)	(8.421)	(0)
bnk_hq_loc_fr	1.552	1.517	0
	(6.008)	(6.067)	(0)
bnk_hq_loc_hk	-43.70***	-42.61***	0
	(15.66)	(15.42)	(0)
bnk_hq_loc_ie	0.419	0.201	0
	(6.931)	(6.969)	(0)
bnk_hq_loc_il	-10.66	-10.06	0
	(11.53)	(11.75)	(0)
bnk_hq_loc_im	-21.05*	-20.71*	0

	(11.26)	(11.20)	(0)
bnk_hq_loc_in	-6.162	-4.896	0
	(10.55)	(10.78)	(0)
bnk_hq_loc_it	-1.537	-1.730	0
	(6.511)	(6.541)	(0)
bnk_hq_loc_jp	-0.362	0.290	0
	(12.30)	(12.25)	(0)
bnk_hq_loc_kr	25.91	25.13	0
	(20.05)	(20.00)	(0)
bnk_hq_loc_kz	-19.54	-19.24	0
	(14.05)	(14.06)	(0)
bnk_hq_loc_li	2.291	2.360	0
	(8.184)	(8.264)	(0)
bnk_hq_loc_lu	-0.773	-1.034	0
	(7.711)	(7.757)	(0)
bnk_hq_loc_mt	10.48	10.65	0
	(6.758)	(6.831)	(0)
bnk_hq_loc_nl	-4.656	-4.825	0
	(6.563)	(6.592)	(0)
bnk_hq_loc_no	4.043	4.572	0
	(17.66)	(17.71)	(0)
bnk_hq_loc_nz	-25.79**	-25.40**	0
	(10.87)	(10.82)	(0)
bnk_hq_loc_om	846.8***	846.8***	0
	(137.7)	(135.9)	(0)
bnk_hq_loc_ph	-204.1	-203.6	0
	(134.5)	(134.7)	(0)
bnk_hq_loc_pt	5.981	5.952	0
	(5.955)	(5.950)	(0)
bnk_hq_loc_ru	-18.59	-17.82	0
	(16.14)	(16.29)	(0)
bnk_hq_loc_sa	-22.12	-21.84	0
	(13.74)	(13.68)	(0)
bnk_hq_loc_se	20.07	19.71	0
	(17.01)	(16.98)	(0)
bnk_hq_loc_sg	-12.58	-11.55	0
	(18.29)	(18.27)	(0)
bnk_hq_loc_uk	9.771	10.24	0
	(10.23)	(10.18)	(0)
bnk_hq_loc_us	-16.20	-15.80	0
	(9.634)	(9.604)	(0)
bnk_hq_loc_za	-20.49	-19.94	0
	(15.50)	(15.40)	(0)
co_hq_co2_pr	0.353**	0.330**	0.297**
	(0.141)	(0.142)	(0.139)
yy_gdp_chg	-23.73	0	0
	(27.65)	(1.20e-07)	(0)
yy_infl	375.7	0	0
	(236.8)	(1.10e-07)	(0)
li_price_s	-0.221	0	0
	(0.137)	(1.51e-10)	(0)
cob_price	0.156	0	0
	(0.113)	(2.64e-10)	(0)
mn_price	0.986	0	0
	(0.826)	(2.81e-09)	(0)
ni_price	-0.0202	0	0
	(0.554)	(2.68e-10)	(0)
bnk_esg_nbm	12.75*	11.05	2.475
	(7.355)	(7.794)	(6.242)
bnk_esg_breg	13.77**	13.71**	29.88**
	(6.336)	(6.104)	(11.00)
bnk_anti_esg_breg	-14.13***	-18.98***	-18.35***
	(4.397)	(5.104)	(4.425)
o.treat			-
o.after20			-
Constant	-23.63	-1.888	-5.940
	(14.91)	(11.15)	(10.60)

Observations	119,526	119,526	119,526
R-squared	0.040	0.041	0.352

Robust standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

Results based on stata’s reghdfe OLS estimation method.

Both time and entity fixed effects treated by means of ‘absorbing’ (Correia, 2016).

B.4.2 Regression Results—Loans All Battery Raw Materials

Table B.22: bat_mat_loans—Sequntial Regressions

VARIABLES	(1) bat_mat_loans_s	(2) bat_mat_loans_s	(3) bat_mat_loans_s	(4) bat_mat_loans_s	(5) bat_mat_loans_s	(6) bat_mat_loans_s	(7) bat_mat_loans_s	(8) bat_mat_loans_s	(9) bat_mat_loans_s	(10) bat_mat_loans_s	(11) bat_mat_loans_s	(12) bat_mat_loans_s	(13) bat_mat_loans_s	(14) bat_mat_loans_s	(15) bat_mat_loans_s	(16) bat_mat_loans_s	(17) bat_mat_loans_s
treat	6.203	1.688	2.245	2.118	1.259	7.457	8.353	7.913	7.784	7.534	7.674	7.756	7.739	7.739	7.629	7.543	7.548
	(11.30)	(10.40)	(10.55)	(10.56)	(10.58)	(11.31)	(11.33)	(11.08)	(11.06)	(11.30)	(11.30)	(11.31)	(11.31)	(11.31)	(11.31)	(11.29)	(11.29)
after	-6.592	-4.699	-5.046	-4.731	-6.473	-0.523	0.646	-0.0242	-0.272	-0.211	-1.159	2.314	-0.535	2.939	2.026	1.161	-1.190
	(10.82)	(11.56)	(11.48)	(11.57)	(10.87)	(12.58)	(12.57)	(11.92)	(11.73)	(11.64)	(11.69)	(12.74)	(11.73)	(14.18)	(14.19)	(13.87)	(13.95)
treat_after	6.064	3.220	3.117	3.102	5.736	-2.126	-3.365	-1.920	-1.603	-1.617	-1.533	-1.564	-1.624	-1.617	-1.634	-1.700	-1.703
	(13.19)	(14.39)	(14.41)	(14.40)	(13.26)	(15.68)	(15.69)	(14.54)	(14.33)	(14.29)	(14.30)	(14.31)	(14.34)	(14.34)	(14.34)	(14.36)	(14.36)
all_loans_s		0.00293	0.00296	0.00303	0.00297	0.00288	0.00299	0.00298	0.00297	0.00300	0.00292	0.00288	0.00291	0.00291	0.00296	0.00302	0.00302
		(0.00211)	(0.00210)	(0.00211)	(0.00205)	(0.00198)	(0.00201)	(0.00202)	(0.00201)	(0.00197)	(0.00197)	(0.00196)	(0.00197)	(0.00197)	(0.00197)	(0.00200)	(0.00200)
co_rev			0.00572	0.00151	-0.00194	-0.00139	-0.00459	-0.000298	1.00e-04	-0.000546	-0.000478	-0.000401	-0.000218	-0.000240	-0.000516	-0.000517	-0.000507
			(0.00423)	(0.00585)	(0.00679)	(0.00622)	(0.00690)	(0.00547)	(0.00555)	(0.00469)	(0.00469)	(0.00468)	(0.00470)	(0.00470)	(0.00473)	(0.00473)	(0.00473)
co_credit_risk				59.61	42.37	11.53	3.636	-13.19	-8.472	-4.141	-4.485	-4.723	-4.942	-4.912	-4.339	-4.182	-4.204
				(73.93)	(73.34)	(66.52)	(71.31)	(67.94)	(66.03)	(64.77)	(64.76)	(64.76)	(64.75)	(64.76)	(64.81)	(64.82)	(64.82)
co_E_rtg					5.893	-20.50*	-19.88	-36.23*	-35.49*	-33.81	-33.88	-33.67	-33.70	-33.70	-33.57	-33.52	-33.51
					(7.208)	(11.99)	(12.28)	(20.67)	(19.84)	(21.89)	(21.88)	(21.85)	(21.86)	(21.86)	(21.86)	(21.84)	(21.84)
co_E_disc						240.9*	163.5	455.7	419.9	412.1	412.9	408.9	408.0	408.2	407.9	407.0	406.8
						(140.9)	(146.3)	(318.7)	(286.5)	(295.4)	(295.3)	(294.4)	(294.2)	(294.3)	(294.3)	(294.0)	(294.1)
co_S_rtg							14.58**	30.27**	30.65**	31.01***	31.01***	30.65***	30.56***	30.57***	30.63***	30.60***	30.57***
							(6.509)	(12.02)	(12.31)	(11.79)	(11.78)	(11.67)	(11.63)	(11.64)	(11.67)	(11.66)	(11.66)
co_S_disc								-317.3	-326.9	-328.8	-329.6	-323.0	-321.8	-322.1	-322.0	-321.0	-320.6
								(205.6)	(216.4)	(213.2)	(213.0)	(211.3)	(211.1)	(211.3)	(211.3)	(211.2)	(211.3)
co_G_rtg									3.488	8.372	8.351	8.159	8.115	8.124	8.173	8.168	8.157
									(8.747)	(16.25)	(16.23)	(16.25)	(16.24)	(16.24)	(16.29)	(16.29)	(16.29)
co_G_disc										-39.71	-39.28	-38.64	-38.29	-38.35	-39.11	-39.27	-39.22
										(137.9)	(137.8)	(138.0)	(138.0)	(138.0)	(138.2)	(138.1)	(138.2)
li_price											-0.000873**	-0.00127***	-0.00129***	-0.00134***	-0.00162***	-0.00131***	-0.00119***
											(0.000389)	(0.000382)	(0.000390)	(0.000398)	(0.000509)	(0.000400)	(0.000389)
mn_price												24.15**	23.75**	19.04***	15.64**	26.62**	24.29**
												(10.97)	(10.79)	(7.036)	(7.151)	(11.72)	(11.63)
ni_price													-4.772*	-5.878	-10.00**	-4.878***	-6.075***
													(2.592)	(3.692)	(4.650)	(1.815)	(2.012)
cob_price														0.898	0.648	1.794	2.183
														(1.138)	(1.153)	(1.713)	(1.817)
cop_price															31.35**	60.72**	58.48*
															(15.52)	(30.72)	(30.42)
al_price																-168.0	-220.0*
																(109.2)	(124.0)
tin_price																	2.724

																	(1.856)
Constant	25.72***	22.41**	19.19*	18.89*	15.90	10.96	9.466	2.861	2.185	3.479	26.08	-76.19	-38.43	-29.12	-66.11	-122.3*	-85.76
	(9.407)	(10.13)	(11.08)	(11.04)	(12.45)	(13.60)	(13.72)	(16.64)	(17.30)	(20.08)	(23.95)	(65.10)	(50.16)	(42.51)	(41.05)	(70.01)	(72.15)
Observations	5,522	5,522	5,522	5,522	5,522	5,522	5,522	5,522	5,522	5,522	5,522	5,522	5,522	5,522	5,522	5,522	5,522
R-squared	0.046	0.048	0.048	0.049	0.050	0.052	0.054	0.057	0.057	0.057	0.057	0.059	0.059	0.059	0.060	0.060	0.060

Robust standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

Results based on stata’s reghdfe OLS estimation method.

Time, company, and bank level fixed effects treated by means of ‘absorbing’ (Correia, 2016).

Table B.23: bat_mat_loans—Baseline Regression

VARIABLES	(1) bat_mat_loans Contemporaneous	(2) bat_mat_loans Lagged 1Q	(3) bat_mat_loans Lagged 2Q	(4) bat_mat_loans Lagged 3Q
treat	6.339	6.374	6.351	4.852
	(11.29)	(11.78)	(11.95)	(11.11)
after	-0.618			
	(13.97)			
treat_after	-2.373			
	(14.37)			
all_loans_adj	0.00342*	0.00332	0.00305	0.00314
	(0.00203)	(0.00204)	(0.00205)	(0.00208)
co_rev	-0.00179	-0.00163	-0.00117	-0.00241
	(0.00494)	(0.00528)	(0.00594)	(0.00685)
co_credit_risk	-8.608	-6.024	-2.957	7.757
	(64.80)	(68.69)	(73.35)	(75.77)
co_fd_yr	0.0115**	0.0120**	0.0125**	0.0125**
	(0.00449)	(0.00471)	(0.00495)	(0.00513)
co_E_rtg	-34.62	-37.10	-40.54	-39.96
	(21.91)	(24.67)	(28.94)	(33.26)
co_E_disc	428.3	462.9	508.7	501.9
	(295.0)	(327.8)	(375.6)	(418.2)
co_S_rtg	30.95***	33.46**	36.49**	36.39**
	(11.69)	(13.45)	(15.74)	(16.99)
co_S_disc	-326.5	-376.5	-443.1	-446.4
	(211.6)	(259.4)	(328.1)	(383.5)
co_G_rtg	8.015	10.20	13.14	13.82
	(16.31)	(16.50)	(16.84)	(17.77)
co_G_disc	-45.92	-50.84	-55.69	-54.77
	(137.9)	(143.5)	(150.2)	(153.2)
li_price	-0.00118***	-0.00110***	-0.000652	-0.000643
	(0.000389)	(0.000392)	(0.000437)	(0.000393)
mn_price	24.37**	27.33*	24.41**	26.02**
	(11.63)	(15.29)	(10.51)	(10.28)
ni_price	-6.028***	-5.314**	-4.922**	-4.547**
	(2.012)	(2.101)	(2.480)	(2.198)
cob_price	2.197	1.221	3.948	3.648
	(1.817)	(2.438)	(3.428)	(2.886)
cop_price	59.40*	67.01**	87.32***	91.18***
	(30.45)	(30.73)	(32.18)	(33.83)
al_price	-222.5*	-191.6	-366.4*	-363.9**
	(124.0)	(140.5)	(210.1)	(173.7)
tin_price	2.694	0.750	3.530	2.999
	(1.858)	(2.767)	(4.596)	(2.997)
L.after		-3.724		
		(22.82)		
L.treat_after		-1.622		
		(14.24)		
L2.after			3.999	
			(19.80)	
L2.treat_after			0.155	
			(13.55)	
L3.after				0
				(0)
L3.treat_after				2.111
				(12.20)
Constant	-101.0	-130.8*	-123.9**	-133.1**
	(73.45)	(75.83)	(61.07)	(64.52)
Observations	5,522	5,271	5,020	4,769
R-squared	0.062	0.064	0.067	0.066

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Results based on stata’s reghdfe OLS estimation method.

Time, company, and bank level fixed effects treated by means of ‘absorbing’ (Correia, 2016)

B.5 The Impact of ESG Performance

B.5.1 ESG Regulation: Impact of ESG Performance

Table B.24: batmat_ph—2019 & 2021 Best and Worst ESG

VARIABLES	(1) batmat_ph Best ESG	(2) batmat_ph Worst ESG
treat	0.699	-41.18**
	(1.183)	(18.76)
after19_21	0	0
	(4.12e-06)	(3.19e-06)
treat_after19_21	0.951	0
	(5.251)	(6.69e-07)
after21	0	-9.642***
	(6.24e-07)	(2.349)
treat_after21	-0.322	-32.74***
	(1.249)	(7.421)
all_ph_s	0.00751*	0.00269
	(0.00436)	(0.00200)
co_hq_loc_au	35.30	-4.324
	(25.60)	(12.52)
co_hq_loc_br	0	-61.37*
	(0.000220)	(33.90)
co_hq_loc_ca	-2.459	-21.37
	(3.153)	(14.26)
co_hq_loc_ch	-7.986	0
	(4.872)	(0.000242)
co_hq_loc_cn	40.45	-16.57
	(35.41)	(14.78)
co_hq_loc_fr	0	71.12
	(0.000258)	(60.45)
co_hq_loc_de	0	0
	(0.000296)	(0.000129)
co_hq_loc_es	0	-51.20***
	(0.000255)	(14.06)
co_hq_loc_hk	0	-0.961
	(0.000409)	(14.84)
co_hq_loc_id	0	82.68
	(0.000175)	(69.33)
co_hq_loc_im	0	20.10
	(0.000294)	(17.25)
co_hq_loc_in	0	-52.93*
	(0.000319)	(27.51)
co_hq_loc_jp	0	-37.06*
	(0.000541)	(21.70)
co_hq_loc_ke	0	-32.86
	(0.000394)	(21.45)
co_hq_loc_kr	0	-1.909
	(0.000222)	(19.03)
co_hq_loc_kz	0	3.223
	(0.000255)	(16.18)
co_hq_loc_lu	0	0
	(8.25e-05)	(0.000358)
co_hq_loc_mx	0	-220.7
	(0.000168)	(135.1)
co_hq_loc_nl	0	0
	(0.000109)	(0.000169)

co_hq_loc_pe	0	-93.57
	(0.000162)	(65.39)
co_hq_loc_ph	0	312.2*
	(0.000189)	(167.3)
co_hq_loc_pl	0	-20.10
	(0.000126)	(24.81)
co_hq_loc_ru	0	0
	(0.000352)	(0.000169)
co_hq_loc_se	0	20.71
	(0.000193)	(22.39)
co_hq_loc_tw	0	-79.89**
	(0.000172)	(30.88)
co_hq_loc_uk	-3.530	-8.743
	(3.516)	(13.51)
co_hq_loc_us	0	-30.00
	(2.25e-09)	(19.22)
co_hq_loc_vg	0	-28.95
	(9.32e-07)	(21.17)
co_hq_loc_za	0	0
	(9.47e-07)	(3.83e-08)
co_share_pr_s	0.204	-0.0123
	(0.221)	(0.123)
co_div	1.164	-4.553
	(4.443)	(5.176)
co_credit_risk	19.45	34.95**
	(44.39)	(16.40)
co_fd_yr	0.0897*	0.0135***
	(0.0446)	(0.00360)
co_rev	0.000114**	-0.00390***
	(4.40e-05)	(0.00120)
co_E	1.629	51.65
	(2.865)	(35.29)
co_E_rtg	-0.182	-52.78
	(1.543)	(31.22)
co_E_disc	-13.05	-0.189
	(11.79)	(73.65)
co_S	-2.997*	-2.252
	(1.645)	(24.75)
co_S_rtg	2.321*	8.480
	(1.269)	(6.286)
co_S_disc	20.05*	-167.9
	(10.81)	(111.5)
co_G	-7.929**	-111.3
	(3.098)	(66.77)
co_G_rtg	7.696**	30.31
	(2.874)	(26.90)
co_G_disc	18.69	526.2*
	(12.30)	(310.9)
bnk_hq_loc_ae	0.715	-60.68*
	(0.499)	(30.88)
bnk_hq_loc_at	3.557	-22.43
	(2.201)	(26.59)
bnk_hq_loc_au	-2.766	-13.61
	(2.671)	(16.04)
bnk_hq_loc_be	0	15.20**
	(2.67e-07)	(7.324)
bnk_hq_loc_br	0	-156.6
	(3.87e-07)	(99.04)
bnk_hq_loc_ca	2.566**	-16.12
	(1.052)	(19.06)
bnk_hq_loc_ch	0.489	-44.59**
	(1.334)	(20.22)
bnk_hq_loc_cn	0	-50.53**
	(6.32e-07)	(24.25)
bnk_hq_loc_co	-2.859**	-16.34**
	(1.124)	(7.775)
bnk_hq_loc_cy	0	25.89***
	(1.32e-07)	(7.984)
bnk_hq_loc_cz	-1.736	0

	(1.357)	(5.84e-07)
bnk_hq_loc_de	0.00784	13.16***
	(1.061)	(4.352)
bnk_hq_loc_dk	3.186	25.99***
	(2.809)	(8.134)
bnk_hq_loc_es	2.980	0.726
	(2.250)	(0.781)
bnk_hq_loc_fr	2.121	9.962***
	(1.714)	(3.451)
bnk_hq_loc_hk	0	-78.10**
	(0)	(34.06)
bnk_hq_loc_ie	0	12.41***
	(0)	(4.300)
bnk_hq_loc_il	-2.860**	-29.54
	(1.122)	(17.52)
bnk_hq_loc_im	4.865**	-39.35**
	(2.325)	(19.30)
bnk_hq_loc_in	0	-8.176
	(0)	(14.12)
bnk_hq_loc_it	2.720	9.604**
	(2.166)	(3.825)
bnk_hq_loc_jp	0.0929	-16.39
	(1.072)	(19.39)
bnk_hq_loc_kr	0	-0.533
	(0)	(18.64)
bnk_hq_loc_kz	0	-36.36*
	(0)	(20.44)
bnk_hq_loc_li	3.051	8.575
	(2.224)	(7.314)
bnk_hq_loc_lu	0	1.363
	(0)	(9.439)
bnk_hq_loc_mt	-3.672***	23.31***
	(1.143)	(7.013)
bnk_hq_loc_nl	0	7.350**
	(0)	(3.289)
bnk_hq_loc_no	23.88	-6.786
	(68.12)	(21.20)
bnk_hq_loc_nz	0	-43.65**
	(0)	(20.14)
bnk_hq_loc_om	0	788.1***
	(0)	(124.3)
bnk_hq_loc_ph	-2.692**	-302.9*
	(1.120)	(172.2)
bnk_hq_loc_pt	0.573	23.19***
	(0.952)	(7.023)
bnk_hq_loc_ru	-2.842**	0
	(1.100)	(1.38e-06)
bnk_hq_loc_sa	0	-39.44*
	(0)	(20.92)
bnk_hq_loc_se	-0.128	28.70*
	(0.624)	(16.23)
bnk_hq_loc_sg	0.690	-27.52
	(3.162)	(25.97)
bnk_hq_loc_uk	-1.354	-2.908
	(2.555)	(16.79)
bnk_hq_loc_us	0	-33.11*
	(0)	(17.93)
bnk_hq_loc_za	0	-25.54
	(0)	(23.09)
co_hq_co2_pr	-0.0145	0.234
	(0.0203)	(0.208)
yy_gdp_chg	0	0
	(0)	(2.03e-08)
yy_infl	0	0
	(0)	(8.80e-08)
li_price_s	0	0
	(0)	(8.88e-11)
cob_price	0	0
	(0)	(2.29e-10)

mn_price	0	0
	(0)	(9.86e-10)
ni_price	0	0
	(0)	(2.98e-10)
bnk_esg_nbm	3.561	8.109
	(3.585)	(8.022)
bnk_esg_breg	2.164	18.71**
	(1.505)	(8.704)
bnk_anti_esg_breg	-2.128	-31.49***
	(1.574)	(7.672)
Constant	-214.2*	19.40
	(109.4)	(22.21)
Observations	13,790	77,190
R-squared	0.319	0.050

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1
Best ESG: first to third quartile of disclosure-adjusted E-, S- and G-rating.
Worst ESG: fourth quartile of disclosure-adjusted E-, S- and G-rating.
Results based on stata’s reghdfe OLS estimation method.
Time fixed effects treated by means of ‘absorbing’ (Correia, 2016).

Table B.25: batmat_ph—2020 Best and Worst ESG

VARIABLES	(1) batmat_ph Best ESG	(2) batmat_ph Worst ESG
treat	0.814	-42.27**
	(0.920)	(18.78)
after20	0	0
	(1.57e-06)	(5.21e-06)
treat_after20	0.0191	-27.78***
	(1.283)	(6.313)
all_ph_s	0.00751*	0.00268
	(0.00435)	(0.00200)
co_hq_loc_au	35.24	-4.358
	(25.48)	(12.52)
co_hq_loc_br	0	-61.43*
	(0.000211)	(33.90)
co_hq_loc_ca	-2.457	-21.34
	(3.156)	(14.25)
co_hq_loc_ch	-7.657	0
	(4.552)	(0.000294)
co_hq_loc_cn	40.38	-16.57
	(35.33)	(14.77)
co_hq_loc_fr	0	71.90
	(7.58e-05)	(60.44)
co_hq_loc_de	0	0
	(0.000103)	(0.000207)
co_hq_loc_es	0	-50.88***
	(0.000151)	(13.99)
co_hq_loc_hk	0	-0.977
	(0.000473)	(14.82)
co_hq_loc_id	0	82.66
	(0.000227)	(69.33)
co_hq_loc_im	0	20.01
	(0.000253)	(17.34)
co_hq_loc_in	0	-52.68*
	(0.000167)	(27.50)
co_hq_loc_jp	0	-37.10*
	(0.000325)	(21.70)
co_hq_loc_ke	0	-32.93
	(6.32e-05)	(21.45)
co_hq_loc_kr	0	-1.828
	(0.000120)	(19.05)
co_hq_loc_kz	0	3.169
	(0.000136)	(16.17)
co_hq_loc_lu	0	0
	(8.35e-05)	(0.000708)
co_hq_loc_mx	0	-221.0
	(7.83e-05)	(135.2)
co_hq_loc_nl	0	0
	(0.000185)	(0.000494)
co_hq_loc_pe	0	-93.79
	(4.11e-05)	(65.39)
co_hq_loc_ph	0	312.1*
	(0.000159)	(167.3)
co_hq_loc_pl	0	-19.54
	(0.000103)	(24.70)
co_hq_loc_ru	0	0
	(8.32e-05)	(0.000223)
co_hq_loc_se	0	20.89
	(4.17e-05)	(22.37)
co_hq_loc_tw	0	-79.82**
	(4.58e-05)	(30.89)
co_hq_loc_uk	-3.428	-8.408
	(3.402)	(13.48)
co_hq_loc_us	0	-30.03
	(1.00e-07)	(19.22)

co_hq_loc_vg	0	-29.02
	(0.000101)	(21.17)
co_hq_loc_za	0	0
	(3.10e-05)	(3.53e-06)
co_share_pr_s	0.204	-0.0141
	(0.220)	(0.123)
co_div	1.163	-4.497
	(4.480)	(5.184)
co_credit_risk	19.46	34.88**
	(44.23)	(16.41)
co_fd_yr	0.0903*	0.0135***
	(0.0452)	(0.00360)
co_rev	0.000109**	-0.00389***
	(4.64e-05)	(0.00120)
co_E	1.637	51.16
	(2.862)	(35.23)
co_E_rtg	-0.188	-52.79
	(1.543)	(31.23)
co_E_disc	-13.20	1.555
	(11.81)	(73.30)
co_S	-3.007*	-1.715
	(1.650)	(24.79)
co_S_rtg	2.330*	8.365
	(1.270)	(6.288)
co_S_disc	20.11*	-168.0
	(10.85)	(111.6)
co_G	-8.058**	-111.2
	(3.056)	(66.77)
co_G_rtg	7.786***	30.15
	(2.853)	(26.90)
co_G_disc	19.02	526.7*
	(12.24)	(311.0)
bnk_hq_loc_ae	0.717	-60.44*
	(0.498)	(30.88)
bnk_hq_loc_at	3.559	-22.40
	(2.198)	(26.56)
bnk_hq_loc_au	-2.768	-13.33
	(2.661)	(16.03)
bnk_hq_loc_be	0	15.23**
	(4.74e-07)	(7.291)
bnk_hq_loc_br	0	-156.5
	(1.23e-07)	(99.05)
bnk_hq_loc_ca	2.568**	-15.87
	(1.050)	(19.06)
bnk_hq_loc_ch	0.471	-44.43**
	(1.317)	(20.21)
bnk_hq_loc_cn	0	-50.81**
	(3.72e-07)	(24.25)
bnk_hq_loc_co	-2.856**	-16.34**
	(1.120)	(7.776)
bnk_hq_loc_cy	0	25.90***
	(3.49e-07)	(7.935)
bnk_hq_loc_cz	-1.735	0
	(1.367)	(2.05e-07)
bnk_hq_loc_de	0.00917	13.17***
	(1.068)	(4.303)
bnk_hq_loc_dk	3.177	26.10***
	(2.802)	(8.107)
bnk_hq_loc_es	2.982	0.725
	(2.245)	(0.788)
bnk_hq_loc_fr	2.122	9.980***
	(1.720)	(3.416)
bnk_hq_loc_hk	0	-78.31**
	(6.56e-08)	(34.05)
bnk_hq_loc_ie	0	12.42***
	(2.20e-07)	(4.278)
bnk_hq_loc_il	-2.857**	-29.30
	(1.118)	(17.51)
bnk_hq_loc_im	4.866**	-39.09*

	(2.321)	(19.28)
bnk_hq_loc_in	0	-7.829
	(0)	(14.13)
bnk_hq_loc_it	2.720	9.620**
	(2.160)	(3.795)
bnk_hq_loc_jp	0.0779	-16.23
	(1.054)	(19.39)
bnk_hq_loc_kr	0	-0.425
	(0)	(18.66)
bnk_hq_loc_kz	0	-36.09*
	(0)	(20.44)
bnk_hq_loc_li	3.052	8.611
	(2.218)	(7.302)
bnk_hq_loc_lu	0	1.381
	(0)	(9.421)
bnk_hq_loc_mt	-3.670***	23.29***
	(1.149)	(6.992)
bnk_hq_loc_nl	0	7.356**
	(0)	(3.261)
bnk_hq_loc_no	23.89	-6.721
	(67.71)	(21.18)
bnk_hq_loc_nz	0	-43.38**
	(0)	(20.13)
bnk_hq_loc_om	0	788.4***
	(0)	(123.8)
bnk_hq_loc_ph	-2.690**	-302.6*
	(1.116)	(172.3)
bnk_hq_loc_pt	0.575	23.17***
	(0.958)	(7.002)
bnk_hq_loc_ru	-2.839**	0
	(1.096)	(1.19e-06)
bnk_hq_loc_sa	0	-39.18*
	(0)	(20.91)
bnk_hq_loc_se	-0.126	28.70*
	(0.628)	(16.20)
bnk_hq_loc_sg	0.662	-27.40
	(3.153)	(25.96)
bnk_hq_loc_uk	-1.361	-2.725
	(2.556)	(16.79)
bnk_hq_loc_us	0	-32.89*
	(0)	(17.91)
bnk_hq_loc_za	0	-25.42
	(0)	(23.08)
co_hq_co2_pr	-0.0158	0.228
	(0.0201)	(0.207)
yy_gdp_chg	0	0
	(0)	(9.17e-08)
yy_infl	0	0
	(0)	(3.69e-08)
li_price_s	0	0
	(0)	(5.64e-11)
cob_price	0	0
	(0)	(1.36e-10)
mn_price	0	0
	(0)	(2.23e-09)
ni_price	0	0
	(0)	(2.41e-10)
bnk_esg_nbm	3.646	8.536
	(3.570)	(8.073)
bnk_esg_breg	2.167	18.95**
	(1.504)	(8.749)
bnk_anti_esg_breg	-2.053	-30.98***
	(1.586)	(7.547)
Constant	-215.3*	19.18
	(110.5)	(22.20)
Observations	13,790	77,190
R-squared	0.319	0.050

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1
Best ESG: first to third quartile of disclosure-adjusted E-, S- and G-rating.
Worst ESG: fourth quartile of disclosure-adjusted E-, S- and G-rating.
Results based on stata’s reghdfe OLS estimation method.
Time fixed effects treated by means of ‘absorbing’ (Correia, 2016).

Table B.26: batmat_ph—2019, 2020 & 2021 Best and Worst ESG

VARIABLES	(1) batmat_ph Best ESG	(2) batmat_ph Worst ESG
treat	0.699	-41.18**
	(1.183)	(18.76)
after19_20	0	0
	(4.12e-06)	(7.33e-07)
treat_after19_20	0.951	-9.350***
	(3.318)	(2.327)
after20_21	0	0
	(1.11e-06)	(7.75e-07)
treat_after20_21	2.492	-10.08***
	(5.251)	(2.429)
after21	0	0
	(6.24e-07)	(7.25e-07)
treat_after21	-0.322	-32.74***
	(1.249)	(7.421)
all_ph_s	0.00751*	0.00269
	(0.00436)	(0.00200)
co_hq_loc_au	35.30	-4.324
	(25.60)	(12.52)
co_hq_loc_br	0	-61.36*
	(0.000220)	(33.90)
co_hq_loc_ca	-2.459	-21.37
	(3.153)	(14.26)
co_hq_loc_ch	-7.986	0
	(4.872)	(0.000235)
co_hq_loc_cn	40.45	-16.57
	(35.41)	(14.78)
co_hq_loc_fr	0	71.12
	(0.000258)	(60.45)
co_hq_loc_de	0	0
	(0.000296)	(0.000180)
co_hq_loc_es	0	-51.20***
	(0.000255)	(14.06)
co_hq_loc_hk	0	-0.961
	(0.000409)	(14.84)
co_hq_loc_id	0	82.68
	(0.000175)	(69.33)
co_hq_loc_im	0	20.10
	(0.000294)	(17.24)
co_hq_loc_in	0	-52.93*
	(0.000319)	(27.51)
co_hq_loc_jp	0	-37.06*
	(0.000541)	(21.70)
co_hq_loc_ke	0	-32.86
	(0.000394)	(21.45)
co_hq_loc_kr	0	-1.913
	(0.000222)	(19.03)
co_hq_loc_kz	0	3.223
	(0.000255)	(16.18)
co_hq_loc_lu	0	0
	(8.25e-05)	(0.000135)
co_hq_loc_mx	0	-220.7
	(0.000168)	(135.1)
co_hq_loc_nl	0	0
	(0.000109)	(0.000159)
co_hq_loc_pe	0	-93.56
	(0.000162)	(65.39)
co_hq_loc_ph	0	312.2*
	(0.000189)	(167.3)
co_hq_loc_pl	0	-20.10
	(0.000126)	(24.81)
co_hq_loc_ru	0	0
	(0.000352)	(0.000287)

co_hq_loc_se	0	20.71
	(0.000193)	(22.39)
co_hq_loc_tw	0	-79.89**
	(0.000172)	(30.88)
co_hq_loc_uk	-3.530	-8.743
	(3.516)	(13.51)
co_hq_loc_us	0	-30.00
	(2.25e-09)	(19.22)
co_hq_loc_vg	0	-28.95
	(9.32e-07)	(21.17)
co_hq_loc_za	0	0
	(9.47e-07)	(2.28e-07)
co_share_pr_s	0.204	-0.0123
	(0.221)	(0.123)
co_div	1.164	-4.551
	(4.443)	(5.178)
co_credit_risk	19.45	34.95**
	(44.39)	(16.40)
co_fd_yr	0.0897*	0.0135***
	(0.0446)	(0.00360)
co_rev	0.000114**	-0.00390***
	(4.40e-05)	(0.00120)
co_E	1.629	51.64
	(2.865)	(35.30)
co_E_rtg	-0.182	-52.77
	(1.543)	(31.22)
co_E_disc	-13.05	-0.170
	(11.79)	(73.65)
co_S	-2.997*	-2.248
	(1.645)	(24.75)
co_S_rtg	2.321*	8.479
	(1.269)	(6.286)
co_S_disc	20.05*	-167.9
	(10.81)	(111.5)
co_G	-7.929**	-111.3
	(3.098)	(66.77)
co_G_rtg	7.696**	30.31
	(2.874)	(26.90)
co_G_disc	18.69	526.2*
	(12.30)	(310.9)
bnk_hq_loc_ae	0.715	-60.68*
	(0.499)	(30.88)
bnk_hq_loc_at	3.557	-22.43
	(2.201)	(26.59)
bnk_hq_loc_au	-2.766	-13.61
	(2.671)	(16.04)
bnk_hq_loc_be	0	15.20**
	(2.67e-07)	(7.324)
bnk_hq_loc_br	0	-156.6
	(3.87e-07)	(99.04)
bnk_hq_loc_ca	2.566**	-16.12
	(1.052)	(19.06)
bnk_hq_loc_ch	0.489	-44.59**
	(1.334)	(20.22)
bnk_hq_loc_cn	0	-50.53**
	(6.32e-07)	(24.25)
bnk_hq_loc_co	-2.859**	-16.34**
	(1.124)	(7.776)
bnk_hq_loc_cy	0	25.89***
	(1.32e-07)	(7.984)
bnk_hq_loc_cz	-1.736	0
	(1.357)	(1.55e-06)
bnk_hq_loc_de	0.00784	13.16***
	(1.061)	(4.353)
bnk_hq_loc_dk	3.186	25.99***
	(2.809)	(8.135)
bnk_hq_loc_es	2.980	0.726
	(2.250)	(0.781)
bnk_hq_loc_fr	2.121	9.962***

	(1.714)	(3.451)
bnk_hq_loc_hk	0	-78.10**
	(0)	(34.06)
bnk_hq_loc_ie	0	12.41***
	(0)	(4.301)
bnk_hq_loc_il	-2.860**	-29.54
	(1.122)	(17.52)
bnk_hq_loc_im	4.865**	-39.35**
	(2.325)	(19.30)
bnk_hq_loc_in	0	-8.176
	(0)	(14.12)
bnk_hq_loc_it	2.720	9.604**
	(2.166)	(3.825)
bnk_hq_loc_jp	0.0929	-16.39
	(1.072)	(19.39)
bnk_hq_loc_kr	0	-0.529
	(0)	(18.64)
bnk_hq_loc_kz	0	-36.36*
	(0)	(20.44)
bnk_hq_loc_li	3.051	8.575
	(2.224)	(7.314)
bnk_hq_loc_lu	0	1.363
	(0)	(9.439)
bnk_hq_loc_mt	-3.672***	23.31***
	(1.143)	(7.016)
bnk_hq_loc_nl	0	7.350**
	(0)	(3.289)
bnk_hq_loc_no	23.88	-6.786
	(68.12)	(21.20)
bnk_hq_loc_nz	0	-43.65**
	(0)	(20.14)
bnk_hq_loc_om	0	788.1***
	(0)	(124.3)
bnk_hq_loc_ph	-2.692**	-302.9*
	(1.120)	(172.2)
bnk_hq_loc_pt	0.573	23.19***
	(0.952)	(7.026)
bnk_hq_loc_ru	-2.842**	0
	(1.100)	(2.02e-06)
bnk_hq_loc_sa	0	-39.44*
	(0)	(20.92)
bnk_hq_loc_se	-0.128	28.70*
	(0.624)	(16.23)
bnk_hq_loc_sg	0.690	-27.52
	(3.162)	(25.97)
bnk_hq_loc_uk	-1.354	-2.908
	(2.555)	(16.79)
bnk_hq_loc_us	0	-33.11*
	(0)	(17.93)
bnk_hq_loc_za	0	-25.54
	(0)	(23.09)
co_hq_co2_pr	-0.0145	0.234
	(0.0203)	(0.208)
yy_gdp_chg	0	0
	(0)	(4.77e-08)
yy_infl	0	0
	(0)	(3.03e-08)
li_price_s	0	0
	(0)	(8.29e-11)
cob_price	0	0
	(0)	(1.81e-10)
mn_price	0	0
	(0)	(2.57e-09)
ni_price	0	0
	(0)	(0)
bnk_esg_nbm	3.561	8.109
	(3.585)	(8.022)
bnk_esg_breg	2.164	18.71**
	(1.505)	(8.704)

bnk_anti_esg_breg	-2.128	-31.49***
	(1.574)	(7.673)
Constant	-214.2*	19.40
	(109.4)	(22.21)
Observations	13,790	77,190
R-squared	0.319	0.050

Robust standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

Best ESG: first to third quartile of disclosure-adjusted E-, S- and G-rating.

Worst ESG: fourth quartile of disclosure-adjusted E-, S- and G-rating.

Results based on stata's reghdfe OLS estimation method.

Time fixed effects treated by means of 'absorbing' (Correia, 2016).

B.6 Share Prices

B.6.1 Share Prices: All Battery Raw Materials

Note: co_share_pr, EUR.

Figure B.22: Average Share Prices All Battery Raw Material Companies

Table B.27: Share Prices All Battery Raw Materials—Parallel Trends Normalized Differences

	Held by Treated		Held by Control		Norm. Diff.
VARIABLES	Mean	Std. Dev.	Mean	Std. Dev.	
co_share_pr	49.42	190.79	46.04	178.78	0.02
co_share_pr (pre-treatment)	10.80	25.88	12.16	21.24	0.06
co_share_pr (post-treatment)	95.30	273.80	86.28	257.69	0.03

Statistics of relevant co-variates of the share prices of All Battery Raw Material companies, whose shares are held by banks of the treated and the control groups. Reported for the overall period (Q1/2015 to Q3/2023), the pre-treatment period (Q1/2015 to Q3/2019) and the post-treatment period (Q4/2019 to Q3/2023). The last column reports normalized differences between the two groups, i.e., differences in averages by treatment status, scaled by the square root of the sum of the variances. An absolute difference smaller than 0.25 indicates that there is no significant difference between the groups. See Table B.8 for detailed variable definitions incl. units.

Rounded values shown.

Chapter 4

Impacts of ECB Banking Supervision on Climate Risk and Sustainable Finance

List of Abbreviations

AUM	Assets under management	GB	Green bonds
CRST	Climate risk stress test	GHG	Greenhouse gas
DiD	Difference-in-difference	LSI	Less Significant Institutions
ECB	European Central Bank	OLS	Ordinary least squares
EU	European Union	SFDR	Sustainable Finance Disclosure Regulation
ESG	Environmental, social and governance	SI	Significant Institutions
E-Score	Environmental Score	YY	Year-over-year
FI	Financial institutions		

4.1 Introduction

Climate change and climate risk have become key concerns for policy makers at central banks and in banking supervision. It is widely acknowledged that climate risks impose an increasing challenge to the transmission mechanisms of central bank's monetary policy, as well as to the financial sector (e.g., Garbarino and Guin, 2021; De Marco, 2023). Furthermore, financial institutions in general, and banks in particular, are supposed to play a central role in providing capital to finance the transition to an environmentally sustainable economy, i.e., to provide green or, more specifically, climate finance (EC, 2023). In this Chapter we focus on the relationship between banking supervision on the one hand and climate risk and climate finance within the banking sector on the other hand.

Banks are affected by climate risk due to two classes of risk: physical and transition risk. Physical risk affects banks because their assets are exposed to risks due to natural disasters induced by climate change. Transition risks, in contrast, emerge due to measures imposed by energy and climate policy and regulation. Even though climate risk analysis is dealing with the pricing of hypothetical future events, there is plenty of recent anecdotical evidence where both classes of climate risk have already materialized[58]. A systematically inadequate and insufficient identification and pricing of these risks in banks' risk identification, assessment and management processes could impose major threats to the stability of the financial system (as argued, e.g., in Monasterolo, 2020; Dafermos and Nikolaidi, 2022)[59]. At the same time, a successful global implementation of a carbon-neutral economy to reach certain emission targets requires considerable investments. For instance, the IPCC (2018) estimates that limiting global warming to 1.5 °C will require worldwide annual investments of approximately 2.4 trillion (tr) USD into the energy system until 2035; BCG (2021) forecasts the annual investments to be 100 billion (bn) EUR until 2030 for Germany only. The private financial sector, including the banking sector, is assigned a central role in mobilizing, and financing these investments, thereby contributing to steer the carbon-neutral transition of economies worldwide. In this sense, Article 2.1c of the 2015 Paris Agreement calls for "making finance flows consistent with a pathway

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[58] Examples in Germany are the recent 2021 flood disaster in the German *Ahrtal*, during which real estate of entire villages got destroyed within hours; the river Rhine's low water levels in summer interrupting supply chains; or the political ambition of the German federal government to speed up the planned phase out of coal-fired power generation from 2034 to 2030 (Bundesregierung, 2023) and, thus, assets becoming stranded earlier than expected (Battiston et al., 2017, 2020; Semienuk et al., 2020; Van der Ploeg and Rezai, 2020).

[59] There are several reasons why banks may not independently internalize physical and transition risks related to climate change despite the clear and present danger these risks represent. Decision-makers within banks often face short-term incentives such as short-term revenue maximization targets. Climate-risk-related information and capabilities are not (fully) available and need to be generated and build-up. This is associated with immediate costs, while climate-related risks might only materialize in the more distant future. Also, immediate regulatory penalties to ignore long-term climate risks are still absent. This might cause short-sighted decision-makers to delay their action. Furthermore, technological conservatism within financial institutions (i.e., a preference for established practices) may slow down banks to adopt new technologies or methodologies that could capture climate-related risks (e.g., Dafermos, 2022; De Marco and Limodio, 2023).

towards low greenhouse gas (GHG) emissions and climate-resilient development" (UN, 2015; 2022).

Regarding the reduction of climate risk in the banking sector, competent authorities, which are responsible for banking supervision, play a key role in ensuring an adequate reflection of climate risk in banks' overall risk identification, assessment, and management[60]. In the euro area, the ECB has introduced a set of activities in 2020 to address climate risks also via banking supervision. These activities—i.e., a climate risk stress test (CRST), a 'Thematic Review' and a 'Short-term Exercise', see Section 4.3—have been carried out for the first time in 2022. Also in other jurisdictions, banking supervisory authorities have conducted similar exercises, such as the US Federal Reserve in 2023, Canada's Office of the Superintendent of Financial Institutions in 2020, or the Australian Prudential Regulation Authority in 2021 (Oliver Wyman, 2023). Potentially, these supervisory efforts have an impact also on banks' capital allocation behavior—at least to an extent to which this is motivated by a change in their risk assessment strategies.

This Chapter sheds light on two research questions: Firstly, do climate-risk-related supervisory activities of the ECB have an effect on the climate risk exposure and management of the affected banks? Secondly, do those activities have an impact on green capital allocation of banks? We empirically assess these two questions by means of a difference-in-difference (DiD) approach. Doing so, we take advantage of the introduction of the Single Supervisory Mechanism from 2012 to 2014[61], mandating the ECB to directly exercise prudential supervision

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[60] In the Eurozone, the ECB is responsible for the supervision of the most system-relevant Significant Institutions (SI); National Competent Authorities are responsible for the supervision of Less Significant Institutions (LSI). Climate-risk-related supervision is guided by the Basel Committees principles on climate-related financial risk (BIS, 2022).

[61] See https://www.bankingsupervision.europa.eu/about/thessm/html/index.en.html (accessed 09/2023).

of banks headquartered in the euro area and classified as Significant Institutions (SIs) via the ECB's own supervisory arm. Meanwhile, banks classified as Less Significant Institutions (LSIs) have remained under the supervision of the national competent authorities[62] (Ampudia et al., 2023). This setup allows us to take the ECB's climate-risk-related supervisory efforts as an external shock to the SIs only and compare the observed effects to the ones observed for the LSIs as a control group. This has the advantage that the treatment and the control groups operate in a very similar environment, thus limiting the number of other potential factors influencing a deviating behavior after the shock. To account for the fact that SIs and LSIs have, nevertheless, also differences (especially in terms of their size), where possible, we include banks headquartered in all EU-non-euro-area economies as a second control group in our analyses. We assess the impact of the introduction of the ECB's climate-risk-related supervision on SIs' climate risk rating (Bloomberg), as well as on SIs' green bond (GB) issuance, their 'environmental, social and governance assets under management' (ESG-AUM) and their lending to green vs. brown debtors. We find statistically significant impacts on both a decrease of climate risk and on an increase in climate finance (as represented by GB issuance, ESG-AUM and green lending)[63]. Apart from these main findings, a key lesson learnt from our research is that coverage, quality, standardization, and granularity of environmental data have to be improved significantly in order to gauge the impact of supervisory measures more

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[62] The criteria for a bank being classified as an SI are: size (total value of assets > EUR30 bn); economic importance (for the specific country or the EU economy as a whole); cross-border activities (total value of assets > EUR5 bn; ratio of cross-border assets/liabilities in more than one other participating Member State to its total assets/liabilities > 20); direct public financial assistance (has requested or received funding from the European Stability Mechanism or the European Financial Stability Facility), see https://www.bankingsupervision.europa.eu/banking/list/criteria/ (accessed 11/2023) (Ampudia et al., 2023).

[63] Note that the results obtained are purely positive and do not allow any direct conclusion regarding the normative requirements to the banks' level of climate risk reduction set, for instance, in the ECB Guide on climate-related and environmental risk and assessed during the benchmarking processes.

diligently. More comprehensive policy, legislative and regulatory efforts will be necessary in particular regarding standardization and harmonization of disclosed data.

The remainder of this Chapter is structured as follows: Section 4.2 provides an overview of the current state-of-the-art research and our contribution. Section 4.3 lays out the theoretical foundations underlying the treatment effects. Section 4.4 specifies the empirical framework, and Section 4.5 the data and descriptive statistics underlying our analysis. Section 4.6 expounds our analyses' results. Section 4.7 concludes and provides some policy recommendations.

4.2 Current State of Research and our Contribution

This Chapter contributes to two strands of research. Firstly, we contribute to the literature that deals with banking regulation and supervision; secondly, this Chapter provides new results in the field of sustainable finance (i.e., climate finance).

The literature strand dealing with banking regulation and supervision sheds light on the impact and optimal design of both climate-unrelated and climate-related supervisory activities. Amongst the climate-unrelated literature in this field, the closest to this Chapter's assessments are analyses of the impact of stress tests on banks' risk exposure and their security holdings and issuance. For instance, Neretina et al. (2015) empirically assess US supervisory banking stress test effects on banks' credit risk, systematic risk, and systemic risk and find a lagged mitigating effect of the stress testing on systemic risk. Luu and Vo (2021), similarly, empirically assess the impact of US supervisory stress tests on banks' risk-taking behavior, finding that banks which are subject to annual supervisory stress tests tend to reduce their overall risk by choosing asset portfolios of lower risk exposures. Archarya et al. (2018), Argawal et al. (2020), Cortés et al. (2020) and Kok et al. (2023) reach similar conclusions for different economies including the EU. Nguyen et al. (2020) examine the effect of US supervisory stress tests on banks' risk exposures to meet higher capital requirements by means of liquidity creation, finding that stress tests have a negative effect on both on- and off-balance sheet bank liquidity creation and asset-side liquidity creation. In contrast, Gambetta et al. (2019) assess the connection between banks' risk factors and the macro stress testing results and find that financial institutions, which are comparatively inefficient or complex, operating at low profitability levels and having a small loan portfolio, receive more negative results in the stress tests. Furthermore, Morgan et al. (2014) and Flannery et al. (2017) study the information generation effect of competent authorities' stress tests and find a significant positive impact. Ellahie (2013) analyzes the consequences of EU supervisory stress tests on the information availability and distribution in capital markets and finds a reducing effect of both the announcement and the implementation of stress tests on information uncertainty and asymmetry in capital markets. Based on a similar reasoning, Borges et al. (2019) assess the impact of information generation of EU bank stress tests on bank behavior and find the most impactful element of the stress testing process on banks being the disclosure of the information on the stress testing methodology. Finally, Bassett and Berrospide (2018) quantify the impact of the stress tests on the amount of loans issued, finding that the 'capital gap', i.e., the delta between the capital implied by the supervisory stress tests and the level of capital implied by the banks' own models has no restricting effect on loan growth. While these climate-unrelated contributions provide some insights regarding the mechanisms of interdependency related to our research questions, literature explicitly assessing the effect of CRST is still very scarce—a lacuna to which this Chapter contributes. Nguyen et al. (2023) assess the impact of a French CRST pilot exercise performed with a group of nine French banks on the banks' sustainable lending. They find that the nine climate-stress-tested banks increase lending to low-carbon debtors, and, at the same time, charge higher interest rates for borrowers with high transition risk. Gianetti (2023) assesses the interrelation of increased ESG disclosure of banks on their sustainable behavior, finding that banks with better ESG disclosure do not necessarily increase their lending to green borrowers, pointing to greenwashing issues. Some other contributions assess other potential undesired effects within climate-related supervisory activities: for instance, Beck et al. (2023) analyze effects of incomplete coverage in climate-related supervisory cooperation and cooperation externalities. Benincasa et al. (2022) assess the impact of domestic climate policy on green and brown cross-border lending. Both find evidence for arbitrage activities, i.e., increased brown lending to borrowers based in economies lacking strict climate-related regulation and supervision of the banking sector. More broadly, and assessing other supervisory tools than CRST, Oehmke and Opp (2023) provide a theoretical framework to assesses the impact of green capital requirements in the form of either a green supporting factor or a brown penalizing factor on banks' sustainable lending activities. Their model predicts that a green supporting factor has the potential to increase sustainability in banks' lending activities, while a brown penalizing factor might have an adverse effect. Gouriéroux (2022) propose a methodology to calculate capital requirements for climate-related long-run risks. Alessi et al. (2022) assess different macro-prudential instruments to address climate risk and propose a temporary extra capital buffer for those risks, until the economy and banks' balance sheets become greener, D'Orazio and Popoyan (2019) and Hidalgo-Oñate et al. (2023) review different macroprudential instruments to reduce climate risk and foster green investment, and D'Orazio (2021) proposes several approaches to better align macroprudential COVID recovery policies with climate goals.

Contributions dealing with sustainable finance or climate finance that are closely related to this Chapter focus on questions around how to best incentivize the financing of initially mentioned investments into setting up a sustainable economy. The EU has clearly communicated the political intention and to strengthen the role of the financial sector in order to act as an enabler to guide the low-carbon transition (EU, 2021). The academic literature that explores different transmission mechanisms of sustainable finance is growing rapidly. Ghisetti et al. (2015), Noally and Smeets (2016) and Egli et al. (2022) describe the role of financing constraints for directed technical change from fossil fuels to renewable energy technology innovation. Mazzucato (2013, 2018) describes the impact of the type of finance—public vs. private—provided. Furthermore, Campiglio (2016) assess the role of banking and monetary policy in financing the transition to a low-carbon economy, and Papoutsi et al. (2022) present an assessment of the impact of quantitative easing on sustainable developments in the economy. Also, public-private approaches are often seen as a vehicle to close investment gaps, as well as to allocate risks in a more efficient manner (cf. e.g., OECD, 2017; 2020). In this context, inter alia OECD (2019) investigates the role of alternative financing vehicles in sustainable finance, including, for instance, public-private partnerships. Monk and Perkins (2020) assess drivers for the emergence and diffusion of green bonds. However, from an academic perspective, the role of finance in contributing effectively and efficiently to the transitioning to a low-carbon economy has so far been considerably underestimated (Mercure et al., 2019; De Haas and Popov, 2022).

Our original contribution is, hence, twofold: Firstly, we contribute to the literature dealing with banking regulation and supervision by shedding some light on the impact of CRST on banks' risk exposure. Secondly, we contribute to the literature dealing with climate finance by analyzing CRSTs as one potential driver for sustainable finance and reductions in carbon emissions.

4.3 Theoretical Framework

4.3.1 Background: the ECB's Climate-risk-related Supervision

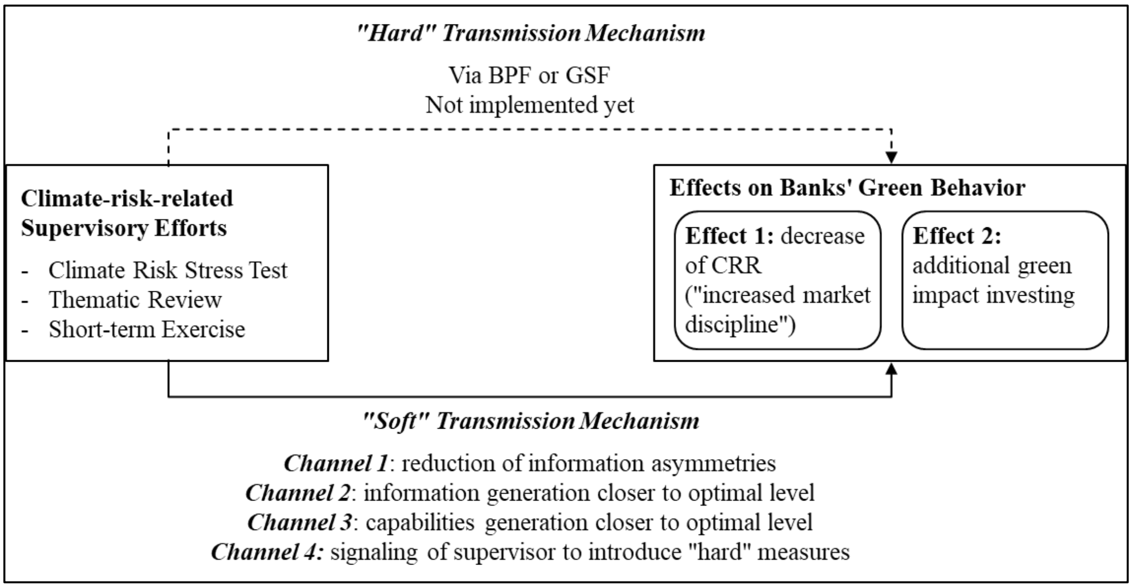
The ECB has initiated its efforts to supervise climate risk in 2020 with the communication of its 'Guide on Climate-related and Environmental Risks: Supervisory expectations relating to risk management and disclosure' (ECB, 2020). In that guide, the ECB specifies its expectations to the SIs relating to (i) business model and strategy, (ii) governance and risk appetite, (iii) risk management; and (iv) disclosure in a climate risk context. The goal is to enhance the banking industry's awareness of and preparedness for managing climate-related and environmental risks. SIs have been "expected to consider the extent to which their current management and disclosure practices for climate-related and environmental risks are sound, effective, and comprehensive in the light of the expectations set out in the guide". Where needed, SIs have been "expected to promptly start enhancing their practices" and have been asked by the ECB's 'Joint Supervisory Teams' to 'inform the ECB of any existing divergences in their practices from the supervisory expectations and of arrangements aimed at progressively addressing these expectations" until 2021 (ECB, 2020, p.8). All expectations will be gradually implemented until 2024. The efforts do not apply for LSIs, which are supervised by the national competent Authorities.

Following the publication of the guide, the ECB has performed three concrete supervisory exercises in 2022 to assess and enhance SIs' level of preparedness for properly managing climate risk: a 'Climate Related Stress Test' (CRST), a 'Thematic Review' (TR) and a 'Short-term Exercise' (STE). The CRST has been carried out in 2022 for the first time as a component of the stress testing in the context of the 'Supervisory Review and Evaluation Process' (see Article 100 of the Capital Requirements Directive CRD IV, ECB, 2022b). The CRST is "seen as a joint learning exercise with pioneering characteristics aimed at enhancing both banks' and supervisors' capacity to assess climate risk", and aims at generating transparency regarding and improving the availability of climate-related information and capabilities (ECB, 2021; 2022b). This goes in line with the established opinion that one key effect of stress testing is to create information, thereby reducing information asymmetries. Particularly, the CRST generates information with regard to climate risk exposure and management, as well as unmanaged climate risk. Furthermore, the relevance of climate risk to the different SIs is determined by means of a 'Risk Tolerance Framework' (ECB 2023b). The CRST is complemented by the Thematic Review exercise, which puts the magnifying glass on SIs' climate risk management capabilities and practices, such as the inclusion of climate risk in the SIs' strategy as well as their cascading down into the operative functions (ECB, 2022a). The Short-term Exercise as the third component of the climate risk supervisory efforts aims at establishing a view on the general disclosure of climate risk information by SIs, i.e., about the coverage of the SI's climate risk reporting (ECB, 2023c). To verify SIs' self-reported results, Joint Supervisory Teams may perform on-site inspections. The climate risk supervisory exercises are intended to be continued and improved throughout the coming years and will be complemented by further exercises such as climate risk reporting as an enhanced Pillar 3 component of the Basel III reporting requirements, which the EU has already embedded within the forthcoming CRR3 regulation (Oliver Wyman, 2023) and further stress testing exercises contributing to the EU's fit-for-55 strategy (ECB, 2023d) under the aegis of the European Banking Authority. While the 2022 exercises had a pilot and informative character, going forward, the according supervision will be further developed and refined (Gouriéroux, 2022; RI, 2022).

4.3.2 Effects of Climate-risk-related Supervisory Efforts

Climate-risk-related supervision might affect banks' green behavior—i.e., the reduction of climate-risk-related and climate finance—through two transmission mechanisms: (i) a 'soft' transmission mechanism, based on additional information, capabilities and signaling effects; and (ii) a 'hard' transmission mechanism based on induced changes in the cost of bank lending, e.g., through a green supporting factor or a brown penalizing factor, see Figure 23.

In this Chapter we focus on the soft transmission mechanism, also because, so far, no green supporting factor or brown penalizing factor resulting from the banks' climate risk assessment have been imposed. This might change in the future and could also intensify the regulatory and supervisory impact; however, political resistance may hamper its implementation (Oliver Wyman, 2023). This setup, i.e., the prevalence of the soft transmission mechanism and absence of the hard transmission mechanism, allows us to analyze the effects that supervisory exercises might have on climate-related information gathering and improvement of skills in isolation, without being distorted by overlapping effects of the hard transmission mechanism. We propose four distinct channels through which the soft transmission mechanism might operate: channel 1 induces a reduction of information asymmetries between banks and their business counterparts, channel 2 a generation of additional information regarding climate risk, channel 3 an increase in climate-risk-related capabilities, and channel 4 a signaling of the supervisory authorities' intention to banks to potentially introduce hard measures in the future.



Note: BPF = brown penalizing factor; GSF = green supporting factor.

Figure 23: Effects of Climate-risk-related Supervisory Efforts on Banks' Green Behavior

As introduced in Section 4.2, especially the investigation of channel 1 is widely rooted in the context of non-climate-related supervisory activities such as regular Supervisory Review and Evaluation Processes and stress testing. However, the fundamental reasoning is transferrable to climate-related supervisory efforts and can be used as a basis for the explanation of soft effects within the climate risk context. The key argument for the introduction of stress testing and the disclosure of its results in the aftermath of the financial crises in 2008/9 is to foster an increase in market discipline via a reduction of information asymmetries (Bernanke, 2013; Ellahie, 2013; Gorton and Ordonez, 2014, Fuchs et al., 2023). An increased disclosure provides market participants with better insights into the risk exposure of banks, yielding more adequately reflected market prices. This might cause a more efficient resource allocation—e.g., less investment into high-risk activities—and could consequently also hamper excessive risk taking of banks (Goldstein and Sapra, 2013). Petrella and Resti (2016) underpin this point by stating that especially the disclosure of historical data is valuable for market participants, especially in the case of skepticism towards forward-looking data (*zoom hypothesis*) and newly generated information such as Common Equity Tier 1 (CET1) capital ratios have a significant explanatory power regarding the future development of banks (*stress hypothesis*) (Ferretti et al., 2023). However, these positive effects are controversially discussed in the literature. Petrella and Resti (2016) argue that the market might disregard the information generated during supervisory exercises (*irrelevance hypothesis*). Furthermore, four levers can potentially induce even negative—i.e., welfare-reducing—effects of disclosing supervisory results: The Hirshleifer effect states that greater disclosure might reduce risk sharing opportunities for economic agents, which experience idiosyncratic shocks (Hirshleifer, 1971); if self-reporting and disclosure are involved, bank managers have a strong incentive to respond myopically trying to inflate the perception of short-term performance at the expense of long-term efficiency—a typical climate risk form is ‘greenwashing’ (Gigler et al., 2014); market participants might react strategically to disclosure; and private information generation might be crowded out (Goldstein and Sapra, 2013). Despite these potential adverse effects, evidence has shown that supervisory action generally has a disciplining effect on markets, especially if an ideal level of disclosure is required (Goldstein and Leitner, 2018).

Within the context of climate-risk-related supervisory efforts, not only the disclosure of additional information and a resulting reduction of information asymmetries is relevant, but also the generation of additional climate risk information itself, even if they remain undisclosed (channel 2). The cost of information generation and distorted incentives for banks to generate such information—for instance, myopic bank managers, who highly discount the long-term benefits of increased climate risk information availability, as well as the public goods nature of such information—might lead to their under-provision (Sharma et al., 2021). Hence, the gathering of additional climate risk information incentivized by regulatory and supervisory efforts might have a welfare-increasing impact.

An analogous reasoning applies to the build-up of climate-risk-related capabilities of banks, such as recruitment or training of employees with skills to generate, interpret and operationalize climate-risk-related information (channel 3) (Hansen, 2022). Indeed, qualitative *ex post* assessments of the ECB's 2022 CRST have revealed that the exercise has led to increases in capabilities (Oliver Wyman, 2023).

Lastly, the introduction of climate-risk-related supervisory efforts might have a signaling effect on banks with respect to the future introduction of hard measures such as brown penalizing factors and green supporting factors (channel 4). If banks are able to anticipate such forthcoming measures—which is one of the intentions of the ECB's climate risk supervisory efforts that communicates explicitly their potential future introduction—they might prepare *ex ante* for this possibility by adjusting their behavior accordingly (see Oliver Wyman, 2023).

4.4 Empirical Strategy

4.4.1 Difference-in-difference Design

In this Section we set up a modeling framework to explore empirically the transmission of climate-risk-related supervisory efforts via the soft transmission mechanism. We use a DiD approach, where we estimate empirical models for four different dependent variables, see Table 28. Those variables are proxies for measuring the two potential effects of climate risk supervision, i.e., a decrease of climate risk (effect 1) and an increase in climate finance (effect 2). As a proxy for climate risk, we use Bloomberg's Environmental Score (E-Score) for FI. As a proxy for climate finance, we use (2.1) banks' green bond issuance; (2.2) banks' ESG-AUM; and (2.3) 'green credit' to reflect the impact on green lending decisions.

Table 28: Dependent Variables as Proxies for Banks' Green Behavior

Effect 1: Decrease of Climate Risk	**Effect 2: Green Impact Investing**
1 Bloomberg E Score (Disclosure Score adjusted)	2.1 Green bonds issuance
	2.2 ESG-AUM
	2.3 Green credit

A detailed description of the proxies follows in Section 4.5. For each of the four dependent variables introduced above, the DiD regression equation takes the form

$$Y_{ibt} = \beta_{0,i} + \beta_{1,i} treat_{ibt} + \beta_{i,2} post_{ibt} + \beta_3 treat_{ibt} \times post_{ibt} + X_{ibt}\gamma_i^T + a_{ibt} + \varepsilon_{ibt} \, , \tag{1}$$

where $Y_{ib}, i \in (1,4)$ represents the four different dependent variables, which serve as proxies for green bank behavior, $treat_{ibt}$ a dummy variable indicating the treatment of the treatment group with the climate risk supervisory efforts, $post_{ibt}$ a dummy variable describing the introduction time of the climate risk supervisory efforts, X_{ibt} the matrix of the control variables, a_{ibt} fixed effects, and ε_{ibt} the error term.

We choose the SIs as the treatment group and the LSIs as the control group[64]. As described in Section 4.3, SIs are subject to climate-risk-related supervisory efforts; their selection is made based on the banks' systemic relevance and does not involve any self-selection, so that this treatment group remains unaffected by any potential self-selection bias. We choose the LSIs as a control group for three main reasons: firstly, and most importantly, LSIs do not face climate-risk-related supervisory efforts induced by the ECB, i.e., they do not undergo the treatment[65]. Secondly, LSIs—like the SIs—are headquartered in the euro area. Thus, many external factors such as macroeconomic, political, regulatory, legal, and societal conditions potentially impacting banks' green behavior apply similarly or equally for both the SIs and the LSIs. Factors that do not impact the two groups equally, such as specific banking regulations, can be relatively easily accounted for by means of the inclusion of adequate control variables or bank-level fixed effects[66] (see below). Thirdly, data for the two groups of banks are generally available from the same data sources, which reduces any potential shortcomings with regard to data comparability[67].

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[64] For the ECB's list of supervised entities, classified into SIs and LSIs, see https://www.bankingsupervision.europa.eu/ecb/pub/pdf/ssm.listofsupervisedentities202304.en.pdf (accessed 08/2023). For regression 2.3 with green credit as the dependent variable, for reasons of data availability, we only include German SIs and LSIs in the sample.

[65] The Netherlands are the only economy, which has introduced CRST for all banks, insurers, and pension funds independently of their system significance. We have, thus, excluded all banks from the Netherlands from our sample. Furthermore, we have excluded all banks from Croatia, which has joined the euro area only in 2022, i.e., during the considered time period.

[66] The total sizes of the treatment and the control group in terms of total assets are approx. $3.48*10^{13}$ EUR (SIs) and $3.54*10^{12}$ EUR (LSIs) for the regression to the green bonds. For the remainder of the regressions, size ratios are comparable.

[67] As an alternative control group to the LSIs and in the case of data availability, we have tested non- euro-area banks, which are headquartered in the EU (EU-non- euro-area banks), i.e., banks from Bulgaria, the Czech Republic, Denmark, Hungary, Poland, Romania, and Sweden. The DiD analyses for which the corresponding data was available as well, revealed similar results to those obtained with the LSIs as the control group.

We treat the SIs with the introduction of climate risk supervision as an exogenous shock from the year 2020 onwards. As described in Section 4.3, in 2020, the ECB Guide on Climate-related and Environmental Risks has been published, announcing the supervisory effort starting with data collection and the SIs' self-assessment, and the CRST, Thematic Review and Short-term Exercise publication in 2022 (see above). Hence, introducing the treatment in 2020, we account for announcement effects. We lag the treatment variable by one year to estimate the effect of the treatment in previous periods on the current period and, thus, test for potential delays in the observed effects.

Within the DiD regressions, we include controls reflecting macroeconomic conditions, the policy and regulatory environment, as well as banks' specificities. To determine the exact control variables, we refer to a body of literature analyzing determinants of green banking behavior, such as the issuance of new sustainable financial instruments. Within this body of literature, the major share of contributions analyzes determinants for green bonds issuance, while analyses of determinants for other green bank behavior such as increasing ESG-AUM or green lending remain subject to future research. Acknowledging this lacuna, and for the benefit of increasing comparability, we choose similar control variables across the four DiD regressions. Firstly, we control for the development of the macroeconomic variables year-over-year (YY) GDP growth and YY inflation (Campiglio, 2016) (both from Refinitiv Eikon). Furthermore, banks' environmental reputation has been identified as a driver of green bonds issuance (e.g., Dossa and Kaeufer, 2014; Serafeim 2014; Basu et al. 2022; Christensen et al. 2022, Dutordoir et al., 2023, Gianetti, 2023); therefore, we control for banks facing environmental controversies (Refinitiv Eikon), which measure banks' involvement in environmentally harmful incidents having the potential to impose reputational risk to the banks and to induce stakeholder pressure. Furthermore, since the regulatory environment has been identified as another key driver for GB issuance (Dan and Tiron-Tudorm, 2021), we control for the introduction of the Sustainable Finance Disclosure Regulation (SFDR) in 2021, as it does not equally affect all banks within our sample, but only banks, which, *inter alia*, exceed a size threshold of 500 employees. Furthermore, since issuer characteristics have been identified as another driver for GB issuance (Bancel and Glavas, 2020), we include bank-level fixed effects[68], such as banks' business model and headquarter (HQ) location. Further drivers for GB issuance are the development of the GB market, the development of premia for GB ('greenium') (Hinsche, 2021), and other environmental regulations. A milestone in the development of the GB market has been the publication of the GB principles (ICMA, 2021). However, these voluntary process guidelines equally apply to all banks within our sample. The same holds true as well for the development of the greenium as well as other environmental regulations on the EU level. We refrain from controlling for carbon prices due to potential endogeneity issues arising from causalities, which have been demonstrated to run from the GB index to CO_2 futures' returns (Marín-Rodriguez et al., 2022). Due to the potential impact of carbon prices on GB issuance (Laeven and Popov, 2022), the inclusion of this control remains subject to future research. Note, however, that for all regressions apart from the regression to the share of GB to all issued bonds, we have included a control variable for annual EU-ETS carbon prices (World Bank), since for the according dependent variables, the above-described causalities have not yet been demonstrated. Lastly, for the regression on green credit only, we control for debtor sector, debtor type, debtor size and debtor risk rating, since the analysis of green lending is debtor specific. We, furthermore, account for time, bank-level, and country-level fixed effects (e.g., Ioannou and Serafeim, 2012, 2017; Baldini et al. 2018). Using Stata's *reghdfe* ordinary

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[68] While we include bank-level fixed effects in the main regressions, we also account for country-level fixed effects in the robustness checks, see Section 4.6.

least squares (OLS) method allows for the inclusion of fixed effects by means of 'absorbing', and for multi-level clustering (Correia, 2016).

4.4.2 Parallel Trends

Critical to the validity of our findings is the exogeneity of changes in banks' green behavior. Therefore, we have to make sure that the differences in the trends we capture have not preceded the announcement of the ECB's climate-risk-related supervision in 2020, i.e., that the SIs were not already before the shock starting to behave greener than the LSIs, and we are not simply picking a continuation of longer-term trends (see, e.g., Angrist and Pischke, 2008).

For testing the 'parallel trends assumption', we perform two alternative tests[69]:

Firstly, we follow the normalized difference approach by Imbens and Wooldridge (2009) to examine trends in banks' green behavior preceding the shock in 2020. According to this test, there must not be a divergence of the dependent variables (climate risk, GB, ESG-AUM and green lending) prior to the treatment. To test this, we calculate the normalized differences as averages by treatment status scaled by the square root of the sum of the variances. This approach has an advantage over the t-test, as it is a scale-free measure of differences in distributions independent of the sample size (Imbens and Wooldridge, 2009). An absolute normalized difference smaller than 0.25 indicates that there is no significant difference in the evolution of characteristics between treated and control groups (Mueller et al., 2023). Table C.38, Table C.40, Table C.42, and Table C.44 in the Appendix report the normalized differences between the treatment and control groups during the pre-treatment period. For all climate risk and sustainable finance proxies (Bloomberg E-Score, GB issuance, ESG-AUM, and green lending), the normalized differences of the dependent variables (0.21; 0.21; 0.06; 0.02) remain well

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[69] For a graphical representation see Figure C.24, Figure C.25, Figure C.26, and Figure C.27.

below the 0.25 rule of thumb. The same holds for the normalized differences of the majority of the controls. Only the normalized difference of the share of banks' lending to sector K[70] (financial and insurance activities) exceeds the threshold with 0.40. This, however, does not invalidate our empirical strategy, since the lending to financial and insurance activities is more reflective of general sector trends, and not our main dependent variables.

Secondly, we perform additional tests and consider the pre-treatment period before the introduction of the ECB's climate-risk-related supervisory efforts, i.e., the time period from 2015 to 2020. We split the time period into the years 2015 to 2016 (first period I) and 2017 to 2019 (second period I), as well as into the years 2015 to 2017 (first period II) and 2018 to 2019 (second period II). We then estimate the following models for the different periods:

$$Y_{ibt} = \beta_{i0} + \beta_{i1} treat_{ibt} + \beta_{i2} post_{ibt}^{n} + \beta_{i3} treat_{ibt} \times post_{ibt}^{n} + X_{ibt}\gamma_i^T + a_{ibt} + \varepsilon_{ibt} \,, \tag{2}$$

with $n \in (2016, 2017)$. The results in Table C.39, Table C.41, Table C.43, and Table C.45 demonstrate no significant trend change in the pre-treatment period (here exemplarily displayed for the first and second period I).

4.5 Data

In this Section, we provide a description of the core data underlying the four DiD analyses introduced in Section 4.4. An exhaustive list of all data points and their sources can be found in Table C.33 in the Appendix. Regarding data quality, it is important to be aware of three aspects: Firstly, especially the availability of reported environmental data is rather incomplete,

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[70] According to the Nomenclature of Economic Activities NACE (https://nacev2.com/en/activity/financial-and-insurance-activities).

both for banks and debtors[71]. Secondly, many ratings, amongst which the Refinitiv Eikon environmental rating and the Bloomberg E-Score, are based on the rated entities' self-reported data; consequently, potential greenwashing issues cannot be ruled out[72]. Thirdly, a lack of standardization both in the environmental reporting of the entities as well as in rating methodologies across different rating agencies prevents meaningful cross-entity comparisons. The fragmented data availability has consequences for the comparability of the four regressions. It is important to note that DiD 1 to 2.2 are based on the same sub-sets of the original data set sourced from Refinitiv Eikon, while DiD 2.3 is based on a different data set extracted from the ECB Corep data base. Since the underlying set of SIs and LSIs is the same for all four DiDs, all data sets do still have a large overlap.

Table C.34 to Table C.37 show the descriptive statistics of the main variables. The final samples for the four analyses consist of 680 (climate risk), 16,124 (GB Issuance), 999 (ESG-AUM) and 22,320 (green lending) observations between the years 2015 and 2022 (climate risk), 2010 and 2023 (green bonds), 2015 and 2023 (ESG-AUM), and 2014 and 2022 (green lending). Sustainable finance activities are generally low, with, e.g., the average share of green to all bonds issued by banks in the observed period from 2010 to 2023 being approx. 0.2%, the average share of banks' green lending from 2014 to 2022 being approx. 1%.

4.5.1 Data 1: Climate Risk (Disclosure-adjusted)

In order to test for the decrease in climate risk we use the Bloomberg E-Score for the FI. The score measures banks' environmental risk exposure and management along the dimensions

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[71] For SIs, data coverage is 79% for GB, 41% for ESG-AUM, and 34% for the Bloomberg E-Score and Disclosure Score. For LSIs, data coverage is 32% for GB, 2% for ESG-AUM and 1% for the Bloomberg E-Score and Disclosure Score. For the debtors, coverage is 10% amongst the non-private-person debtors.

[72] For larger entities, reported environmental data are audited, however, entities for which this applies represent a minor share of all rated entities.

ESG integration, exclusions, financed emissions, industry exposure, sustainable lending & underwriting, engagement, market initiatives, and portfolio climate transition risk on a scale from 0 (high environmental risk exposure and/or bad management) to 10 (low environmental risk exposure and/or good management). It, thus, serves as a proxy for banks' exposure to unmanaged environmental risk. Furthermore, for each bank's E-Score, Bloomberg provides a disclosure score, which measures the share of the available to the queried data points from which the E-Score is aggregated on a percentage scale. Since taking the E-Score as a stand-alone proxy for the banks' environmental risk exposure implicitly assumes full and constant disclosure, we multiply the E-Score and the according Disclosure Score on the bank level, hence accounting for the fact that disclosure is incomplete and time-varying.

4.5.2 Data 2.1: Green Bonds Issuance

To the end of determining the impact of climate risk supervisory efforts on banks' green impact investment and finance, we, firstly, investigate the impact on the issuance of green bonds, which have emerged in 2007 as a new sustainable financial instrument whose 'proceeds will be exclusively applied towards new and existing green projects' (ICMA, 2014). Like for any standard fixed-income product, investors who purchase a green bond from the bond issuer—e.g., a bank—receive an agreed interest rate, as well as their original investment once the bond reaches maturity (Monk and Perkins, 2020). GB have been used to finance (and refinance) a range of green projects such as renewable energy, energy efficiency, green buildings, and low-carbon transportation (Ng and Tao, 2016). Hence, banks' GB issuance (Refinitiv Eikon, issued amount in EUR) can be used as a proxy for banks' green impact investment. We normalize banks' GB issuance to banks' total bonds issuance to correct for any effects due to fluctuations in the total bonds issuance (Tolliver et al., 2019). Hence, our proxy is expressed on a percentage scale. Furthermore, it is important to note that GB can also contribute to the reduction in banks' climate risk exposure.

4.5.3 Data 2.2: ESG-AUM

As a second proxy to test the impact of the climate risk supervisory efforts on climate finance, we test the impact on banks' ESG-AUM. The data is retrieved from Refinitiv Eikon in EUR. The classification of AUM as ESG-AUM is based on the self-reporting of the banks according to a set of uniform criteria. For instance, Socially Responsible Investment (SRI) and ethical funds can be considered, as well as investments in environmental assets such as renewable energy assets. Hence, compared to GB, ESG-AUM are more broadly defined, and reflect, besides banks' green investment, also their social investment. Therefore, we expect to see a lower impact of climate risk supervisory efforts compared to the effects on GB. As it is the case for GB, ESG-AUM can contribute to the reduction of banks' climate risk exposure.

4.5.4 Data 2.3: Green Lending

The third proxy for testing the impact of the climate-risk-related supervisory efforts on the impact of climate finance is a variable that measures banks' green lending activities. In order to obtain a measure of its relative importance, we use the share of green lending to total lending of banks as a percentage scale. The ECB's Corep database contains annual data of SI's and LSI's lending activities including debtor information and the credit size. We classify the debtors according to their Refinitiv Eikon environmental rating on a continuous scale from 0 to 1, with 0 being a non-sustainable debtor with an environmental rating of D-, and 1 being a highly sustainable debtor with an environmental rating of A+. Unclassified debtors are treated as non-sustainable.

4.6 Results

We find statistically significant impacts of climate-risk-related supervisory efforts on both disclosure-adjusted climate risk exposure and climate finance (green bonds, ESG-AUM, green lending). In the following, we present the results of the four different DiD analyses.

4.6.1 Results 1: Climate Risk (Disclosure-adjusted)

The DiD analysis for the impact of climate-risk-related supervisory efforts on the environmental risk exposure of banks provides evidence that banks reduce their climate risk exposure significantly, i.e., there is a positive impact on their disclosure-adjusted E-score. This result is robust with regards to the inclusion and exclusion of the control variables, see Table 29. Furthermore, the dynamic analysis reveals some significant lead effects of the climate risk supervision, see Table C.46. Amongst the control variables, YY GDP growth, YY inflation, and carbon prices have a significant positive impact on banks' environmental risk. To limit potential endogeneity issues of the control variables, we regress the product of the Bloomberg E-Score and the Disclosure Score to the control variables and find no significant impact, both in the contemporary and the lagged regression.

Table 29: Env. Risk x Disclosure—Sequential Regressions w/o Non-euro-area Banks

VARIABLES	(1) env_risk_disc	(2) env_risk_disc	(3) env_risk_disc	(4) env_risk_disc	(5) env_risk_disc	(6) env_risk_disc
after	0.161***	0.162***	0.183***	0.137***	0.0782	0.0826
	(0.0482)	(0.0484)	(0.0509)	(0.0486)	(0.0479)	(0.0591)
o.treatment	-	-	-	-	-	-
treat_after	0.371***	0.369***	0.369***	0.369***	0.368***	0.380***
	(0.115)	(0.114)	(0.114)	(0.114)	(0.114)	(0.105)
env_controv		-0.174	-0.163	-0.157	-0.177	-0.176
		(0.128)	(0.117)	(0.117)	(0.117)	(0.119)
gdp_growth_yy			1.883***	1.297***	1.106***	1.225**
			(0.426)	(0.364)	(0.363)	(0.579)
inflation_yy				1.406***	0.505	0.534*
				(0.341)	(0.307)	(0.299)
log_CO2_price					0.0558***	0.0562***
					(0.0148)	(0.0150)
sfdr						-0.0243
						(0.0923)
Constant	0.0678***	0.0747***	0.0370	0.0346	-0.0798	-0.0833
	(0.0201)	(0.0198)	(0.0255)	(0.0258)	(0.0503)	(0.0535)
Observations	680	680	680	680	680	680
R-squared	0.622	0.623	0.637	0.640	0.643	0.643

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1
Env_risk_disc on a scale from 0 (bad) to 10 (good), disclosure-adjusted.
Results based on stata’s reghdfe OLS estimation method; time and entity fixed effects treated by means of ‘absorbing’ (Correia, 2016).

4.6.2 Results 2.1: Green Bonds Issuance

The DiD regression of climate risk supervisory efforts on green bonds issuance also reveals a positive significant impact, see Table 30. This result is robust with regards to the inclusion and exclusion of the control variables. In this analysis, only the introduction of the SFDR has a small significant impact on GB issuance. The dynamic analysis reveals that the lagged effects slightly exceed the non-lagged effects in terms of their intensity, which points to a delayed reaction of banks to the treatment, see Table C.47. To reduce the likelihood of the occurrence of potential endogeneity issues (a necessary, but not sufficient condition), we perform a regression of the share of green bonds to the control variables and find no significant impact.

4.6.3 Results 2.2: ESG-AUM

The DiD analysis of climate risk supervisory efforts on banks' ESG-AUM also reveals a positive significant impact, see Table 31. Compared to DiD 2.1, we observe effects of an even smaller magnitude. This result is intuitive, as ESG-AUM include also social and governance AUM besides environmental AUM, on which it is reasonable to assume that climate risk supervisory efforts have a limited impact. This result is robust with regard to the sequential inclusion of the control variables. In this analysis, only the YY inflation has a small but significant impact on ESG-AUM. The dynamic analysis reveals that lagged effects are slightly more pronounced, again pointing to an adjustment period of banks' behavior, see Table C.48. To reduce the likelihood of the occurrence of potential endogeneity issues (a necessary, but not sufficient condition), we perform a regression of the ESG-AUM to the control variables and find no significant impact.

4.6.4 Results 2.3: Green Lending

The DiD analysis of climate risk supervisory efforts on banks' green lending also reveals a strong positive and significant impact, see Table 32. Also, this result is robust with regard to the inclusion and exclusion of the control variables. In this analysis, we do not observe any significant impact of the macroeconomic and bank-specific controls. Amongst the debtor-specific controls, we observe significant effects of both debtor sizes and debtor sectors. Regarding debtor size, the analysis reveals a significant negative impact of debtors being of a very small and of a medium size. The negative effect of debtors of a very small size reflects that many of these debtors, such as private individuals or very small companies, often lack a sustainability rating and are, thus, classified as non-sustainable. The negative effect of debtors of a medium size reflects a combination of many medium-sized companies being unrated and having a non-sustainable score. Following this argumentation, we could also expect the control for small debtors having a significant negative impact. The absence of this result might be rooted in the fact that many project companies (e.g., special purpose vehicles) of renewable energy projects, such as solar and wind parks, are classified as small companies, which generally have very good environmental ratings. Regarding the sectors, we observe a significant negative impact of debtors stemming from the sectors agriculture, forestry, and fishing, mining, and quarrying, and construction. A negative impact of human health services and arts, entertainment and recreation can potentially be rooted in the fact that most of the debtors from these sectors do not have a sustainability rating, and are, thus, classified as non-sustainable. For the sectors transport and storage, financial and insurance activities as well as for public administration and defense, we observe a significant positive impact. This points to a generally positive environmental performance of those sectors, which is reasonable especially for public administration, having ambitious climate policy goals and taking an intended model role in environmental protection topics. This holds true as well for the financial and insurance activities sector, which has a high visibility regarding environmental protection topics, and thus an increased need to disclose environmental information and perform well in the according ratings. Beyond these observations to be explained in terms of content, however, also data availability and comparability might partially cause these results. Especially for the sector transport and storage, good performance within environmental ratings is often rooted in the sector-wide comprehensive setting of ambitious climate targets, which, in turn, is partially caused by the high visibility of this sector. The set climate policy targets contribute positively to the rating, even though no positive environmental contribution has materialized, and it also remains unclear if the targets will actually be reached. Furthermore, for the sector financial institutions and insurance, data-related distortions of the results might be caused by the fact that the majority of environmental ratings—amongst which the Refinitiv Eikon rating, used in our analysis—mainly accounts for the financial institutions' and insurances' own environmental performance in a narrower sense, only marginally taking into account their portfolios' environmental performance. Therefore, the leverage effect attributed to the financial sector is only very poorly reflected in the data. It remains subject to future research to scrutinize the exact relations and impact. The dynamic analysis reveals that lagged effects are slightly more intense, again pointing to an adjustment period of banks' behavior, see Table C.49. To reduce the likelihood of the occurrence of potential endogeneity issues (a necessary, but not sufficient condition), we perform a regression of the issuance share of green lending to the control variables and find no significant impact.

Table 30: Green Bonds—Sequential Regressions w/o Non-euro-area Banks

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	GB_to_all_bonds	GB_to_all_bonds	GB_to_all_bonds	GB_to_all_bonds	GB_to_all_bonds	GB_to_all_bonds
after	0.000193	0.000181	0.000181	0.000322**	-0.000360	-0.000940
	(0.000122)	(0.000128)	(0.000128)	(0.000142)	(0.000554)	(0.000687)
o.treatment	-	-	-	-	-	-
treat_after	0.0572***	0.0571***	0.0571***	0.0571***	0.0571***	0.0540***
	(0.0111)	(0.0111)	(0.0111)	(0.0111)	(0.0111)	(0.0106)
env_controv		0.0126	0.0126	0.0127	0.0128	0.0125
		(0.0415)	(0.0415)	(0.0414)	(0.0414)	(0.0414)
gdp_growth_yy				0.0285**	0.0208*	0.0125
				(0.0115)	(0.0109)	(0.00896)
inflation_yy					0.0232	0.0175
					(0.0185)	(0.0174)
sfdr						0.00502**
						(0.00212)
Constant	0.000174	0.000141	0.000141	-0.000257	-0.000463	-0.000270
	(0.000247)	(0.000267)	(0.000267)	(0.000359)	(0.000460)	(0.000403)
Observations	16,142	16,142	16,142	16,142	16,142	16,142
R-squared	0.222	0.222	0.222	0.223	0.223	0.224

Robust standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

GB_to_all_bonds on a percentage scale.

Results based on stata's reghdfe OLS estimation method; time and entity fixed effects treated by means of 'absorbing' (Correia, 2016).

Table 31: ESG-AUM—Sequential Regressions w/o Non-euro-area Banks

VARIABLES	(1) ESG_AUM_Abs_s	(2) ESG_AUM_Abs_s	(3) ESG_AUM_Abs_s	(4) ESG_AUM_Abs_s	(5) ESG_AUM_Abs_s
after	0.000133	0.000103	0.000545	-0.00215*	-0.00364
	(0.000133)	(0.000148)	(0.000353)	(0.00123)	(0.00227)
o.treatment	-	-	-	-	-
treat_after	0.0205**	0.0205**	0.0205**	0.0205**	0.0158**
	(0.00960)	(0.00966)	(0.00967)	(0.00967)	(0.00746)
env_controv		0.00488	0.00485	0.00504	0.00504
		(0.00972)	(0.00999)	(0.00990)	(0.0101)
gdp_growth_yy			0.0409	0.00976	-0.0273
			(0.0279)	(0.0144)	(0.0200)
inflation_yy				0.0746*	0.0567**
				(0.0408)	(0.0284)
sfdr					0.00848
					(0.00620)
Constant	0.000505	0.000329	-0.000479	-0.000604	0.000305
	(0.00177)	(0.00170)	(0.00219)	(0.00225)	(0.00173)
Observations	999	999	999	999	999
R-squared	0.311	0.311	0.313	0.314	0.316

Robust standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

ESG_AUM_Abs_s in EUR.

Results based on stata's reghdfe OLS estimation method; time and entity fixed effects treated by means of 'absorbing' (Correia, 2016).

Table 32: Green Credit—Sequential Regressions w/o Non-euro-area Banks

VARIABLES	(1) debt_env_rel	(2) debt_env_rel	(3) debt_env_rel	(4) debt_env_rel	(5) debt_env_rel	(6) debt_env_rel	(7) debt_env_rel	(8) debt_env_rel
after	-12.16***	-12.16***	-12.16***	-12.00***	-8.505***	-1.860	-0.737	-0.724
	(1.859)	(1.859)	(1.859)	(1.831)	(2.799)	(2.431)	(2.842)	(2.867)
o.treatment	-	-	-	-	-	-	-	-
treat_after	19.41**	19.41**	19.41**	19.41**	19.41**	19.42**	16.93**	17.49**
	(8.027)	(8.027)	(8.028)	(8.028)	(8.028)	(8.028)	(8.346)	(8.844)
env_controv			1.425	1.741	1.761	2.016	0.176	0.0475
			(1.400)	(1.545)	(1.548)	(1.616)	(2.755)	(2.873)
gdp_growth_YY				16.29	61.23***	96.75***	93.61***	96.50***
				(14.07)	(14.71)	(22.82)	(29.93)	(30.57)
inflation_YY					-107.2**	96.63	136.6	153.7
					(46.27)	(161.7)	(147.2)	(156.2)
CO2_price						-0.299	-0.316	-0.338
						(0.198)	(0.199)	(0.209)
dbtr_sect_A							-46.19***	-32.76***
							(8.847)	(12.15)
dbtr_sect_B							-148.3**	-126.2**
							(65.25)	(59.16)
dbtr_sect_C							225.3	231.4
							(200.6)	(207.0)
dbtr_sect_D							-7.645	-3.990
							(9.481)	(11.76)
dbtr_sect_E							-0.844	2.613
							(9.046)	(9.457)
dbtr_sect_F							-15.51***	-9.599
							(4.804)	(6.254)
dbtr_sect_G							-12.90***	-1.950
							(4.748)	(8.116)
dbtr_sect_H							42.81	62.05**
							(28.45)	(28.46)
dbtr_sect_I							-19.18*	-10.89
							(10.92)	(13.80)
dbtr_sect_J							-1.220	11.39
							(15.67)	(12.46)

dbtr_sect_K							25.88***	27.81***
							(5.038)	(3.296)
dbtr_sect_L							-12.05***	-4.913
							(3.347)	(5.356)
dbtr_sect_M							-17.96***	-8.818
							(5.104)	(7.780)
dbtr_sect_N							-11.59	-7.705
							(7.762)	(19.20)
dbtr_sect_O							9.451***	9.568***
							(3.242)	(3.160)
dbtr_sect_P							-24.61	-32.79
							(33.71)	(33.81)
dbtr_sect_Q							-37.08**	-27.13*
							(15.50)	(15.01)
dbtr_sect_R							-41.00**	-37.19*
							(19.43)	(19.62)
dbtr_sect_S							-36.09	-23.66
							(24.62)	(24.01)
dbtr_sect_T							-17.18	-6.045
							(32.97)	(36.00)
debt_vsmall_rel								-17.40
								(11.19)
debt_small_rel								-22.70*
								(11.83)
debt_medium_rel								-32.75***
								(8.317)
debt_large_rel								1.937
								(32.74)
o.debt_vlarge_rel								-
Constant	12.04***	12.04***	12.04***	11.73***	11.84***	12.66***	0.416	1.356
	(0.657)	(0.657)	(0.656)	(0.727)	(0.743)	(1.153)	(2.037)	(2.356)
Observations	22,320	22,320	22,320	22,320	22,320	22,320	22,320	22,320
R-squared	0.184	0.184	0.184	0.184	0.184	0.184	0.199	0.200

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Debt_env_rel on a percentage scale

Results based on stata’s reghdfe OLS estimation method; time and entity fixed effects treated by means of ‘absorbing’ (Correia, 2016)

4.7 Discussion and Policy Implications

Banking Supervision plays a key-role in fostering an adequate reflection of climate risk in banks' overall risk identification, assessment, and management strategies (see, e.g., Hansen, 2022). Wrong quantitative assessments or even disregarding climate risk might over time increase systemic risks to the financial sector and, hence, jeopardize financial stability. From a political economy point of view there is a discussion whether supervisory authorities could and should foster the guidance towards carbon-neutral transition of economies by steering capital into sustainability-increasing investments. While the mandate given to central banks and supervisory authorities is less clear—especially as there is a potential trade-off between the mandate of guaranteeing financial stability and financing a green transition (e.g., Skinner, 2021), the ECB has positioned itself generally as a promoter of green banking supervision (UN, 2017; Lagarde, 2021). The concrete implications of this positioning, however, are not yet fully defined. Other competent authorities, such as Federal Reserve's Waller, take a more hesitant position, pointing out that "climate change does not pose such 'significantly unique or material' financial stability risks that the Federal Reserve should treat it separately in its supervision of the financial system" (Reuters, 2023).

In this Chapter, we have shown that climate-risk-related supervisory efforts have a statistically significant impact on banks' climate risk reduction and climate finance. This indicates that banks, once additional and better information is generated and becomes available due to the climate-risk-related supervisory efforts, capabilities are enhanced, and as soon as they expect the introduction of future climate-risk-related capital requirements, start focusing on the reduction of their climate risk exposure, and also increase their green capital allocation. It is important to note that demonstrating the statistically significant impact does not allow us to derive any normative statement regarding whether the effort of the SIs suffices the requirements defined within the ‘ECB Guide on Climate-related and Environmental Risks’.

Further important observations concern data availability. Firstly, we have shown that regarding the impact on climate risk reduction, the neglection of the disclosure levels leads to an over-estimation of the positive impact of the climate-risk-related supervisory efforts. This is especially important to note, since such an overestimation can lead supervisory authorities to take insufficient action. As described in Section 4.5, data coverage, data quality (mainly due to self-reporting in combination with limited auditing currently only for big companies and resulting greenwashing) a lack of standardization, and, hence, comparability, as well as insufficient data granularity (e.g., no distinct measurement of the climate risk impact, exposure, management, and unmanaged risk) are the main issues, which have to be tackled to improve this situation. While these data-related shortcomings represent a limiting factor to the measurability of the impact of climate-risk-related supervisory efforts on banks’ green behavior, we have also seen that—as intended—the climate risk supervisory efforts themselves have a significant positive impact on the climate-risk-related information disclosure of the banks.

From these findings, we can derive three key recommendations for policy makers, regulators, and supervisory authorities: Firstly, since the climate-risk-related supervisory efforts show a positive impact on both climate risk reduction and green impact investing, supervisory authorities should continue the exercise. This is especially the case due to the positive effect on banks’ risk reduction, which is at the core of the mandate of supervisory authorities. Secondly, while continuing the efforts, it is important to also announce the continuation early on, since we have seen that already the expectation of the climate-risk-related supervisory efforts leads to positive effects. Thirdly, policy makers, regulators and supervisory authorities should focus on an improvement of climate-risk-related data availability, data quality, and a standardization of indicators. On the one hand, this will significantly improve insights regarding the effectiveness and efficiency of the introduction of policies, regulations, and supervisory efforts, as well as their continuous improvement. On the other hand, given the results of the above analyses, we can assume that further increasing information availability will also have further positive impacts on both the reduction of banks' climate risk and an increase in green impact investing.

Building on our findings in this Chapter, we will further investigate both empirical and policy issues. From an empirical perspective, we have been able to demonstrate that our results are remarkably robust with regard to different choices of control variables and different types of fixed effects. Nevertheless, we will further investigate potential endogeneity issues, for example for the price of CO_2 certificates. This variable plays clearly a role in explaining the green dependent variables in our models. At the same time, carbon prices should be also demand-driven. From a policy perspective, we will investigate whether there are significant discrepancies between agencies' evaluations of banks' greening activities on the one hand (e.g., the environmental risk exposure and management proxy used in this Chapter) and the assessments by supervisory authorities (e.g., via Supervisory Review and Evaluation Process score) on the other hand. Furthermore, the analyses could be extended to non-EU economies. Regarding this, firstly, the treatment group could be changed to non-EU banks facing comparable supervisory efforts. Secondly, an additional comparison of the present treatment group of euro area SIs with similarly large banks from other non-EU economies, such as banks from the US or China, would potentially reveal interesting insights, even though we have already controlled for bank size fixed effects. The most interesting future research, however, will be possible, as soon as data quality has improved, and it will be worthwhile to re-run the analysis and compare those results with the present ones.

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Appendix C

Impacts of ECB Banking Supervision on Climate Risk and Sustainable Finance

C.1 Data and Descriptive Statistics

C.1.1 Variables Overview

Table C.33: Variables Overview

Variable Name	Variable	Unit	Description	Database
Banks’ unmanaged environmental risk	Env_risk	Scale 0 to 10	Bloomberg E-Score, scale 0 (lowest) to 10 (highest), annual, 2015-2022	Bloomberg
Banks’ disclosure of unmanaged environmental risk	Env_disc	%	Bloomberg E-Score Disclosure Score, percentage of available data points, annual, 2015-2022	Bloomberg
Banks’ disclosed unmanaged environmental risk	Env_risk_disc	n.a.	Product of Bloomberg E-Score and Disclosure Score	Calculated
Banks’ total bonds issuance	All_bonds	EUR	Banks’ (SI, LSI, EU-non-euro-area) total bonds issuance, annual, 2010 -2023	Refinitiv Eikon
Banks’ green bonds issuance	Green_bonds	EUR	Banks’ (SI, LSI, EU-non-euro-area) green bonds issuance, annual, 2010 -2023	Refinitiv Eikon
Share of green bonds to all bonds	GB_to_all	%	Share of banks’ green bonds to total bonds issuance, annual, 2010 -2023	Calculated
ESG-AUM	ESG_AUM_Abs	EUR	Banks’ (SI, LSI, EU-non- euro-area) total ESG-AUM, annual, 2015-2023	Refinitiv Eikon
ESG-AUM scaled	ESG_AUM_Abs_s	EUR * 10^9	Banks’ (SI, LSI, EU-non- euro-area) total ESG-AUM, annual, 2015-2023, scaled	Refinitiv Eikon
Total credit (lending)	All_debt	EUR	Banks’ (SI, LSI) total credit (lending), annual, 2014-2022	ECB Corep
Green credit (lending)	Debt_env	EUR	Banks’ (SI, LSI) green credit (lending), annual, 2014-2022, based on environmental rating of debtors	Calculated based on ECB Corep and Refinitiv Eikon
Share of green to total credit (lending)	Debt_env_rel	%	Share of green to total credit (lending), annual, 2014-2022, based on environmental rating of debtors	Calculated
GDP growth YY	Gdp_growth_yy	%	YY GDP growth, 2010-2023, euro area and EU-non- euro-area countries	Refinitiv Eikon
Inflation YY	Inflation_yy	%	YY inflation, 2010-2023, euro area and EU-non-euro-area countries	Refinitiv Eikon
CO2 prices EU ETS	CO2_price	EUR/ tCO2e	Carbon prices in EU ETS, annual, 2010-2023	World Bank
Introduction of SFDR	SFDR	dummy	Dummy variable for the introduction of the SFDR for banks w/ >500 employees in the EU in 2021	Determined based on Refinitiv Eikon
Banks’ HQ country	HQ_country	n.a.	Banks’ HQ country	ECB Corep

Banks’ total assets	Log_ta	n.a.	Banks’ (SI, LSI, EU-non- euro-area) total assets as proxy for bank size, average, ln, 2010 -2023,	ECB Corep; Banks’ financial reports
Banks’ environmental controversies	Env_controv	dummy	Dummy variable for banks facing environmental controversies, annual, 2010-2023	Refinitiv Eikon
Banks’ lending to very small debtors	debt_vsmall_rel	%	Share of banks’ lending to very small debtors to total lending, annual, 2015-2022	Calculated based on S&P Capital IQ
Banks’ lending to small debtors	debt_small_rel	%	Share of banks’ lending to small debtors to total lending, annual, 2015-2022	Calculated based on S&P Capital IQ
Banks’ lending to medium-sized debtors	debt_medium_rel	%	Share of banks’ lending to medium-sized debtors to total lending, annual, 2015-2022	Calculated based on S&P Capital IQ
Banks’ lending to large debtors	debt_large_rel	%	Share of banks’ lending to large debtors to total lending, annual, 2015-2022	Calculated based on S&P Capital IQ
Banks’ lending to very large debtors	debt_vlarge_rel	%	Share of banks’ lending to very large debtors to total lending, annual, 2015-2022	Calculated based on S&P Capital IQ
Banks’ lending to sector A	dbtr_sect_A	%	Share of banks’ lending to debtors from sector A (agriculture, forestry, and fishing) to total lending, annual, 2015-2022	ECB Corep
Banks’ lending to sector B	dbtr_sect_B	%	Share of banks’ lending to debtors from sector B (mining and quarrying) to total lending, annual, 2015-2022	ECB Corep
Banks’ lending to sector C	dbtr_sect_C	%	Share of banks’ lending to debtors from sector C (manufacturing) to total lending, annual, 2015-2022	ECB Corep
Banks’ lending to sector D	dbtr_sect_D	%	Share of banks’ lending to debtors from sector D (electricity, gas, steam and air conditioning supply) to total lending, annual, 2015-2022	ECB Corep
Banks’ lending to sector E	dbtr_sect_E	%	Share of banks’ lending to debtors from sector E (water supply) to total lending, annual, 2015-2022	ECB Corep
Banks’ lending to sector F	dbtr_sect_F	%	Share of banks’ lending to debtors from sector F (construction) to total lending, annual, 2015-2022	ECB Corep
Banks’ lending to sector G	dbtr_sect_G	%	Share of banks’ lending to debtors from sector G (wholesale and retail trade) to total lending, annual, 2015-2022	ECB Corep
Banks’ lending to sector H	dbtr_sect_H	%	Share of banks’ lending to debtors from sector H (transport and storage) to total lending, annual, 2015-2022	ECB Corep
Banks’ lending to sector I	dbtr_sect_I	%	Share of banks’ lending to debtors from sector I (accommodation and food service activities) to total lending, annual, 2015-2022	ECB Corep
Banks’ lending to sector J	dbtr_sect_J	%	Share of banks’ lending to debtors from sector J (information and communication) to total lending, annual, 2015-2022	ECB Corep
Banks’ lending to sector K	dbtr_sect_K	%	Share of banks’ lending to debtors from sector K (financial and insurance activities) to total lending, annual, 2015-2022	ECB Corep
Banks’ lending to sector L	dbtr_sect_L	%	Share of banks’ lending to debtors from sector L (real estate activities) to total lending, annual, 2015-2022	ECB Corep
Banks’ lending to sector M	dbtr_sect_M	%	Share of banks’ lending to debtors from sector M (professional, scientific, and technical activities) to total lending, annual, 2015-2022	ECB Corep

Banks’ lending to sector N	dbtr_sect_N	%	Share of banks’ lending to debtors from sector N (administrative and support service activities) to total lending, annual, 2015-2022	ECB Corep
Banks’ lending to sector O	dbtr_sect_O	%	Share of banks’ lending to debtors from sector O (public administration and defence, compulsory social security) to total lending, annual, 2015-2022	ECB Corep
Banks’ lending to sector P	dbtr_sect_P	%	Share of banks’ lending to debtors from sector P (education) to total lending, annual, 2015-2022	ECB Corep
Banks’ lending to sector Q	dbtr_sect_Q	%	Share of banks’ lending to debtors from sector Q (human health services and social work activities) to total lending, annual, 2015-2022	ECB Corep
Banks’ lending to sector R	dbtr_sect_R	%	Share of banks’ lending to debtors from sector R (arts, entertainment, and recreation) to total lending, annual, 2015-2022	ECB Corep
Banks’ lending to sector S	dbtr_sect_S	%	Share of banks’ lending to debtors from sector S (other services) to total lending, annual, 2015-2022	ECB Corep
Banks’ lending to sector T	dbtr_sect_T	%	Share of banks’ lending to debtors from sector T (activities of households as employers) to total lending, annual, 2015-2022	ECB Corep

C.1.2 Descriptive Statistics

Table C.34: Environmental Risk x Disclosure—Summary Statistics

VARIABLES	Observations (matched)	Mean	Std. Dev	P25	Median	P75
env_risk_disc	680 (304*; 376**)	0.19 (0.32*; 0.09**)	0.48 (0.61*; 0.30**)	0.00 (0.00*/**)	0.00 (0.02*; 0.00**)	0.10 (0.03*; 0.00**)
env_risk_disc (2015-2019)	425 (190*; 376**)	0.07 (0.12*; 0.03**)	0.18 (0.24*; 0.10**)	0.00 (0.00*/**)	0.00 (0.01*; 0.00**)	0.01 (0.13*; 0.00**)
env_controv	680 (304*; 376**)	0.04 (0.07*; 0.02**)	0.20 (0.26*; 0.13**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
CO2_price	680 (304*; 376**)	26.18 (26.18*/**)	26.35 (26.35*/**)	7.33 (7.33*/**)	17.45 (17.45*/**)	30.82 (30.82*/**)
gdp_growth_YY	680 (304*; 376**)	0.02 (0.02*/**)	0.03 (0.03*/**)	0.02 (0.02*/**)	0.02 (0.02*/**)	0.03 (0.03*/**)
inflation_YY	680 (304*; 376**)	0.02 (0.02*/**)	0.03 (0.03*/**)	0.00 (0.00*/**)	0.01 (0.01*/**)	0.02 (0.02*/**)
SFDR	680 (304*; 376**)	0.15 (0.25*; 0.07**)	0.36 (0.43*; 0.25**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)

This table reports descriptive statistics for the variables used in the main empirical analysis for banks' disclosure-adjusted climate risk. The baseline sample consists of 680 env_risk_disc observations between 2015 and 2022 (except env_risk_disc (2015-2019)). Separate values for SIs and LSIs are indicated as (SI-Value*; LSI-Value**). See Table C.33 for detailed variable definitions incl. units.

Rounded values shown.

Table C.35: Green Bonds Issuance—Summary Statistics

VARIABLES	Observations (matched)	Mean	Std. Dev	P25	Median	P75
GB_to_all	16,142 (1,264*; 14,896**)	0.001 (0.018*; 0.000**)	0.03 (0.09*; 0.00**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
GB_to_all (2010-2019)	11,530 (890*; 10,640**)	0.000 (0.002*; 0.000**)	0.00 (0.01*; 0.00**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
env_controv	16,142 (1,264*; 14,896**)	0.003 (0.032*; 0.001**)	0.05 (0.18*; 0.02**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
gdp_growth_YY	16,142 (1,264*; 14,896**)	0.013 (0.013*/**)	0.02 (0.02*/**)	0.01 (0.01*/**)	0.02 (0.02*/**)	0.02 (0.02*/**)
inflation_YY	16,142 (1,264*; 14,896**)	0.021 (0.021*/**)	0.02 (0.02*/**)	0.00 (0.00*/**)	0.02 (0.02*/**)	0.03 (0.03*/**)
SFDR	16,142 (1,264*; 14,896**)	0.053 (0.241*; 0.040**)	0.22 (0.41*; 0.20**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)

This table reports descriptive statistics for the variables used in the main empirical analysis for banks' green bonds issuance. The baseline sample consists of 16,142 GB_to_all observations between 2010 and 2023 (except GB_to_all (2010-2019)). Separate values for SIs and LSIs are indicated as (SI-Value*; LSI-Value**). See Table C.33 for detailed variable definitions incl. units. Rounded values shown.

Table C.36: ESG-AUM—Summary Statistics

VARIABLES	Observations	Mean	Std. Dev	P25	Median	P75
ESG_AUM_Abs_s	999 (414*; 585**)	0.43 (1.04*; 0.01**)	3.62 (5.56*; 0.14**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
ESG_AUM_Abs_s (2015-2019)	555 (230*; 325**)	0.05 (0.12*; 0.00**)	1.19 (1.85*; 0.00**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
env_controv	999 (414*; 585**)	0.04 (0.08*; 0.01**)	0.20 (0.28*; 0.11**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
gdp_growth_YY	999 (414*; 585**)	0.01 (0.01*/**)	0.03 (0.03*/**)	0.02 (0.02*/**)	0.02 (0.02*/**)	0.03 (0.03*/**)
inflation_YY	999 (414*; 585**)	0.02 (0.02*/**)	0.03 (0.03*/**)	0.00 (0.00*/**)	0.02 (0.02*/**)	0.03 (0.03*/**)
SFDR	999 (414*; 585**)	0.19 (0.33*; 0.09**)	0.39 (0.47*; 0.28**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (1.00*; 0.00**)

This table reports descriptive statistics for the variables used in the main empirical analysis for banks' ESG-AUM. The baseline sample consists of 999 ESG_AUM_Abs_s observations between 2015 to 2023 (except ESG_AUM_Abs_s (2015-2019)). Separate values for SIs and LSIs are indicated as (SI-Value*; LSI-Value**). See Table C.33 for detailed variable definitions incl. units. Rounded values shown.

Table C.37: Green Lending—Summary Statistics

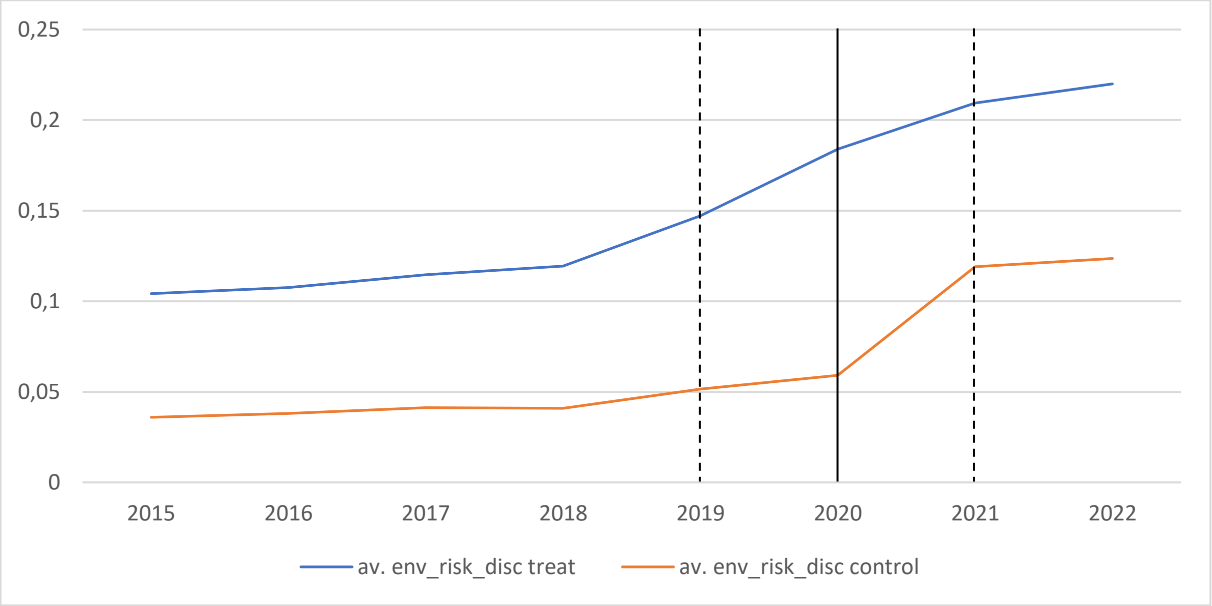
VARIABLES	Observations (matched)	Mean	Std. Dev	P25	Median	P75
debt_env_rel	22,320 (3,366*; 18,954**)	0.01 (0.01*/**)	0.14 (0.20*; 0.12**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
debt_env_rel (2014-2019)	14,880 (2,244*; 12,636**)	0.01 (0.01*/**)	0.16 (0.20*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
env_controv	22,320 (3,366*; 18,954**)	0.00 (0.00*/**)	0.03 (0.07*; 0.02**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
dbtr_sect_A	22,320 (3,366*; 18,954**)	0.01 (0.00*; 0.01**)	0.06 (0.00*; 0.07**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
dbtr_sect_B	22,320 (3,366*; 18,954**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
dbtr_sect_C	22,320 (3,366*; 18,954**)	0.01 (0.02*; 0.01**)	0.08 (0.11*; 0.07**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
dbtr_sect_D	22,320 (3,366*; 18,954**)	0.00 (0.00*/**)	0.03 (0.02*; 0.03**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
dbtr_sect_E	22,320 (3,366*; 18,954**)	0.00 (0.00*/**)	0.03 (0.00*; 0.03**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
dbtr_sect_F	22,320 (3,366*; 18,954**)	0.01 (0.00*; 0.01**)	0.06 (0.00*; 0.06**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
dbtr_sect_G	22,320 (3,366*; 18,954**)	0.01 (0.01*/**)	0.07 (0.08*; 0.06**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
dbtr_sect_H	22,320 (3,366*; 18,954**)	0.00 (0.00*/**)	0.03 (0.05*; 0.02**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
dbtr_sect_I	22,320 (3,366*; 18,954**)	0.00 (0.00*/**)	0.03 (0.00*; 0.03**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
dbtr_sect_J	22,320 (3,366*; 18,954**)	0.00 (0.00*/**)	0.02 (0.03*; 0.02**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
dbtr_sect_K	22,320 (3,366*; 18,954**)	0.40 (0.28*; 0.40**)	0.43 (0.41*; 0.43**)	0.00 (0.00*/**)	0.10 (0.00*; 0.22**)	0.88 (0.60*; 0.90**)
dbtr_sect_L	22,320 (3,366*; 18,954**)	0.02 (0.00*; 0.02**)	0.10 (0.03*; 0.11**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
dbtr_sect_M	22,320 (3,366*; 18,954**)	0.00 (0.00*/**)	0.05 (0.02*; 0.05**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
dbtr_sect_N	22,320 (3,366*; 18,954**)	0.00 (0.00*/**)	0.04 (0.03*; 0.04**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
dbtr_sect_O	22,320 (3,366*; 18,954**)	0.06 (0.08*; 0.06**)	0.18 (0.23*; 0.17**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
dbtr_sect_P	22,320 (3,366*; 18,954**)	0.00 (0.00*/**)	0.01 (0.01*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
dbtr_sect_Q	22,320 (3,366*; 18,954**)	0.00 (0.00*/**)	0.02 (0.01*; 0.03**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)
dbtr_sect_R	22,320 (3,366*; 18,954**)	0.00 (0.00*/**)	0.02 (0.00*; 0.02**)	0.00 (0.00*/**)	0.00 (0.00*/**)	0.00 (0.00*/**)

dbtr_sect_S	22,320	0.00	0.02	0.00	0.00	0.00
	(3,366*; 18,954**)	(0.00*/**)	(0.00*; 0.02**)	(0.00*/**)	(0.00*/**)	(0.00*/**)
dbtr_sect_T	22,320	0.00	0.03	0.00	0.00	0.00
	(3,366*; 18,954**)	(0.00*/**)	(0.00*; 0.03**)	(0.00*/**)	(0.00*/**)	(0.00*/**)
debt_vsmall_rel	22,320	0.06	0.18	0.00	0.00	0.00
	(3,366*; 18,954**)	(0.02*; 0.06**)	(0.07*; 0.19**)	(0.00*/**)	(0.00*/**)	(0.00*/**)
debt_small_rel	22,320	0.01	0.07	0.00	0.00	0.00
	(3,366*; 18,954**)	(0.01*/**)	(0.11*; 0.07**)	(0.00*/**)	(0.00*/**)	(0.00*/**)
debt_medium_rel	22,320	0.03	0.13	0.00	0.00	0.00
	(3,366*; 18,954**)	(0.02*; 0.03**)	(0.21*; 0.14**)	(0.00*/**)	(0.00*/**)	(0.00*/**)
debt_large_rel	22,320	0.04	0.15	0.00	0.00	0.00
	(3,366*; 18,954**)	(0.07*; 0.03**)	(0.21*; 0.14**)	(0.00*/**)	(0.00*/**)	(0.00*/**)
debt_vlarge_rel	22,320	0.04	0.15	0.00	0.00	0.00
	(3,366*; 18,954**)	(0.07*; 0.03**)	(0.07*; 0.14**)	(0.00*/**)	(0.00*/**)	(0.00*/**)
gdp_growth_yy	22,320	0.02	0.03	0.02	0.02	0.03
	(3,366*; 18,954**)	(0.02*/**)	(0.03*/**)	(0.02*/**)	(0.00*/**)	(0.03*/**)
inflation_yy	22,320	0.02	0.02	0.00	0.01	0.02
	(3,366*; 18,954**)	(0.02*/**)	(0.03*/**)	(0.00*/**)	(0.01*/**)	(0.02*/**)
sfdr	22,320	0.00	0.37	0.00	0.00	0.00
	(3,366*; 18,954**)	(0.00*/**)	(0.00*/**)	(0.00*/**)	(0.00*/**)	(0.00*/**)

This table reports descriptive statistics for the variables used in the main empirical analysis for banks' green lending. The baseline sample consists of 22,320 debt_env_rel observations between 2014 and 2022 (except debt_env_rel (2014-2019)). Separate values for SIs and LSIs are indicated as (SI-Value*; LSI-Value**). See Table C.33 for detailed variable definitions incl. units. Rounded values shown.

C.2 Parallel Trends

C.2.1 Parallel Trends 1: Climate Risk (Disclosure-adjusted)



Pre-treatment period until 2019 (Start of lead effects)

Figure C.24: Environmental Risk x Disclosure—Treated vs. Control

Table C.38: Environmental Risk x Disclosure—Parallel Trends Normalized Differences

	Treated		Control		Norm. Diff.
VARIABLES	Mean	Std. Dev.	Mean	Std. Dev.	
env_risk_disc	0.32	0.61	0.09	0.30	0.21
env_controv	0.07	0.26	0.02	0.13	0.09
CO2_price	26.81	26.37	26.81	26.37	0.00
gdp_growth_YY	0.02	0.03	0.02	0.03	0.00
inflation_YY	0.01	0.01	0.01	0.01	0.00
sfdr	0.25	0.43	0.07	0.25	0.22

This table reports statistics of relevant co-variates over the pre-shock period (2015 to 2019) dividing the sample between treated (SIs) and control group (LSIs). The last column reports normalized differences between treatment and control groups (differences in averages by treatment status, scaled by the square root of the sum of the variances). An absolute difference smaller than 0.25 indicates that there is no significant difference between the groups. See Table C.33 for detailed variable definitions incl. units.

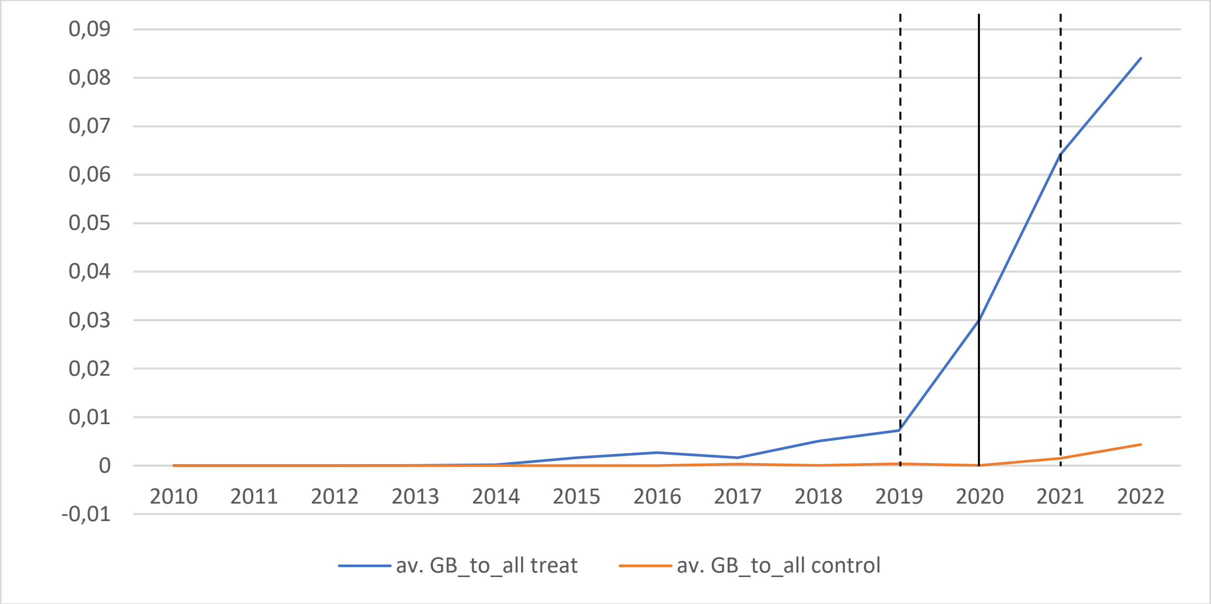
Rounded values shown.

Table C.39: Environmental Risk x Disclosure—Parallel Trends Pre-treatment Period

VARIABLES	(1) env_risk_disc Parallel Trends
afterPT	0.0384
	(3.451)
o.treatment	-
treat_afterPT	0.0402
	(0.0258)
env_controv	-0.0653
	(0.0646)
gdp_growth_yy	-2.486
	(60.33)
inflation_yy	-1.519
	(230.2)
o.log_CO2_price	-
o.sfdr	-
Constant	0.0913
	(1.671)
Observations	340
R-squared	0.768

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

C.2.2 Parallel Trends 2.1: Green Bonds Issuance



Pre-treatment period until 2019 (Start of lead effects)

Figure C.25: GB Issuance—Treated vs. Control

Table C.40: GB Issuance—Parallel Trends Normalized Differences

	Treated		Control		Norm. Diff.
VARIABLES	Mean	Std. Dev.	Mean	Std. Dev.	
GB_to_all	0.01	0.01	3.44	0.01	0.21
env_controv	0.03	0.17	0.00	0.02	0.25
gdp_growth_yy	0.02	0.00	0.02	0.00	0.00
inflation_yy	0.01	0.01	0.01	0.01	0.00
sfdr	0.00	0.00	0.00	0.00	n.a.

This table reports statistics of relevant co-variates over the pre-shock period (2010 to 2023) dividing the sample between treated (SIs) and control group (LSIs). The last column reports normalized differences between treatment and control groups (differences in averages by treatment status, scaled by the square root of the sum of the variances). An absolute difference smaller than 0.25 indicates that there is no significant difference between the groups. See Table C.33 for detailed variable definitions incl. units.

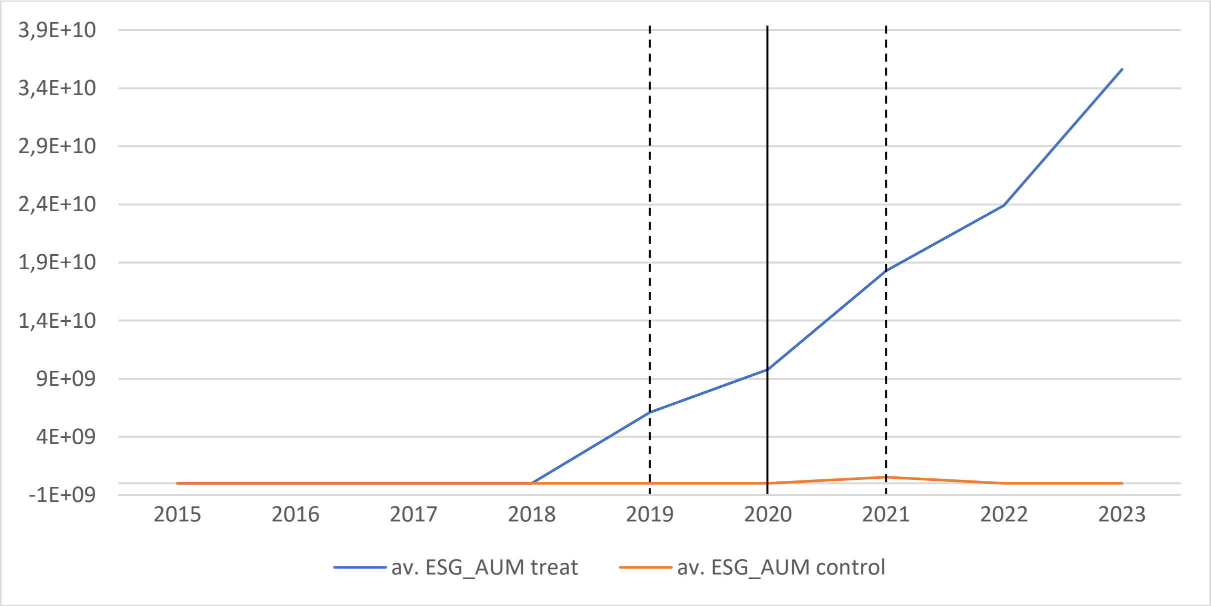
Rounded values shown.

Table C.41: GB Issuance—Parallel Trends Pre-treatment Period

VARIABLES	(1) GB_to_all Parallel Trends
afterPT2	0.000130
	(0.000145)
o.treatment	-
treat_afterPT2	0.00171
	(0.00109)
env_controv	0.000855**
	(0.000341)
gdp_growth_yy	0.00260
	(0.00230)
inflation_yy	0.000381
	(0.00404)
o.sfdr	-
Constant	-1.14e-05
	(0.000111)
Observations	9,224
R-squared	0.148

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

C.2.3 Parallel Trends 2.2: ESG-AUM



Pre-treatment period until 2019 (Start of lead effects). End-of-year values shown, therefore, increase already visible between 2018 and 2019 data points.

Figure C.26: ESG-AUM—Treated vs. Control

Table C.42: ESG-AUM—Parallel Trends Normalized Differences

	Treated		Control		Norm. Diff.
VARIABLES	Mean	Std. Dev.	Mean	Std. Dev.	
ESG_AUM_Abs_s	0.12	1.84	0.00	0.00	0.06
env_controv	0.06	0.26	0.02	0.15	0.24
gdp_growth_yy	0.02	0.003	0.02	0.003	0.00
inflation_yy	0.01	0.007	0.01	0.007	0.00
sfdr	0.00	0.00	0.00	0.00	n.a.

This table reports statistics of relevant co-variates over the pre-shock period (2015 to 2023) dividing the sample between treated (SIs) and control group (LSIs). The last column reports normalized differences between treatment and control groups (differences in averages by treatment status, scaled by the square root of the sum of the variances). An absolute difference smaller than 0.25 indicates that there is no significant difference between the groups. See Table C.33 for detailed variable definitions incl. units.

Rounded values shown.

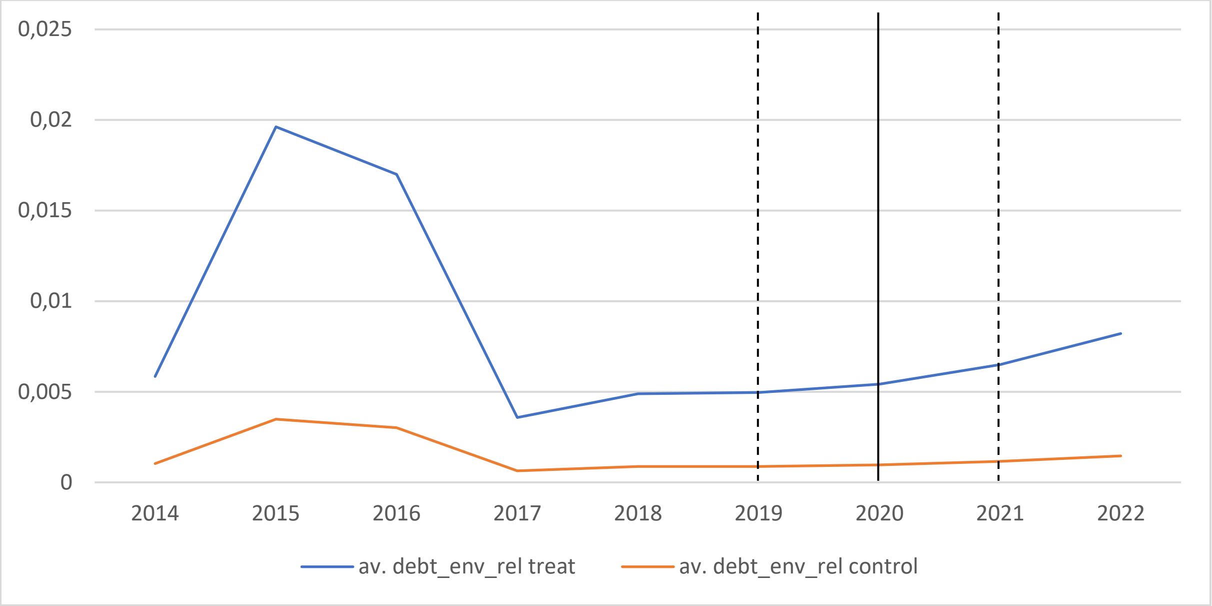
Table C.43: ESG-AUM—Parallel Trends

VARIABLES	(1) ESG_AUM_Abs_s Parallel Trends
afterPT	0.00579
	(0.00390)
treatment	-0.000687
	(0.00159)
treat_afterPT	0.00169
	(0.00204)
env_controv	0.0138***
	(0.00269)
gdp_growth_yy	-0.0904
	(0.147)
inflation_yy	-0.437
	(0.288)
o.sfdr	-
Constant	0.00248
	(0.00294)
Observations	555
R-squared	0.057

Robust standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

C.2.3 Parallel Trends 2.3: Green Lending



Pre-treatment period until 2019 (Start of lead effects)

Figure C.27: Green Lending—Treated vs. Control

Table C.44: Green Lending—Parallel Trends Normalized Differences

	Treated		Control		Norm. Diff.
VARIABLES	Mean	Std. Dev.	Mean	Std. Dev.	
debt_env_rel	0.01	0.04	0.01	0.02	0.02
env_controv	0.01	0.07	0.00	0.02	0.09
dbtr_sect_A	0.00	0.00	0.01	0.07	0.20
dbtr_sect_B	0.00	0.00	0.00	0.00	0.03
dbtr_sect_C	0.02	0.12	0.01	0.07	0.17
dbtr_sect_D	0.00	0.02	0.00	0.03	0.03
dbtr_sect_E	0.00	0.00	0.00	0.03	0.09
dbtr_sect_F	0.00	0.00	0.01	0.06	0.15
dbtr_sect_G	0.01	0.08	0.01	0.07	0.02
dbtr_sect_H	0.00	0.05	0.00	0.02	0.09
dbtr_sect_I	0.00	0.00	0.00	0.03	0.08
dbtr_sect_J	0.00	0.03	0.00	0.01	0.10
dbtr_sect_K	0.26	0.39	0.42	0.42	0.40
dbtr_sect_L	0.00	0.02	0.02	0.10	0.25
dbtr_sect_M	0.00	0.01	0.00	0.05	0.10
dbtr_sect_N	0.00	0.04	0.00	0.04	0.01

dbtr_sect_O	0.09	0.24	0.07	0.18	0.10
dbtr_sect_P	0.00	0.01	0.00	0.01	0.04
dbtr_sect_Q	0.00	0.01	0.00	0.02	0.05
dbtr_sect_R	0.00	0.00	0.00	0.02	0.07
dbtr_sect_S	0.00	0.00	0.00	0.02	0.07
dbtr_sect_T	0.00	0.00	0.00	0.03	0.10
debt_vsmall_rel	0.02	0.11	0.06	0.18	0.28
debt_small_rel	0.01	0.08	0.01	0.07	0.01
debt_medium_rel	0.02	0.10	0.04	0.14	0.18
debt_large_rel	0.07	0.21	0.04	0.14	0.16
debt_vlarge_rel	0.07	0.21	0.04	0.14	0.16
gdp_growth_yy	0.02	0.003	0.02	0.003	0.00
inflation_yy	0.01	0.007	0.01	0.007	0.00
sfdr	0.00	0.00	0.00	0.00	n.a.

This table reports statistics of relevant co-variates over the pre-shock period (2014 to 2022) dividing the sample between treated (SIs) and control group (LSIs). The last column reports normalized differences between treatment and control groups (differences in averages by treatment status, scaled by the square root of the sum of the variances). An absolute difference smaller than 0.25 indicates that there is no significant difference between the groups. See Table C.33 for detailed variable definitions incl. units.

Rounded values shown.

Table C.45: Green Lending—Parallel Trends

VARIABLES	(1) debt_env_rel Parallel Trends
afterPT	5.652
	(3.532)
o.treatment	-
treat_afterPT	9.708
	(7.004)
o.sfdr	-
env_controv	5.643
	(57.90)
gdp_growth_yy	1,119***
	(325.7)
inflation_yy	-1,630***
	(261.3)
dbtr_sect_A	-30.28
	(30.55)
dbtr_sect_B	-197.1
	(449.6)
dbtr_sect_C	324.7***
	(20.44)
dbtr_sect_D	-18.80
	(49.41)
dbtr_sect_E	6.365
	(51.18)
dbtr_sect_F	-6.671
	(30.61)
dbtr_sect_G	-2.660
	(24.08)
dbtr_sect_H	79.67
	(61.00)
dbtr_sect_I	-12.79
	(61.05)
dbtr_sect_J	-0.561
	(79.37)
dbtr_sect_K	24.25***
	(4.027)
dbtr_sect_L	-2.115
	(17.70)
dbtr_sect_M	-9.244
	(32.18)
dbtr_sect_N	-4.483
	(40.25)
dbtr_sect_O	3.477
	(8.804)
dbtr_sect_P	-128.9
	(212.0)
dbtr_sect_Q	-38.49
	(69.15)
dbtr_sect_R	-49.22
	(90.79)
dbtr_sect_S	-54.85
	(107.8)
dbtr_sect_T	-35.35
	(59.63)
debt_vsmall_rel	-30.12***
	(11.31)
debt_small_rel	-26.36
	(21.11)
debt_medium_rel	-26.69**
	(11.20)
debt_large_rel	0.462

	(11.10)
o.debt_vlarge_rel	-
Constant	-8.891
	(6.100)
Observations	14,880
R-squared	0.308

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

C.3 Results: Robustness Checks

C.3.1 Results 1: Climate Risk (Disclosure-adjusted)

Table C.46: Environmental Risk x Disclosure—Baseline Regression

VARIABLES	(1) env_risk_disc Contemporaneous	(2) env_risk_disc 1 Year Lead	(3) env_risk_disc 1 Year Lagged
after	0.0826		
	(0.0591)		
o.treatment	-	-	-
treat_after	0.380***		
	(0.105)		
env_controv	-0.176	-0.0569	-0.303*
	(0.119)	(0.0754)	(0.159)
gdp_growth_yy	1.225**	-0.687	-1.812***
	(0.579)	(0.495)	(0.479)
inflation_yy	0.534*	3.454***	-0.297
	(0.299)	(1.182)	(0.357)
log_CO2_price	0.0562***	0.0276***	0.0474***
	(0.0150)	(0.0105)	(0.0141)
sfdr	-0.0243	0.225***	-0.110
	(0.0923)	(0.0750)	(0.0993)
F.after		0.0154	
		(0.0343)	
F.treat_after		0.230***	
		(0.0807)	
L.after			0.242***
			(0.0800)
L.treat_after			0.414***
			(0.120)
Constant	-0.0833	-0.0214	0.0156
	(0.0535)	(0.0343)	(0.0418)
Observations	680	595	595
R-squared	0.643	0.598	0.673

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1
Env_risk on a scale from 0 (bad) to 10 (good)
Results based on stata’s reghdfe OLS estimation method; time and entity fixed effects treated by means of ‘absorbing’ (Correia, 2016)

C.3.2 Results 2.1: Green Bonds Issuance

Table C.47: GB Issuance—Baseline Regression

VARIABLES	(1) GB_to_all Contemporaneous	(2) GB_to_all 2 Years Lead	(3) GB_to_all 1 Year Lead	(4) GB_to_all 1 Year Lagged
after	-0.000940			
	(0.000687)			
o.treatment	-	-	-	-
treat_after	0.0540***			
	(0.0106)			
env_controv	0.0125	-0.00650	0.00127	0.0179
	(0.0414)	(0.0203)	(0.0272)	(0.0467)
gdp_growth_YY	0.0125	-0.00886	-0.00507	-0.0176*
	(0.00896)	(0.00671)	(0.00760)	(0.0105)
inflation_YY	0.0175	-0.00656*	0.0220	0.00562
	(0.0174)	(0.00361)	(0.0153)	(0.0205)
SFDR	0.00502**	0.0155***	0.0124***	0.000434
	(0.00212)	(0.00466)	(0.00346)	(0.000571)
F2.after		-0.000708***		
		(0.000209)		
F2.treat_after		0.0227***		
		(0.00544)		
F.after			-0.00150***	
			(0.000491)	
F.treat_after			0.0400***	
			(0.00828)	
L.after				0.000387
				(0.000953)
L.treat_after				0.0634***
				(0.0133)
Constant	-0.000270	0.000315**	-0.000104	0.000391
	(0.000403)	(0.000133)	(0.000312)	(0.000440)
Observations	16,142	13,836	14,989	14,989
R-squared	0.224	0.169	0.199	0.234

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
GB_to_all on a percentage scale.
Results based on stata’s reghdfe OLS estimation method; time and entity fixed effects treated by means of ‘absorbing’ (Correia, 2016).

C.3.3 Results 2.2: ESG-AUM

Table C.48: ESG-AUM—Baseline Regression

VARIABLES	(1) ESG_AUM_Abs_s Contemporaneous	(2) ESG_AUM_Abs_s 1 Year Lead	(3) ESG_AUM_Abs_s 1 Year Lagged
after	-0.00364		
	(0.00227)		
o.treatment	-	-	-
treat_after	0.0158**		
	(0.00746)		
env_controv	0.00504	0.00988	0.00559
	(0.0101)	(0.0116)	(0.0109)
gdp_growth_YY	-0.0273	-0.0160	-0.0613**
	(0.0200)	(0.0266)	(0.0283)
inflation_YY	0.0567**	0.0355*	0.0203
	(0.0284)	(0.0184)	(0.0161)
SFDR	0.00848	0.00815	-0.000280
	(0.00620)	(0.00607)	(0.000280)
F2.after			
F2.treat_after			
F.after		-0.00187	
		(0.00137)	
F.treat_after		0.0112**	
		(0.00444)	
L.after			0.00104
			(0.00113)
L.treat_after			0.0228*
			(0.0115)
Constant	0.000305	-0.000355	0.00113
	(0.00173)	(0.00143)	(0.00174)
Observations	999	888	888
R-squared	0.316	0.319	0.350

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
ESG_AUM in EUR.
Results based on stata's reghdfe OLS estimation method; time and entity fixed effects treated by means of 'absorbing' (Correia, 2016)

C.3.4 Results 2.3: Green Credit

Table C.49: Green Lending—Baseline Regression

VARIABLES	(1) debt_env_rel Contemporaneous	(2) debt_env_rel 1 Year Lead	(3) debt_env_rel 1 Year Lagged
after	-0.724		
	(2.867)		
o.treatment	-	-	-
treat_after	17.49**		
	(8.844)		
o.sfdr	-	-	-
env_controv	0.0475	-0.261	0.0235
	(2.873)	(2.318)	(4.313)
gdp_growth_YY	96.50***	150.0***	49.95***
	(30.57)	(41.88)	(13.97)
inflation_YY	153.7	-1,201***	237.5
	(156.2)	(361.1)	(150.4)
CO2_price	-0.338	0.411***	-0.521**
	(0.209)	(0.119)	(0.210)
dbtr_sect_A	-32.76***	-30.16**	-39.51***
	(12.15)	(14.01)	(13.61)
dbtr_sect_B	-126.2**	-159.8**	-137.0**
	(59.16)	(71.52)	(63.58)
dbtr_sect_C	231.4	263.7	249.1
	(207.0)	(239.3)	(226.2)
dbtr_sect_D	-3.990	-13.29	-2.226
	(11.76)	(12.61)	(17.71)
dbtr_sect_E	2.613	1.975	11.69
	(9.457)	(10.99)	(11.18)
dbtr_sect_F	-9.599	-4.716	-10.17
	(6.254)	(6.512)	(7.431)
dbtr_sect_G	-1.950	1.078	2.374
	(8.116)	(9.136)	(10.58)
dbtr_sect_H	62.05**	59.46**	72.90***
	(28.46)	(30.02)	(28.06)
dbtr_sect_I	-10.89	-5.652	-11.32
	(13.80)	(14.84)	(17.01)
dbtr_sect_J	11.39	9.617	10.83
	(12.46)	(13.18)	(11.79)
dbtr_sect_K	27.81***	23.26***	32.84***
	(3.296)	(2.670)	(3.670)
dbtr_sect_L	-4.913	0.639	-6.872
	(5.356)	(5.679)	(6.700)
dbtr_sect_M	-8.818	-5.021	-7.381
	(7.780)	(7.630)	(10.21)
dbtr_sect_N	-7.705	-18.32	-4.249
	(19.20)	(24.34)	(22.91)
dbtr_sect_O	9.568***	2.736	11.43***
	(3.160)	(3.180)	(3.804)
dbtr_sect_P	-32.79	-72.59**	-35.73
	(33.81)	(35.32)	(38.48)
dbtr_sect_Q	-27.13*	-47.70**	-34.79*
	(15.01)	(19.61)	(20.25)
dbtr_sect_R	-37.19*	-52.11**	-39.61*
	(19.62)	(22.71)	(22.81)
dbtr_sect_S	-23.66	-20.64	-13.16
	(24.01)	(28.72)	(25.83)
dbtr_sect_T	-6.045	8.832	-8.096
	(36.00)	(32.41)	(45.48)
debt_vsmall_rel	-17.40	-20.59	-20.61
	(11.19)	(13.62)	(13.66)
debt_small_rel	-22.70*	-20.47*	-28.17*

	(11.83)	(10.79)	(15.71)
debt_medium_rel	-32.75***	-28.66***	-35.55***
	(8.317)	(6.190)	(12.80)
debt_large_rel	1.937	7.550	3.560
	(32.74)	(37.67)	(41.79)
o.debt_vlarge_rel	-	-	-
F.after		-14.54***	
		(2.719)	
F.treat_after		12.67*	
		(7.687)	
L.after			6.495
			(4.329)
L.treat_after			17.33
			(10.95)
Constant	1.356	8.216***	2.636
	(2.356)	(2.317)	(2.625)
Observations	22,320	19,840	19,840
R-squared	0.200	0.234	0.224

Robust standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

Chapter 5

New Green Alliances: Requirements to Implement Long-Run International Sustainable Energy Partnerships

List of Abbreviations

DFBOM	Design-Finance-Build-Operate-Maintain	NPV	Net present value
EU	European Union	OM	Operate-Maintain
EUR	Euros	PPP	Public-private partnership
GW	Gigawatt	RES	Renewable energy sources

5.1 Introduction

How can international sustainable energy partnerships involving multiple countries as well as private sector investment successfully contribute to the global sustainability transition? With an ever-increasing global population, a growing demand for energy, the mounting evidence of climate change, and a complex geopolitical landscape marked by aggravating tensions, relying on finite and environmentally damaging fossil fuels supplied by a limited number of countries is no longer a viable long-term strategy. Instead, adopting renewable energy sources (RES) has become crucial to ensure a prosperous future for all. In the quest to provide sufficient renewable energy at economically viable conditions, new sustainable energy partnerships between multiple governments have emerged and form an integral part of many economies' decarbonization strategies[73]. The partnerships can play an essential role in accelerating the development, adoption, and scale-up of clean energy technologies, by pooling resources, sharing knowledge, driving innovation, and exploiting comparative advantages in RES generation. The latter primarily refer to locational advantages, meaning that renewable energy is generated at locations with the better geographical conditions such as the availability of land to install RES, higher solar densities, or a more continuous occurrence of wind. The energy is then transported to the locations, where it is consumed. Enabling higher amounts of RES generation at lower cost, new sustainable energy partnerships, hence, have the potential to contribute to climate change mitigation, energy security, and socio-economic development.

Since setting up international energy systems including RES generation, transmission and distribution requires considerable investment, and public means to raise financial capital remain limited[74], many governments attach great importance to the private sector providing the

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[73] For instance, Germany and Australia have signed an agreement establishing the 'Australian-German Energy Transition Hub' in 2020, and an 'Australia-Germany Hydrogen Accord' in 2021 to strengthen collaboration in RES research, development, and commercialization. Japan and Australia have signed a 'Joint Statement on Enhanced Energy Cooperation' in 2020, outlining their shared commitment to the development of RES with a focus on green hydrogen. Also, multiple countries have set up energy partnerships with African countries. For instance, the United States have set up the 'US-Africa Clean Energy Finance Initiative' in 2013 (see https://www.whitehouse.gov/briefing-room/statements-releases/2022/12/13/fact-sheet-u-s-africa-partnership-in-supporting-conservation-climate-adaptation-and-a-just-energy-transition/), India and different African countries have set up several initiatives regarding a cooperation on RES, such as the 'International Solar Alliance' (see https://isolaralliance.org/), and China has established the 'China-Africa Energy Partnership' as part of the broader 'Forum on China-Africa Cooperation' already in 2000. Furthermore, the EU and African countries have established the 'Africa-EU Energy Partnership' in 2007. Key initiatives include the 'EU-Africa Infrastructure Trust Fund' and the 'Africa Renewable Energy Initiative', as well as an EU-Africa hydrogen partnership. Regarding decarbonization strategies, the European Union, for instance, has incorporated sustainable energy partnerships as a key pillar into the European Green Deal (EC, 2020).

[74] This is, e.g., due to high government expenditures and high government debt, aggravated by currently rising interest rates—especially in developing economies, which are already even more heavily indebted than most developed economies, while being economically weaker (IMF, 2021; Sinn, 2021).

financial means to overcome the ‘investment gap’ into green energy infrastructure projects[75] (e.g., IMF, 2014; 2020). Different public-private financing options exist, including, e.g., public-private equity or debt finance, and alternative financing vehicles[76]. The most common approach amongst the latter is to set up public-private partnerships (PPPs) due to their manifold potential benefits[77] (APAC/OECD, 2019; OECD, 2019). While the potential benefits of the new sustainable energy partnerships are considerable, their actual setup is lagging behind: out of the planned RES capacities, only a negligible fraction has been installed so far. On the academic side, not much research exists, yet, which comprehensively assesses the long-term success of such partnerships.

In this Chapter, we present an evolutionary game theoretical approach to investigate the long-term stability of sustainable international energy partnerships involving multiple

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[75] The ‘investment gap’ into green energy projects should be understood as a positive description that required investments to realize sustainability policy targets exceed actual investments. Any normative conclusion, e.g., in a context of welfare maximization, requires further investigation.

[76] Previous research has assessed the question how to best channel private sector investments into sustainable (infrastructure) projects, such as Casteels et al., (2005), Della Croce (2012; 2014), OECD (2012-21), van Nieuwerburgh et al. (2015), DB AM (2017), Floater et al., (2017), G20 Global Infrastructure Initiative (2017), Hartzmark and Sussman (2019), Andonov et al. (2021), Polzin and Sanders (2020; 2021), Iskandarova et al. (2021), and Polzin et al. (2021).

[77] PPPs have emerged as a popular (funding) mechanism for governments to collaborate with the private sector in delivering public services and infrastructure projects. PPPs are contractual agreements between public authorities and private entities, where both parties share risks, responsibilities, and rewards in delivering public services or infrastructure projects (World Bank, 2020). They have gained prominence due to their potential to overcome financial constraints and bring efficiency, innovation, and cost-effectiveness to public projects (Hodge and Greve, 2007; Estache et al., 2014; Romboutsos and Saussier, 2014). Especially in a context involving developing economies, realizing public services and infrastructure projects via PPPs bears promising advantages (Dykes and Jones, 2016; Yahaya et al., 2020). However, PPPs also face criticism related to transparency, accountability, and equitable distribution of benefits (Roumboutsos, 2015; Petersen, 2019). In this context, a large body of literature assesses general aspects of PPPs, such as optimal contract setup or the impact of re-negotiations. For a literature review, see, e.g., Narbaev et al., 2019; for a comprehensive assessment of the economics of PPPs see Saussier and de Brux (2018).

governments—notably, between developed and developing economies—and private sector investors and financiers. We assess the long-term stability under different sets of framework conditions, including macroeconomic and environmental policy conditions, technological developments, different designs of international cooperation agreements, and distinct setups of public-private partnerships. We parametrize the game theoretical model based on a partnership between European Union (EU) member states and Northern African economies with hydrogen as an energy carrier[78]. In this partnership, renewable energy is generated in the Northern African countries, and used to produce green hydrogen on location. The green hydrogen is then partially transported to the consumption centers in the EU via pipelines, and partially used to meet the increasing energy demand of the Northern African countries themselves.

We find that currently, due to the considerable costs of RES—especially, its high capital expenditure intensities—and incompletely priced in environmental externalities, business cases associated with the partnerships are not yet very attractive, inhibiting a sufficient cooperation of the private sector. However, also improvements in the business case are insufficient to incentivize a long-term participation. The design of the cooperation agreements between the governments as well as the design of the PPP contracts are important influencing factors regarding the long-term success of sustainable energy partnerships. In particular, a co-investment of all involved governments is crucial, as otherwise, governments can realize windfall profits, which disincentivize them to cooperate in the long run. Also, we show that availability-based public-private partnerships with a full-fledged private sector involvement in

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[78] The results of the exemplary consideration of the EU-Africa energy partnership can be generalized since the setup is representative for other sustainable energy partnerships. In all sustainable energy partnerships, the interaction takes place between countries with less advantageous and countries with better RES production conditions. In most sustainable energy partnerships, developed and developing economies interact. Furthermore, we consider hydrogen as an energy carrier, which is currently the most intensively discussed and most promising way to transport energy between the partner economies.

designing, financing, building, operating, and maintaining the partnership are the preferrable setup, as under this design, the business case for private investors is improved, while windfall benefits for governments are further reduced.

5.2 Current State of the Research and our Contribution

This Chapter contributes to three strands of literature in the areas of international cooperation, public-private investment and finance, and techno-economic assessments of sustainable energy systems. Building upon and contributing to all three research fields, we generate new insights related to new sustainable energy partnerships involving both international cooperation and public-private investment and finance. Choosing a game theoretical approach allows us to capture the high-level cooperation dynamics based on insights from the field of international cooperation, while grounding them in their financial and techno-economic realities. Bringing together these perspectives allows us to assess influencing factors on the success of sustainable energy partnerships more comprehensively, advancing both the academic and the public policy debate.

International cooperation is ‘the coordinated behavior of independent and possibly selfish [international] actors that benefits them all’, in an environment with limited possibilities for external enforcement such as binding agreements subject to sanctioning (Taylor, 1976; Axelrod, 1981, 1984; Axelrod and Keohane, 1985; Oye, 1986; Powell, 1994). Contributions describe rationales for decision-making (Axelrod, 1981; Grieco, 1988; Milner, 1992; Dai et al., 2017) under different conditions, such as the number of actors and interactions, the time horizon, and international regimes (e.g., Krasner, 1982). Assessments are often based on (non-cooperative) game theoretical models, such as the investigation of the dynamics underlying the provision of public goods or club goods (Buchanan, 1965; Olson, 1965) or the design of self-enforcing international agreements (Telser, 1980). Within the context of energy, for instance, Lotfi and Navidi (2012), Chang et al. (2014), Wood et al. (2016), and Toufighi (2022) investigate dynamics in international oil and gas provision by means of game theoretical approaches. Van Graaf and Colgan (2016) explore the link between energy security and the 2014 Ukraine crisis; Richman and Ayyılmaz (2019) and Jafarzadeh et al. (2021) model the strategic decision-making process of the EU choosing alternatives to Russian O&G suppliers. Related to sustainability, for instance, Kalfagianni and Young (2022) and Pouw et al. (2022) provide a comprehensive review of literature analyzing multilateral environmental agreements. Numerous of these contributions deploy game theoretical approaches, and most assess climate issues. Barrett (1994) analyzes self-enforcing international environmental agreements (see also, e.g., Ulph and Rubio, 2004 and Eichner and Pethig, 2013); many contributions assess the role of developed vs. developing economies in climate cooperation (e.g., Warr, 1983; Rübbelke, 2005; McAfee, 2016). The most prominent contribution stems from Nordhaus (2015), in which he introduces ‘climate clubs’ as a means to overcome free-riding in international climate policy (see also, e.g., Silva and Yamaguchi, 2018; Nordhaus, 2021).

Public-private investment and finance play a key role in the provision of sustainable energy infrastructure (e.g., Pollitt, 1997; Newbery, 2002; Nakano and Managi, 2008). Flyvbjerg (2003; 2014) and McDowell (2018) assess the influence of public-private infrastructure megaprojects on their contribution to economic growth, with a focus on good governance (e.g., procurement, regulatory oversight, and stakeholder engagement) as a key success factor. Calderón and Servén (2010) and Bhattacharya et al. (2015) focus on sustainability principles in this context. With regards to infrastructure financing via PPPs, the research focus has been on how to design optimal partnerships (e.g., Estache and Fay, 2007; Inderst, 2013). For instance, De Clerck and Demeulemeester (2016) assess PPP procurement markets, Ouenniche et al. (2016) investigate selection mechanisms of PPPs, both based on game theoretical approaches. Assessments of energy PPPs account for specificities in the energy sector, such as their capital intensity, the longevity of contracts or the particular regulatory environment, and elevated merchandizing risk (cf., e.g., Vagliasindi, 2013; Fleta-Asín and Munoz, 2021). In a broader sustainability context, there is a body of literature dealing with 'transnational development PPPs' set up between developing and developed economies to realize (sustainable) development goals (see, for instance, Schäferhoff et al., 2007; Yu et al., 2015).

Techno-economic assessments of sustainable energy partnerships consider the technical setup of energy systems of specific partnerships. For instance, BDI (2021) outlines the potential setup of a German-Australian energy partnership. With regards to an Africa-EU Energy Partnership, Timmerberg and Kaltschmitt (2019) and Timmerberg et al. (2019, 2020), assess potential technical setups and estimate the associated costs. Van Wijk et al. (2019), Bhagwat and Olczak (2020) and AbouSead and Hatem (2022) state desired goals of such cooperations. Furthermore, the literature includes *ex post* assessments of previous sustainable energy partnerships, such as DESERTEC (Schmitt, 2018). This literature strand informs the structure and the parametrization of our model.

5.3 The Model

We present a continuous tripartite evolutionary game to describe the interaction of two groups of governments and private sector investors to identify setups, in which all players are incentivized to join and remain in sustainable energy partnerships in the long run. The approach is comparable to discrete non-cooperative games in classical game theory[79]. However, it allows

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[79] For instance, in a sense that the games take place in an environment of anarchy. In classical game theory, stable outcomes are described by Nash equilibria (Nash, 1950, 1951), and (subgame-) perfect equilibria (Selten, 1965, 1975, 1980; Harsanyi, 1967, 1968a, b). In evolutionary game theory, similarly, evolutionary stable strategies mark the long-term stable states of the evolutionary games, i.e., the equilibrium points, wherein the stakeholders cannot improve their outcomes no matter how their strategies change.

us to assess the long-term evolution of the game, in which a stock of infrastructure is built up. The proposed model, thus, describes sustainable energy partnerships as an infinite game. Sustainable energy partnerships are aimed at meeting the long-term RES requirements of the parties involved. Therefore, the model not only describes stand-alone international PPPs with finite durations, but long-term international energy partnerships, under whose cooperation multiple PPPs can be realized, in parallel, overlapping, or subsequent order. For governments, hence, cooperation implies a long-term commitment to the partnership, setting the institutional framework conditions for the investment cooperation, while private sector cooperation describes the commitment to PPPs, which are set up within this context. Throughout the game, parameters, such as hydrogen production costs or interest rates, can evolve over time. Furthermore, the evolutionary approach reflects limitations in the rational behavior of the players. Thus, the evolutionary setup describes the behavior of stakeholders in sustainable energy partnerships more realistically[80].

5.3.1 Players and Model Structure

The model includes three groups of players i: EU governments, EG, African governments, AG, and private sector investors, PR. EU governments represent developed countries with high energy consumption, often referred to as the 'global North', and African governments represent

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[80] This is, since outcomes are often difficult to predict, and the rationally best, i.e., utility-maximizing, decision, even if it can be identified, is not possible to be implemented due to political reasons. Also, strategies of the actors might change over time, based on the actions of the other actors or due to changes in the exogenous influencing factors, such as macroeconomic conditions or technological developments. Furthermore, the assessed setup involves larger groups of actors, i.e., amongst the private sector actors, which can be summarized as one representative actor in the model setup (cf. Nowak and Sigmund, 2004; Gintis, 2009; Friedman and Sinervo, 2016). While evolutionary game theory is rooted in the description of biological systems, it has fed back to economic contexts, in which long-term relationships between groups of myopic agents are of interest (cf., e.g., Friedman, 1991; Kandori, 1997; Sandholm, 2010; Fan and Hui, 2020; Krapohl et al., 2021).

developing economies with locational advantages in RES generation, often referred to as the 'global South'. Private sector investors subsume all private sector actors potentially being involved in PPPs, ranging from construction companies to financial investors[81]. The model reflects two relations between the players: cooperation agreements between the EU and African governments, and joint PPPs, which are set up under the aegis of the cooperation agreements, see Figure 28. The financial flows between the players are modeled as payoffs.

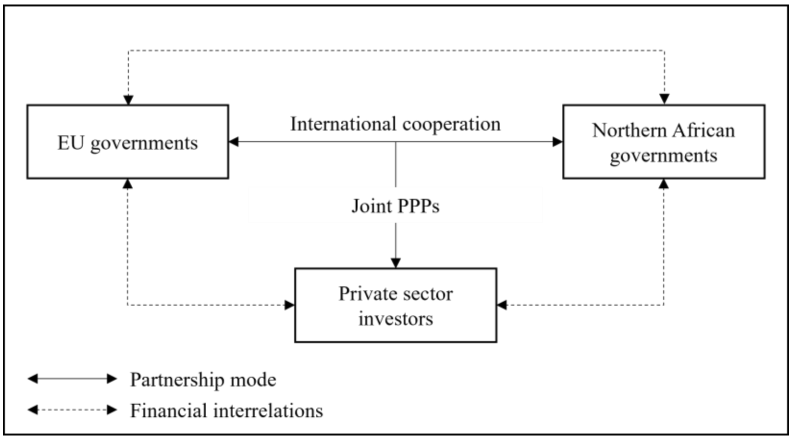

Figure 28: Players and their Interrelations

5.3.2 Strategic Choices and Cooperation Dynamics

The three groups of players $i \in \{EG, AG, PR\}$ face the following strategic choices: each of the groups can pursue two strategies S_{ij}, $j \in \{1,2\}$, meaning that they can decide to *cooperate* or *not cooperate*. The continuous evolutionary model reflects an infinitely repeated game, covering a time period from today onwards. That means that the players start facing the choice whether to cooperate or not to cooperate today, and continuously and repeatedly re-evaluate their decisions until the infinite. Depending on their own chosen strategy, as well as on the strategy chosen by the two other groups of players, the players realize different payoffs,

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[81] Within the model, the exact number of governments and private investors is not specified. However, generally, groups of players in evolutionary game theoretical models include multiple players with similar properties.

$PO_{ik}(S_{ij}), k \in \{1,2,\dots,8\}$, with k being the different combinations of strategic choices of the three groups of players. The payoffs are summarized in the game strategy matrix, see Figure 29.

		EU governments, EG			
		Cooperate		Not cooperate	
		African governments, AG		**African governments, AG**	
		Cooperate	Not cooperate	Cooperate	Not cooperate
Private sector actors, PR	Cooperate	$(PO_{PR,1}, PO_{EG,1}, PO_{AG,1})$	$(PO_{PR,2}, PO_{EG,2}, PO_{AG,2})$	$(PO_{PR,3}, PO_{EG,3}, PO_{AG,3})$	$(PO_{PR,4}, PO_{EG,4}, PO_{AG,4})$
	Not cooperate	$(PO_{PR,5}, PO_{EG,5}, PO_{AG,5})$	$(PO_{PR,6}, PO_{EG,6}, PO_{AG,6})$	$(PO_{PR,7}, PO_{EG,7}, PO_{AG,7})$	$(PO_{PR,8}, PO_{EG,8}, PO_{AG,8})$

Figure 29: Game Strategy Matrix of the Players

When deciding which strategy to play, the players generally maximize their respective utility (as expressed by the payoffs) in a forward-looking manner: they consider their expected payoffs of the current round including the net present value (NPV) of the payoffs of all future rounds. Thereby, they assume that the players, once chosen their most advantageous strategy, will follow that choice consistently. Generally, the players do not act strategically to punish or reward the other players' strategic choices of the previous rounds[82]. However, since each round of cooperation contributes to the build-up of a stock of infrastructure (see Section 5.3.3), players take into account the strategic choices of their fellow players in the previous rounds in a sense that payoffs from cooperation increase with a larger stock of infrastructure resulting from the previous rounds' cooperative behavior, and non-cooperation becomes more costly coincidingly. The probability that the players decide to play strategy S_{ij} is $p_{ij} \in [0,1]$. In our evolutionary

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[82] This, and also the fact that players take the current strategic choice of their fellow players as the best guess for predicting their future behavior, reflects that we assume players with bounded rationality. This is, since in the context of the sustainable energy partnerships, players are only able to a very limited extent to make predictions regarding their fellow players' future strategic choices based on their past behavior. Firstly, a magnitude of contextual and cultural factors can influence the players' behavior. For instance, in a prospective hydrogen partnership between the German and the Moroccan governments, a reason for freezing cooperation was a political statement regarding the status of Western Sahara, which was entirely unrelated to the hydrogen partnership. Furthermore, besides the unknown factors within the current set of players' decision-making strategies, players—and, thus, their decision-making strategies—can also change quickly to follow different rules, for instance, if there is a change in governments.

game theoretical model this means, that for each round of the game and for each group of players i, a likelihood to cooperate is determined, expressed by means of the dynamic equation for each of the three groups of players,

$$\frac{dp_{i1}}{dt} = p_{i1}(1 - p_{i1})\varDelta a_{ij}, \tag{1}$$

with $\varDelta a_{ij} = (a_{i1} - a_{i2})$ being the difference between the expected payoffs a_{i1} and a_{i2} for the groups of players given p_{ij} of all players[83]. The set of the three differential equations for the three groups of players represents the so-called replicator dynamic system to be solved. The evolutionary process starts with an initial likelihood of each player to cooperate. In the following process, the players interact with each other based on the rules of the game, i.e., the strategies and payoffs. Strategies that yield higher expected payoffs are more likely to be selected, meaning that the likelihood within each group of players to play that strategy increases over the rounds of the game. The strategic choice, which repeatedly outperforms the other potential strategic choices in the long run, also in view of the other players' responses to that strategy, is called the evolutionary stable strategy, and is comparable to the Nash equilibrium in classical game theory.

The cooperation problem generally facing the players is a commitment problem, following from a public goods game. This means while mutual cooperation would yield the best outcome for all, the individual groups of players are incentivized not to cooperate. If all players assume

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[83] With the differences in expected payoffs for the three players $\varDelta a_{EGj} = p_{AG1}[p_{PR1}PO_{EG1} + (1 - p_{PR1})PO_{EG5}] + (1 - p_{AG1})[p_{PR1}PO_{EG2} + (1 - p_{PR1})PO_{EG6}] - p_{AG1}[p_{PR1}PO_{EG3} + (1 - p_{PR1})PO_{EG7}] - (1 - p_{AG1})[p_{PR1}PO_{EG4} + (1 - p_{PR1})PO_{EG8}]$ for the EU governments, $\varDelta a_{AGj} = p_{EG1}[p_{PR1}PO_{AG1} + (1 - p_{PR1})PO_{AG5}] + (1 - p_{EG1})[p_{PR1}PO_{AG2} + (1 - p_{PR1})PO_{AG6}] - p_{EG1}[p_{PR1}PO_{AG3} + (1 - p_{PR1})PO_{AG7}] - (1 - p_{EG1})[p_{PR1}PO_{AG4} + (1 - p_{PR1})PO_{AG8}]$ for the Northern African governments, and $\varDelta a_{PRj} = p_{EG1}[p_{AG1}PO_{PR1} + (1 - p_{AG1})PO_{PR2}] + (1 - p_{EG1})[p_{AG1}PO_{PR3} + (1 - p_{AG1})PO_{PR4}] - p_{EG1}[p_{AG1}PO_{PR5} + (1 - p_{AG1})PO_{PR6}] - (1 - p_{EG1})[p_{AG1}PO_{PR7} + (1 - p_{AG1})PO_{PR8}]$.

selfish and utility-maximizing behavior of the other groups of players, not to cooperate is their respective strategic choice with the highest payoff. This is primarily due to potential free-riding when investing into sustainable energy, and external effects of greenhouse gas emissions, which are only partially reflected in carbon prices. The players' optimal strategic choices can be altered by changing the framework conditions of the partnership, which is done throughout the analyses in Section 5.5.

5.3.3 Payoff Functions

The payoff functions of the three groups of players describe the concrete payoffs $PO_{ik}(S_{ij}, t)$, which materialize in the different outcomes of the game at each time $t, t \in [0, T]$, i.e., at each round of the game. The components of the payoff functions are informed by, firstly, lessons learned from existing sustainable energy partnerships such as DESERTEC (see Section 1.3.4.2) as well as based on the declared goals of such partnerships. In the following, we describe the high-level structure of the payoffs. More granular descriptions of the variables are summarized in Table D.50 and Table D.51 in the Appendix. The governments' payoffs can be described as

$$PO_{ik} = W_{ik}(S_{ij}, t) + D_{ik}(S_{ij}, t) + M_{ik}(S_{ij}, t) \; \forall \; i \in \{EG, AG\}, \tag{2}$$

with welfare payoffs, W_{ik}, general payoffs related to the cooperation agreement, D_{ik}, and monetary payoffs, M_{ik}, from the operation of the energy system. The private sector investors' payoffs can be described as

$$PO_{ik}(S_{ij}, t) = D_{ik}(S_{ij}, t) + M_{ik}(S_{ij}, t) \; \forall \; i \in \{PR\}, \tag{3}$$

with payoffs related to the cooperation, D_{PRk}, and monetary payoffs, M_{PRk}, from the operation of the energy system. The welfare payoffs,

$$W_{ik} = ENV_{ik} + SOC_{ik} + MAC_{ik} \; \forall \; i \in \{EG, AG\}, \tag{4}$$

represent the desired public policy outcomes of the sustainable energy partnerships (see, e.g., Schmidt, 2018; van Wijk et al., 2019; Bhagwat and Olczak, 2020; AbouSead and Hatem, 2022), with ENV_{ik} being environmental benefits resulting from reduced greenhouse gas emissions, SOC_{ik} being social benefits from increased energy security, job creation, and improved energy access in African countries, and MAC_{ik} being macroeconomic benefits, e.g., from increased economic activity due to greenfield energy infrastructure investments (see, e.g., Aschauer, 1989; Munnell, 1992; Romp & de Haan, 2007). Payoffs related to the cooperation agreement,

$$D_{ik} = \pm P_{ik} \pm DA_{EGk} - TC_{ik}, \tag{5}$$

subsume penalties, P_{ik}, for the non-compliance with PPP contracts[84], development aid, DA_{EGk}, paid from the developed economies, i.e., the EU governments, to the developing economies, i.e., the African countries[85], and transaction costs, TC_{ik}, arising from the initiation and administration, monitoring, and enforcement (incl. dispute settlement) of the cooperation agreements and PPP contracts (Gopinath et al., 2014). Monetary payoffs, M_{ik}, depend on the concrete setup of the PPPs under the aegis of the international cooperation agreement.

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[84] Penalties can be imposed by the governments to the private sector investors and vice versa as contractual penalties of PPP contracts. Penalties imposed by the European to the Northern African governments and vice versa for the non-compliance with the cooperation agreements are not reflected. This is, since due to the lack of effective supra-national institutional structures, international agreements generally cannot be enforced via institutional—i.e., legal—mechanisms, and the only way a long-term stable cooperation can be reached is via self-enforcing agreements (Ulph and Rubio, 2004; Gopinath et al., 2014).

[85] The goal of the assessed sustainable energy partnerships are long-term international cooperation agreements under private sector involvement via PPPs. A key determinant for PPPs to be successful is their governance, ensured by an adequately designed cooperation agreement. As Yu et al. (2015), and Osei-Kyei and Chang (2016) point out in their comparative assessment of implementation constraints in PPPs in developed and developing countries, weak institutional structures, which can imply, inter alia, corruption and a flawed monitoring and legal enforcement of the PPPs, are the main reasons for high transaction costs or even the failure of PPPs. Since institutional structures of developing economies usually show considerable room for improvement, the developed economies can pay development aids, targeted at the improvement of structures enabling an improved PPP governance. For private sector investors, $DA_{EGk} = 0$.

In particular, different designs of PPPs are reflected in the model. Generally, different designs of PPPs can be classified along two dimensions: private sector involvement along the infrastructure projects' life cycle, and the remuneration model. Regarding the former, the typical life cycle of an infrastructure project consists of designing, building, financing, operating, and maintaining (including the decommissioning) of the infrastructure asset. The private sector actors can be involved in the different steps of the life cycle, resulting in PPPs ranging from partial private sector involvement in only the operation and maintenance ('OM-PPPs') to full-fledged private sector involvement in all life cycle steps ('DBFOM-PPPs'). Any forms in between can be observed (see, e.g., Giglio and Friar, 2017). Remuneration models range from concession contracts (a), where the concessionaire, i.e., the private sector investor, generates his returns from the service operation in the form of user payments and bears the full revenue risk, to availability-based PPPs (b), where the private investors collect availability-payments from the public counterpart, which, generally, are less fraught with revenue risks. Also here, any mixed form can be observed (see, e.g., Saussier and de Brux, 2018). The degree of private sector involvement is modeled by means of investment shares: $x_{PR,EGk}^{EG}$ ($x_{PR,EGk}^{AG}$) are the shares of European private investments, $x_{PR,AGk}^{EG}$ ($x_{PR,AGk}^{AG}$) the shares of African private investments for sales to EU (African) markets, x_{EGk}^{EG} (x_{EGk}^{AG}) are the shares of EU governments' investments, x_{AGk}^{EG} (x_{AGk}^{AG}) are the shares of African governments' investments for sales to EU (African) markets. If $x_{PR,EGk}^{EG}$, $x_{PR,EGk}^{AG}$, $x_{PR,AGk}^{EG}$, and $x_{PR,AGk}^{AG}$ are set to zero, an operation and maintenance PPP is modeled; if they unequal zero, a full-fledged private sector involvement is modeled. The magnitude of the below-described variables is dependent on the investment shares, see Table D.50 for details. With regards to the remuneration model, the two pure forms are reflected in the payoff functions themselves via a dummy variable, A. For concession contracts, A is set to zero, for availability-based PPPs, A is set to unity. Monetary payoffs of the governments are described as

$$M_{ik} = (1 - A)\big(T_{nat,ik} - S_{var,ik}\big) + A(\Pi_{ik} - R_{ik}) \pm T_{intl,ik}\ \forall\ i \in \{EG, AG\}, \tag{6}$$

with $T_{nat,ik}$ being taxes private sector actors pay on their revenues in the case of concession contracts, and $S_{var,ik}$ being variable subsidies paid by the governments to the private sector, depending on the amount of hydrogen generated and sold. In the case of availability-based PPPs, Π_{ik} denote the revenues collected by the governments, and R_{ik} the availability payments paid by the governments to the private sector actors. $T_{intl,ik}$ denote tariffs, which can be introduced for the export of energy from the African countries and the import to the EU, as well as tariffs related to foreign direct investment. Monetary payoffs for the private sector are described as

$$M_{ik} = (1 - A)\big(\Pi_{ik} - T_{nat,ik} - T_{intl,ik}\big) + AR_{ik}\ \forall\ i \in \{PR\}, \tag{7}$$

with $\Pi_{ik} = \Pi_{ik}^{EG} + \Pi_{ik}^{AG}$ being revenues of the private sector from hydrogen sales to the EU and African markets, and $T_{nat,ik}$ and $T_{intl,ik}$ being the according tax payments to the governments under concession contracts. Under availability-based PPPs, private sector actors receive availability payments, R_{ik}.

The magnitude of the payoffs generally depends on the scope of the partnership, which is reflected in the model as the annual infrastructure investment, $INV_{H2an,k}^{i}$, under the aegis of the partnership (see Table D.50 and Table D.51 in the Appendix).

5.3.4 Payoffs Under the Different Strategic Choices

Following the structure of the payoff functions defined above, the concrete realization of payoffs depends on the combination of the players' strategic choices (see the game strategy matrix in Figure 29). In the following, we provide an overview of the logic according to which the payoffs along the payoff functions materialize[86]. For a comprehensive overview see Table D.52 in the Appendix.

The welfare payoffs, W_{ik}, materialize to the extent, to which the three groups of players invest into and operate the infrastructure assets. If, for instance, all three groups of players cooperate, all potential welfare payoffs materialize, i.e., $\sum W_1 = \sum_{EG,AG} W_i$. If only the EU governments and the private sector investors cooperate, only these players invest and operate their respective shares of the infrastructure assets, and only the according welfare payoffs materialize, i.e., $\sum W_2 = \sum_{EG,AG}\left(x_{PR,EG}^i + x_{PR,AG}^i + x_{EG}^i\right)W_i$.

Amongst the payoffs related to the cooperation agreement, D_{ik}, transaction costs incur for a group of players as long as it cooperates. For instance, if only the EU and the African governments cooperate, it is $\sum TC_5 = \sum_{EG,AG} TC_i$. Penalties, P_{ik}, are imposed from the cooperating groups of players to the non-cooperating ones. For the groups of players, which impose penalties to their non-cooperating counterparts, enforcement costs, $TC_{enf,ik}$, incur. Development aid, DA_{EGk}, is paid by the EU governments, as long as they decide to cooperate.

Amongst the monetary payoffs, M_{ik}, revenues materialize for all groups of players, which cooperate, depending on the PPP remuneration model. Under concession contracts (a), private sector investors generate the revenues from all installed infrastructure assets, Π_{PRk}^i. If, for instance, only the EU governments and the private sector investors cooperate, $\sum \Pi_{PR2}^i = \sum_{EG,AG}\left(x_{PR,EG}^i + x_{PR,AG}^i + x_{EG}^i\right)\Pi_{PR}^i$. Taxes and tariffs, $T_{nat,ik}$ and $T_{intl,ik}$ incur accordingly. Under availability-based PPPs (b), the governments' revenue collection, Π_{ik}, follows an analogous logic. Availability payments, R_{ik}, and variable subsidies, $S_{var,ik}$, are paid by the cooperating governments, as long as the private sector investors cooperate.

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[86] In the following variable representations, we refrain from displaying the universally applicable dependency on the strategic choice and the time for better readability.

5.4 Model Parametrization

As introduced above, even though the players are described as EU and African governments, the model in its general setup can be used to analyze any sustainable energy partnership between countries with high energy consumption ('global North'), developing economies with locational advantages in RES generation ('global South'), and private sector investors. In the following, the model is parametrized based on a green hydrogen partnership between the EU and Northern African governments, which has been discussed to be established under the aegis of the EU-Africa Energy Partnership[87]. Under the green hydrogen partnership, which is a component of the EU's 2030 Hydrogen Strategy, electrolyzer capacities of up to 40 gigawatt (GW) are supposed to be installed until 2030[88].

The above-introduced players are specified to the EU-27 member states, and the Northern African countries Morocco, Algeria, Libya, Tunisia, and Egypt. The payoffs are expressed in Euros (EUR) per year, and NPVs of future payoffs are considered, whenever the players expect future payoffs. The modeled scope of the partnership is based on the 2030 Hydrogen Strategy's goal to install 40 GW of green hydrogen electrolyzer capacity in the EU's neighboring countries. It is assumed that approximately 50% of this goal can be met partnering with Northern African countries. Based on data sets from IRENA (2017; 2018; 2021), Timmerberg and Kaltschmitt (2019), van Wijk et al. (2019), Timmerberg (2020), IEA (2020), and ICCT

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[87] See https://africa-eu-energy-partnership.org/ (accessed 11/2023).

[88] Green hydrogen partnerships constitute a key pillar of the European Green Deal (EC, 2020). The goal laid down in the EU's 2030 Hydrogen Strategy, which is part of the European Green Deal, is to install at least 40 GW of green hydrogen electrolyzers until 2030 in the EU's neighboring countries with locational advantages. The green hydrogen is then supposed to be used as a medium to store and transport energy to the EU, and to decarbonize industry sectors where the decarbonization is particularly challenging. A high proportion of the green hydrogen generation facilities is discussed to be installed in (mainly Northern) African countries (EC, 2019a; Bghatwat and Olczak, 2020).

(2022), this is translated into annual infrastructure investments for hydrogen production for the EU market, $INV_{H2an,k}^{EG}$, of approximately (approx.) EUR 11 billion (bn.). Additional annual investments, $INV_{H2an,k}^{AG}$, of approx. EUR 9 bn. serve the hydrogen supply to the African markets, based on the assumption that approximately 35% of the total forecasted hydrogen demand of the Northern African countries are covered by the EU-Africa hydrogen partnership (EC, 2020). In the following, the parametrization of the key parameters of the model is described. For a comprehensive overview of the model parametrization, see Table D.53 in the Appendix. For the detailed underlying calculations, see the Supplementary Material (available upon request). For many parameters, ranges of values are given in the data sets. In these cases, sensitivity analyses are performed, testing the results with regards to their sensitivity to setting the parameters to their minimum and maximum values.

With regards to the welfare payoffs, W_{ik}, environmental benefits, ENV_{ik}, which primarily reflect benefits from reduced carbon emissions[89], are quantified with a carbon price within a range of 60 to 100 EUR/tCO2e for both the EU and African governments, assuming that both assign a value to environmental protection reflecting current and projected carbon prices. Social benefits, SOC_{ik}, resulting from an increase in the security of energy supply due to a diversification of the supplier landscape, are quantified by means of an average value of lost load of approx. 12 EUR/kWh (Swinand et al., 2019; WEF, 2022). Also, the value of new job creations is considered, with approximately 300 to 700 new jobs being created per GW of installed green hydrogen electrolyzer capacity, and the monetary value of one additional job being quantified with the currently paid unemployment benefits in the respective countries.

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[89] Net carbon reduction potentials are considered, i.e., the delta between possible gross carbon reductions due to the deployment of green hydrogen instead of the fossil energy mix, which can be replaced with green hydrogen in the specific case of the EU-Africa hydrogen partnership and life-cycle carbon emissions along the green hydrogen value chain.

Macroeconomic benefits, MAC_{ik}, are quantified based on multiplier effects of the public-private infrastructure investment, setting an average multiplier value of 1.05 (5% increase of economic activity) for EU countries, and of 1.25 for Northern African countries[90], as well as an average tax rate of approx. 21%.

With regards to the payoffs related to the partnership, D_{ik}, PPP contractual penalties, P_{ik}, are set to approx. 15% of the total investment volume. Transaction costs for the governments, $TC_{ik} \in \{EG, AG\}$, consist of costs for the administration of the EU-Africa cooperation (4 MEUR/a, see OECD (2018)), the monitoring of the PPPs (5% of the annual investment costs, see Farajian (2010), Leigland (2018), and Yahaya et al. (2020)), dispute settlement, enforcement, and contract renegotiations (3% of the annual investment costs). Transaction costs for the private sector, TC_{PRk}, arise from the administration of the PPPs (4% of the total investment costs, see Hart (2009), Petersen (2019)). Development aid payments, DA_{EGk}, are set to zero in the initial parametrization.

Monetary payoffs, M_{ik}, generally describe the profits from the operation of the infrastructure assets, which, depending on the PPP setup, are realized by the governments and the private sector investors as described above. While the exact composition of the monetary payoffs follows a more complex structure (see Table D.50 and Table D.51 in the Appendix), we describe the parametrization of the main drivers of the profits in the following. On the revenue side, the hydrogen market prices are the main determinant. Since the maturity of green hydrogen markets is low and hydrogen prices data is scarce, we approximate the hydrogen price by considering the counterfactual, this is, the market price of the alternative energy source, which

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[90] There is a large body of literature assessing multiplier effects of infrastructure investment, with controversial findings regarding the magnitude of the effects. Ranges reach from negative values in the case of purely public infrastructure investments due to the crowding out of private infrastructure investment to significantly positive values (World Bank, 2022).

can be replaced by hydrogen-based solutions. The rational consumer will be willing to pay a price for hydrogen, which equals or falls below the price for its alternative. Hence, in the equilibrium, it is $p_{H2}^{EG} = p_{alt}^{EG}$, and $p_{H2}^{AG} = p_{alt}^{AG}$, with p_{alt}^{EG} (p_{alt}^{AG}) being the price of the alternative energy source on the EU (Northern African) markets, and p_{H2}^{EG} (p_{H2}^{AG}) being the equilibrium hydrogen price on the EU (Northern African) markets[91]. Based on the assumption that in the EU, 75% of the hydrogen is used to replace natural gas in industrial processes, and 25% is used to replace diesel in heavy-duty transport, $p_{H2}^{EG} = p_{alt}^{EG}$ is calculated to be 52 EUR/MWh. Assuming that in Northern African countries, hydrogen replaces natural gas in industrial processes, diesel in heavy-duty transportation, as well as electricity in heating and energy storage at approx. equal shares, $p_{H2}^{AG} = p_{alt}^{AG}$ is calculated to be 30 EUR/MWh. On the cost side,

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[91] Generally, the largest application area for hydrogen are industrial processes, e.g., in the steel and chemical industries, which currently use fossil fuels such as natural gas to run their processes, and are, hence, challenging to de-carbonize by means of green electricity. The second largest application area is the transportation sector, in which mostly diesel-powered heavy-duty transports are intended to be replaced by fuel cell vehicles. Other applications are district heating and energy storage in the power sector (Agora, 2021; EWE, 2022). In the case of the EU, within the scope of the EU-Africa hydrogen partnership, the most relevant application areas of hydrogen are industrial processes and heavy-duty transport, since in the application of hydrogen in district heating, waste heat from local RES generation is used—which, in the case of hydrogen production in Northern Africa, is not available in EU locations. Also, the use case in energy storage arises if mismatches in locally generated RES supply and demand must be balanced. More than 99% of the total consumption is expected to result from the two former application areas, of which 75% in industry processes, and 25% in heavy-duty transport (Agora, 2021; BCG, 2021a, b). In industrial processes, mostly natural gas, and some coal and lignite are replaced. In heavy-duty transport, mostly diesel as a fuel is replaced. With the 2021 EU average natural gas price for industry customers and the 2021 EU average diesel price as proxies (destatis, 2022; EC, 2022), it is $p_{alt}^{EG} = p_{H2}^{EG}$ = 52.3 EUR/MWh. Price increases in natural gas and diesel prices due to the war in Ukraine are accounted for within the *ceteris paribus* analyses. In the Northern African markets, potential hydrogen applications are also mostly in industry processes and some in heavy-duty transport. For instance, in Morocco, there are fields of potential application in the fertilizer industry (Brookings, 2022), in hydrogen heavy-duty road transport and in hydrogen rail systems (Alstom, 2021), as well as in heating and energy storage. Based on the shares of the applications reported in Bhagwat and Olczak (2020), we obtain for Northern African markets $p_{alt}^{AG} = 0.24 p_{NG,2021}^{AG} + 0.27 p_{Diesel,2021}^{AG} + (0.21 + 0.28) p_{el,2021}^{AG}$. Based on multiple data sources $p_{alt}^{AG} = p_{H2}^{AG}$ = 29.7 EUR/MWh.

the investment costs, and the operational expenses, as well as tax payments are the main determinants for the payoffs. Investment costs result from the above-described annual investments, with initial investment shares of x_{EG}^{i} = 50%, $x_{PR,EG}^{i}$ = 45%, $=$ $x_{PR,AG}^{i}$ = 5%, and x_{AG}^{i} = 0%, assuming that in the initial state, the majority of the investment costs is covered by the EU governments and EU-based private investors (EIB, 2022). Other constellations, for instance, where investment costs are more equally distributed amongst the PPP parties are tested in scenario analyses presented in Section 5.5. Operational expenses are calculated as a share of the investment, based on levelized costs of hydrogen between approx. 45 and 250 EUR/MWh (Timmerberg and Kaltschmitt, 2019; IEA, 2020). Taxes and tariffs are parametrized based on rates customary in the respective energy markets. Market and revenue risks are modeled by means of random components in the form of Brownian motions in the levels and realization of prices and costs.

5.5 Simulation: Stability Analysis

In the following, the model is deployed to analyze the influencing factors on the long-term strategic choices of the potential participants of sustainable energy partnerships. The stability analysis follows a two-step approach: firstly, based on the initial model parametrization described in Section 5.4, several *ceteris paribus* (*c.p.*) analyses are performed to test the isolated impact of different influencing factors on the long-term stability of the partnership. Influencing factors include external developments, such as hydrogen market prices and levelized costs of hydrogen[92], as well as developments related to different setups of the international cooperation and PPP designs including policy instruments. Secondly, based on the *c.p.* analyses' results,

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[92] These developments are considered as external, since the energy partnerships are assumed to be 'small', meaning that they do not influence market conditions significantly.

comprehensive framework conditions are identified, under which all three groups of players jointly cooperate in the long run and, thus, a long-term sustainable energy partnership can be achieved.

5.5.1 Ceteris Paribus Analyses

Running the model under the initial parametrization (see Section 5.4) generates the reference case, which the results of the *c.p.* analyses are based on. Model results reveal that under the initial parametrization, only the EU governments choose cooperation as their long-term strategy. For the Northern African governments as well as for the private sector investors, the likelihood to cooperate is zero in the long run. These results apply both under concession contracts (a) and availability-based PPPs (b), see Figure 30. A main driver for the EU governments is that they assign a high value to carbon reduction. Furthermore, since their initial investments are high, they face sunk costs in the case of non-cooperation. The African governments do not cooperate mainly since it can realize windfall welfare benefits from the EU governments' cooperation without facing any costs. The private investors do not cooperate since they are disincentivized by the non-profitability of the business case, despite the EU governments participating in the upfront infrastructure financing.

With regards to the initial parametrization, two types of sensitivity analyses are performed: firstly, different initial probabilities of the players to cooperate are tested. In the initial parametrization, the initial probabilities of all players to cooperate are set to 0.5, meaning that the players are indifferent whether they want to cooperate. Initial probabilities of 0.001 and 0.999 are tested, with the result that different initial probabilities do not change the long-term stability results (see Figure 30 and Figure D.35 in the Appendix).

Secondly, minimum, and maximum values of the initial parameters are tested (see Table D.53 in the Appendix), with the result that changing the initial parameters in these ranges generally does not change the analyses results (in the case of their occurrence, deviations are discussed in the *c.p.* analyses).

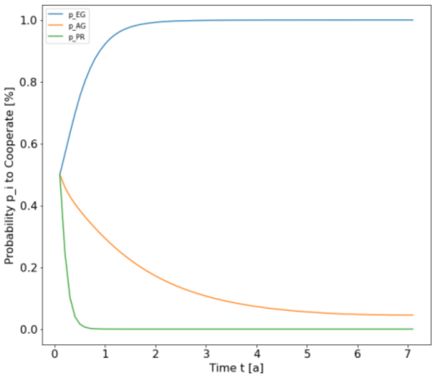
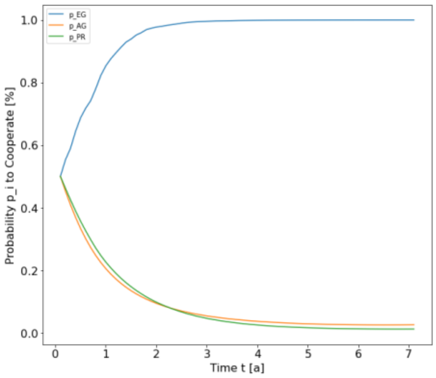
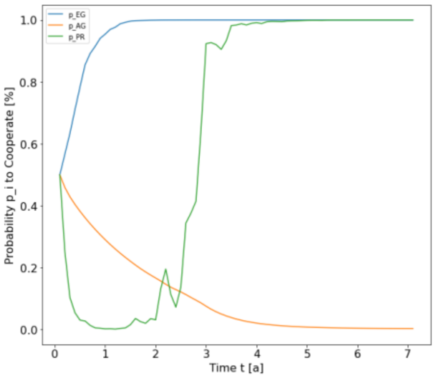
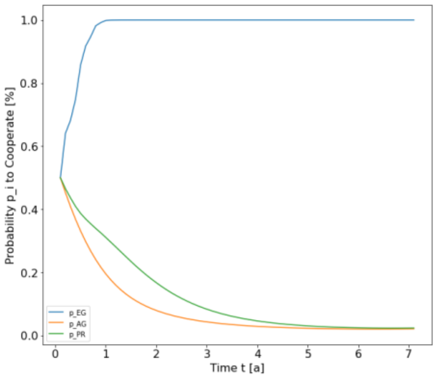
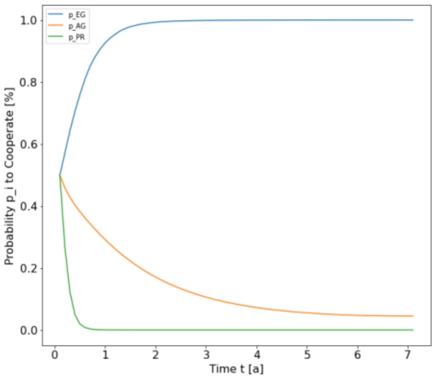
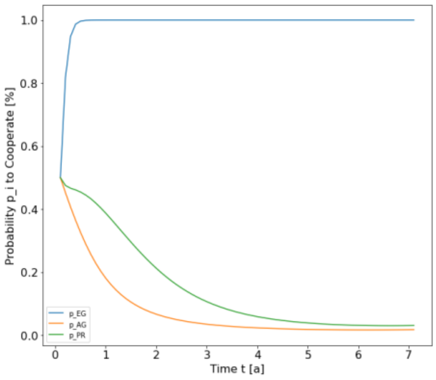
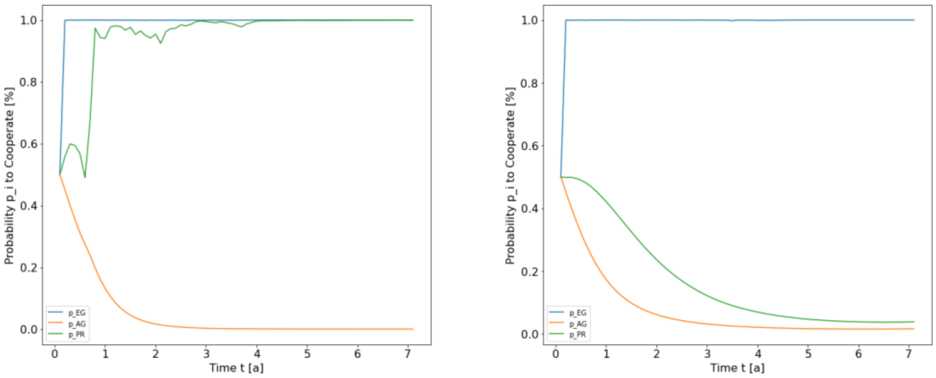
Initial Probability	**Long-term Cooperation Outcomes Under (a) Concession Contracts**	**Long-term Cooperation Outcomes Under (b) Availability-based PPPs**
$p_{EG1,init} = 0.5$ $p_{AG1,init} = 0.5$ $p_{PR1,init} = 0.5$		

Figure 30: Model Results—Initial Parametrization

To the end of testing the impact of external influencing factors, we consider the impact of changes in hydrogen prices, in the levelized costs of hydrogen, in carbon prices set by the EU and African governments, as well as capital costs (see Figure 31).

***C.p.* Changed Parameters**	**Long-term Cooperation Outcomes Under (a) Concession Contracts**	**Long-term Cooperation Outcomes Under (b) Availability-based PPPs**
Hydrogen price increase, successive (threshold) (a), (b) $p_{H2}^{EG}(t = 0) = 52$ EUR/kWh $p_{H2}^{EG}(t = T) = 2{,}600$ EUR/kWh $p_{H2}^{AG}(t = 0) = 30$ EUR/kWh $p_{H2}^{AG}(t = T) = 1{,}500$ EUR/kWh		
Levelized costs of hydrogen decrease, successive (a), (b) $\alpha_{cOM}(t = 0) = 0.025$ $\alpha_{cOM}(t = T) = 0.00$		

Carbon price increase (threshold)
(a), (b)
$p_{CO2}^{EG} = 7{,}000$
EUR/tCO2e
$p_{CO2}^{AG} = 7{,}000$



Capital cost decrease, successive
(a), (b)
$c_{WACC}^{EG}(t = 0) =$
$c_{WACC}^{AG}(t = 0) = 4.5$
%
$c_{WACC}^{EG}(t = T) =$
$c_{WACC}^{AG}(t = T) = 0.0$
%

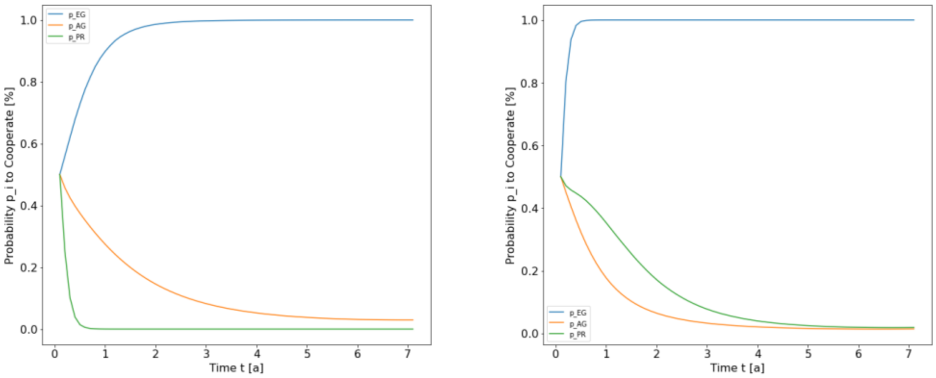


Figure 31: Model Results—Changes in External Influencing Factors

With regards to hydrogen prices, only very high increases (to approx. 2,000 EUR/kWh as compared to the current 52 EUR/kWh) under concession contracts incentivize the private sector investors to cooperate. Under availability-based PPPs, even very high hydrogen market prices do not incentivize the private investors to cooperate (see also Figure D.36 in the Appendix). This reflects the considerable lack of attractiveness of the business case due to high levelized costs of hydrogen, high transaction costs and unfavorable risk characteristics, i.e., due to the immaturity of the technology and the sales on the African markets. The African governments remain disincentivized to cooperate. Decreases in the variable component of the levelized costs of hydrogen, for instance due to technological developments, do not incentivize private investors and African governments to cooperate. This, again, points to the unattractiveness of the business case for private investors, revealing that even if operational expenses strive towards zero, the initial investment into hydrogen infrastructure assets does not amortize. With regards to carbon prices, only very high increases under concession contracts lead to a cooperation of private investors (see also Figure D.37 in the Appendix). Decreases in capital costs—here decreases to zero—do not lead to a cooperation. Therefore, we can conclude that developments in external factors are not sufficient to incentivize a long-term stable partnership, as the European governments are cooperating, but not the African governments and the private investors.

To the end of testing the impact of more complete cooperation agreements, targeted development aid and hydrogen taxes and international tariffs are analyzed (see Figure 32).

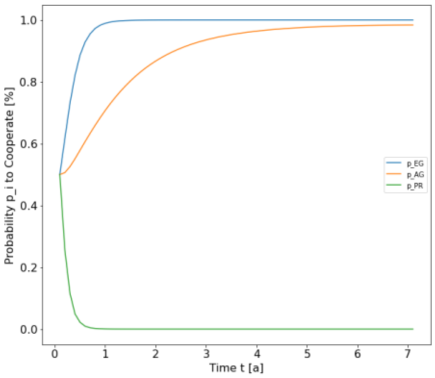
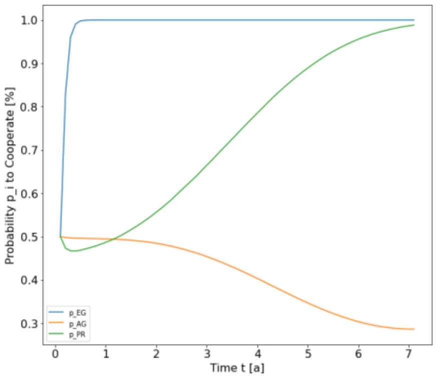
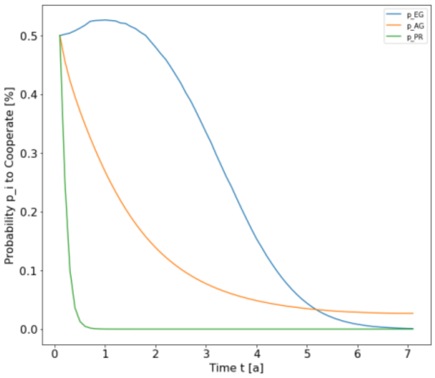
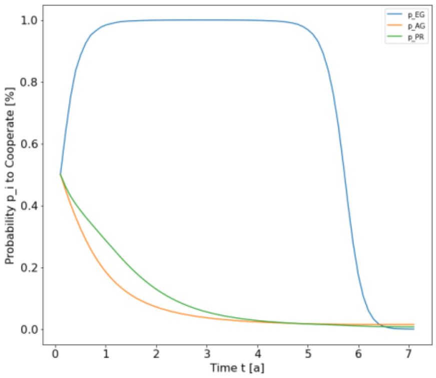
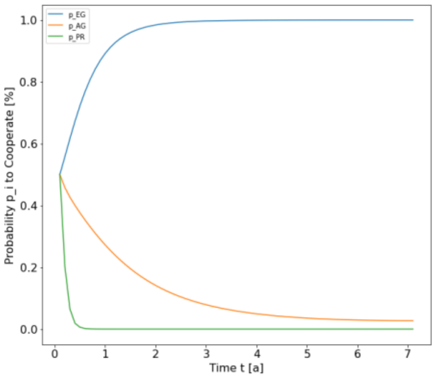
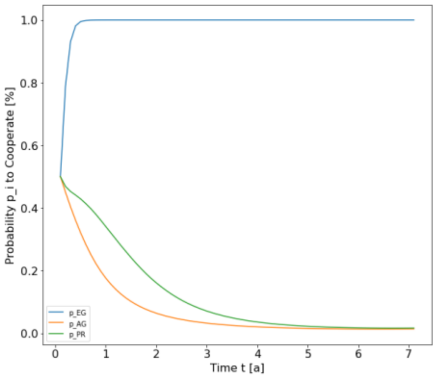
C.p. **Changed Parameters**	**Long-term Cooperation Outcomes Under (a) Concession Contracts**	**Long-term Cooperation Outcomes Under (b) Availability-based PPPs**
More complete cooperation agreements (a), (b) $\eta_{TC,EG} = 100\%$ $\eta_{TC,AG} = 100\%$		
Development aid (threshold) (a) $DA_{EG} = 10\%\ INV_{H2}$ $\beta_{\pi,DA} = 0.5$ $\beta_{GP,DA} = 0.5$ (b) $DA_{EG} = 35\%\ INV_{H2}$ $\beta_{\pi,DA} = 0.5$ $\beta_{GP,DA} = 0.5$		
Taxes and tariffs (zero) $\tau_{intl,var}^{EG} = \tau_{intl,fix}^{EG}$ $= \tau_{intl,var}^{AG} = \tau_{intl,fix}^{AG}$ $= \tau_{nat}^{EG} = \tau_{nat}^{AG} = 0$		

Figure 32: Model Results—Changes in International Cooperation

The impact of more complete cooperation agreements can be conceptualized based on transaction cost theory in the context of international cooperation agreements. The theory describes a tradeoff between increasing transaction costs of the cooperation agreement with increasing contract completeness[93], and coincidingly decreasing transaction costs from contract monitoring and enforcement. In our context, the more complete the cooperation agreement, the lower the monitoring and enforcement costs for PPPs[94]. Under concession contracts, more complete cooperation agreements incentivize the African governments to cooperate. Under availability-based PPPs, the private investors are incentivized to cooperate. Development aid from the EU to the African governments targets the improvement of market conditions on the African markets on the one hand, and of regulatory and legal structures allowing an efficient monitoring and enforcement of PPPs on the other. Under both concession contracts and availability-based PPPs, development aid payments are not an adequate policy instrument to achieve cooperation since development aids in a magnitude that would incentivize the private investors to cooperate would coincidingly disincentivize the EU governments to cooperate. Taxes on hydrogen sales as well as international trade tariffs and tariffs on foreign direct investment have a dampening effect on the likelihood of the players to cooperate. However, setting all taxes and tariffs to zero does not incentivize the players to cooperate.

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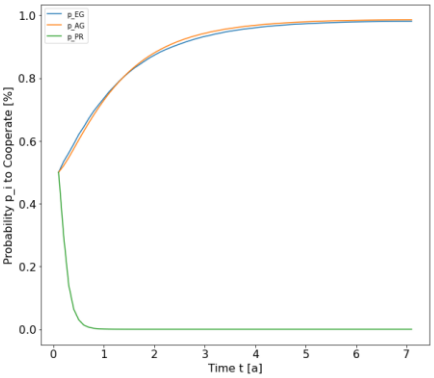
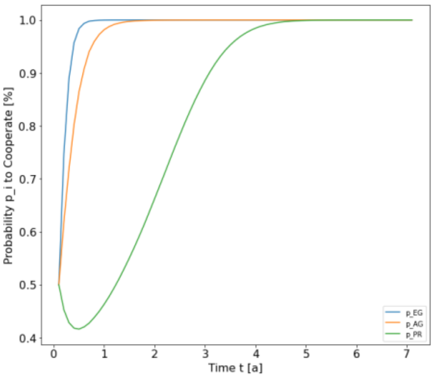
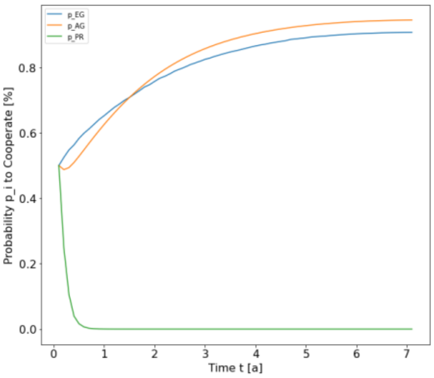
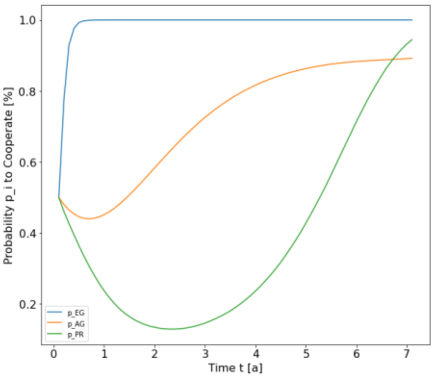
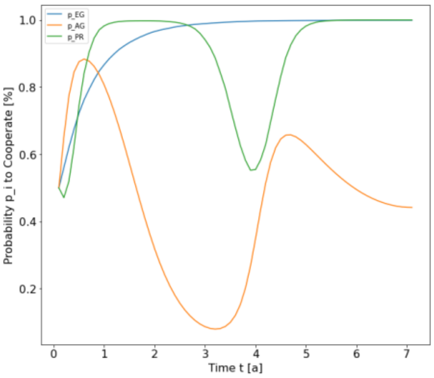
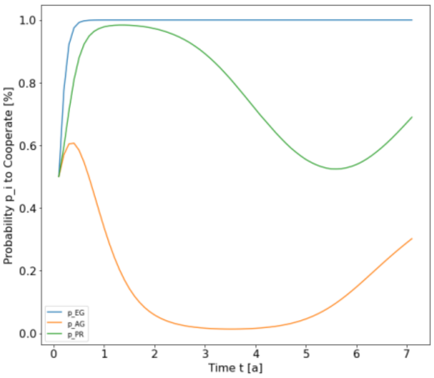
[93] When an international cooperation agreement is described as ‘more complete’ in transaction cost theory, this typically refers to a high degree of specificity of the agreement, meaning that the agreement contains specific provisions, goals, timelines, and mechanisms for implementation. This includes detailed descriptions of commitments, responsibilities, and the processes through which objectives will be achieved. Furthermore, it refers to a high degree of comprehensiveness, meaning that a broad framework for collaboration is provided, which also includes rules for indirect influencing factors, such as international trade tariffs. Also, it includes clear mechanisms for monitoring compliance, resolving disputes, and enforcing the terms of the agreement. This might include the establishment of international monitoring bodies or the specification of arbitration procedures.

[94] This relation is not quite straight forward to quantify. Therefore, we have incorporated the interrelation into the model in a way that in all other *c.p.* analyses, it does not affect the model outcomes. Within the *c.p.* analysis, we assess tendencies in the impact that are based on estimates of the degree of the interrelation.

To the end of testing the impact of different PPP setups, different distributions within the infrastructure investment, different distributions in the governments' responsibilities with regards to the PPPs, higher penalties, variable subsidies payments as well as higher availability payments are tested (see Figure 33).

C.p. **Changed Parameters**	**Long-term Cooperation Outcomes Under (a) Concession Contracts**	**Long-term Cooperation Outcomes Under (b) Availability-based PPPs**
Distribution of investments *African governments' moderate co-investment* (a), (b) $x_{PR,EG}^{EG} = 0.35$ $x_{PR,AG}^{EG} = 0.05$ $x_{EG}^{EG} = 0.425$ $x_{AG}^{EG} = 0.175$ $x_{PR,EG}^{AG} = 0.35$ $x_{PR,AG}^{AG} = 0.05$ $x_{EG}^{AG} = 0.425$ $x_{AG}^{AG} = 0.175$		
Enforcement mostly by African governments, (a) $\beta_{enf} = 0.15$ (b) $\beta_{enf} = 0.10$ (a), (b) $\beta_{\pi} = 0.5$		
Higher penalties (a), (b) $g = 0.5$ (b) $g = 0.35$		

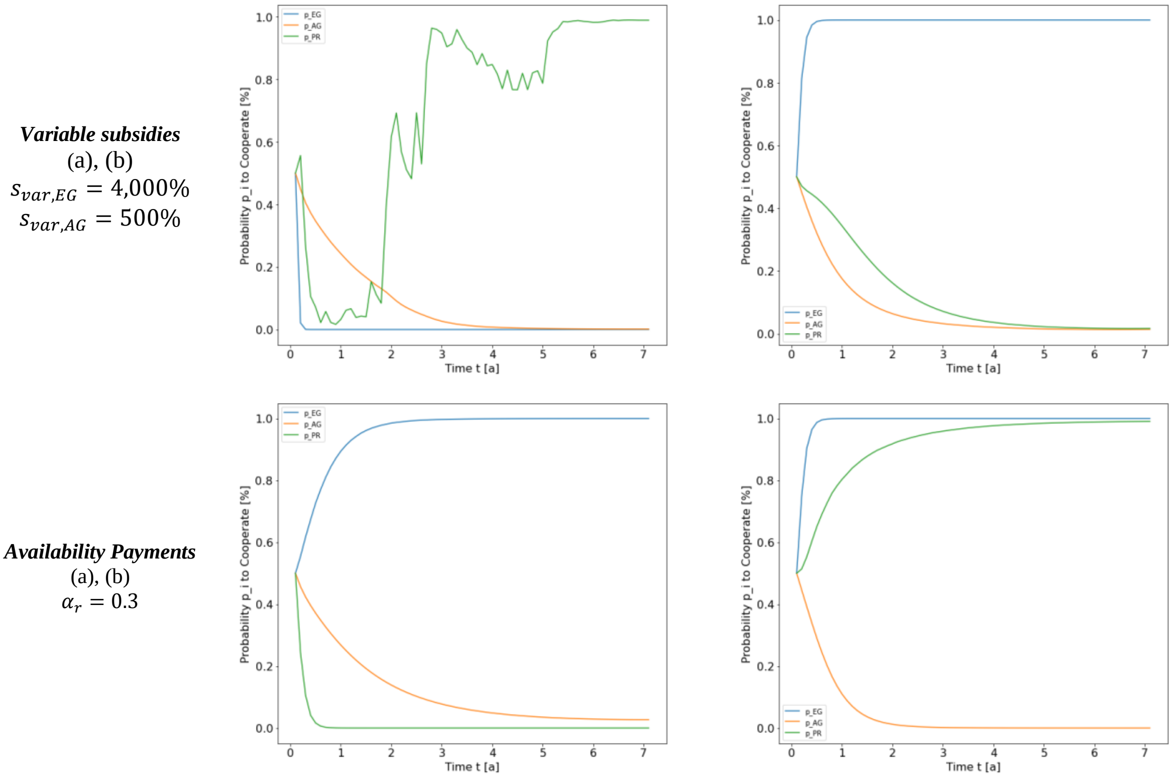
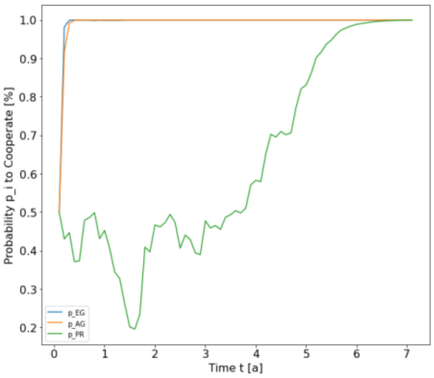


Figure 33: Model Results—Changes in the PPP Setup

With regards to the different distributions of the infrastructure investment costs, we assess different forms of involvement of the public and private sectors along the infrastructure projects' life cycle in the PPPs. While many different forms of involvement exist, in our model we reflect the two extreme forms introduced above, i.e., DBFOM-PPPs, where the private sector is (co-)involved in designing, building, financing, operating, and maintaining the infrastructure asset, and OM-PPPs, where the private sector is only (co-)responsible for the operation and maintenance. In the initial parametrization of the model, we reflect a DBFOM-PPP, where mostly European and some African private investors, as well as EU governments (e.g., via dedicated investment funds such as from the European Investment Bank) are involved. Based on this, we test the case in which not only EU governments, but also African governments are involved in the investments, finding that public co-investment incentivizes the African governments to cooperate (see Figure D.38 in the Appendix). This is mainly since the African governments can realize windfall benefits from the EU governments' investments if they do not co-invest. If the African governments co-invest, they also have a financial incentive to cooperate and thus amortize the investment. The same logic applies vice versa for the other players. With an increasing co-investment of the African governments the EU governments become less incentivized to cooperate (under concession contracts). In the case of availability-based PPPs the co-investment of the African governments incentivizes all players to cooperate, since both groups of governments provide availability payments to the private investors, which leads to a positive business case and allows the private sector investors to amortize their investments. In the case of OM-PPPs, where only the governments are involved in the investment into the infrastructure assets, private investors are not incentivized to cooperate. Furthermore, we assess different distributions of responsibilities amongst the governments within the monitoring and enforcement of the PPPs, as well as within the revenue collection and availability payments to the private sector in the case availability-based PPPs. Giving higher responsibilities to the African governments generally incentivizes the African governments to cooperate, following an analogous reasoning of windfall benefits as above. With regards to the private investors, an allocation of responsibilities at the governments with the higher implementation efficiency leads to increased incentives to cooperate. This is in particular under availability-based PPPs due to the private business cases' dependence on availability payments (see Figure D.39 in the Appendix). Higher penalties—both for the governments and private investors in the case of non-cooperation—do not lead to a stable long-term cooperation. This is especially since the introduction of penalties requires an agreement of all involved parties during the initiation and negotiation phases of the PPP contract. It needs to be assessed based on more detailed dynamics, whether the parties would agree to high penalties, or if they would refrain from entering into the contract. Hence, higher penalties cannot be considered to incentivize compliance without further assessment. Finally, we assess the impact of variable subsidies (for concession contracts) and increases in availability payments (for availability-based PPPs) by the governments to the private investors. Both variable subsidies (under concessions) and increases in availability payments (under availability-based PPPs) generally have an incentivizing effect on the private investors. However, variable subsidies are necessary to an extent that the governments become dis-incentivized to cooperate (see Figure D.40 in the Appendix).

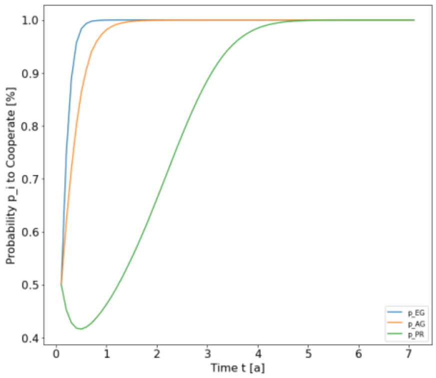
5.5.2 Combined Measures for Scenarios of Cooperation

In the *ceteris paribus* analyses, we have identified influencing factors on the likelihood of the three groups of players to cooperate. In the following, the different influencing factors incentivizing cooperation are combined to the end of generating scenarios, under which all three players are incentivized to cooperate in the long run. These outcomes represent constellations, in which a sustainable energy partnership between developed and developing countries can persist. There are four scenarios of cooperation, of which two are stable (i.e., all players cooperate with certainty), see Figure 34. Amongst the two stable scenarios, one reflects a PPP based on a concession contract, the other an availability-based PPP. The two unstable scenarios of cooperation (i.e., the likelihood of at least one group of players to cooperate remains below unity) reflect PPPs based on concession contracts.

Scenario Name	**Description**	**Graph of Joint Cooperation**
Stable joint cooperation: *co-investment of African governments and high carbon prices*	• Concession contracts • Co-investment of African governments (moderate is sufficient, here 17.5% of the annual investments by African governments, 42.5% by the EU governments, the remainder by private investors) • High carbon prices in both EU and in African countries (5,000 EUR/tCO2e) • High energy prices lower the magnitude of carbon prices, which is necessary to incentivize the private sectors to cooperate	

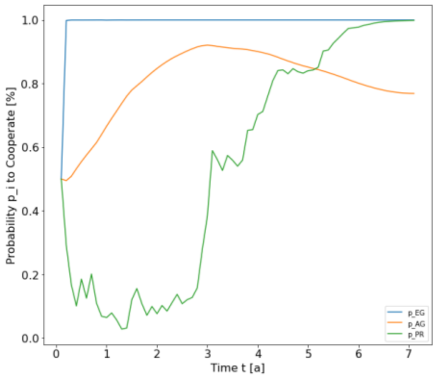
Stable joint cooperation: *co-investment of African governments under availability-based PPP*

- Availability-based PPPs
- Co-investment of African governments (moderate is sufficient, here 17.5% of the annual investments by African governments, 42.5% by the EU governments, the remainder by private investors)



Unstable joint cooperation: *PPP responsibility of African governments and high carbon prices*

- Concession contracts
- No co-investment of African governments
- High carbon prices in EU (7,500 EUR/tCO2e) and in African countries (2,500 EUR/tCO2e)
- High responsibility for PPPs allocated at African governments
- Likelihood of African governments' and private sector cooperation depends on randomized component of energy prices and hydrogen cost development



Unstable joint cooperation: *Complete cooperation agreements and high carbon prices*

- Concession contracts
- No co-investment of African governments
- High carbon prices in EU (7,000 EUR/tCO2e) and in African countries (3,000 EUR/tCO2e)
- Highly complete cooperation agreements between EU and African governments
- Likelihood of African governments' and private sector cooperation depends on randomized component of energy prices and hydrogen cost development

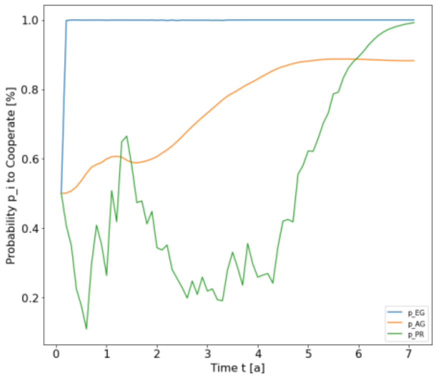


Figure 34: Overview of Scenarios of Joint Cooperation

The stable scenario under PPPs based on concession contracts involves co-investment of the African and EU governments under a DBFOM scheme, as well as very high carbon prices. Regarding the co-investments of the African governments, a moderate level of approx. 17.5% of the total annual investments is sufficient, while approx. 42.5% are borne by the EU governments, and the remainder by private investors. However, very—read: unrealistically—high carbon prices, immediately introduced by both the EU and the African governments are necessary to incentivize the private investors to cooperate. Very high energy prices can mitigate the necessary carbon prices to some extent. Also, the lead time until the private sector actors cooperate with certainty strongly depends on the randomized component of the energy prices. Under availability-based PPPs, a stand-alone co-investment of the African governments is sufficient to incentivize all three groups of players to cooperate in the long run. Again, a moderate level of co-investment under a DBFOM scheme is sufficient, where the African governments cover approx. 17.5% of the total annual investments, while approx. 42.5% are borne by the EU governments, and the remainder is covered by private investors. The two scenarios of unstable cooperation arise in the case of concession contracts under DBFOM schemes, in which, however, the African governments do not co-invest. The first scenario of unstable joint cooperation involves very high carbon prices, as well as a high responsibility for PPPs allocated at the African governments. The likelihood of African governments' and private sector cooperation, however, strongly depends on the randomized component of energy prices and hydrogen cost development. The same applies for the second scenario of unstable joint cooperation, where the higher responsibility of the African governments in the context of the PPP monitoring and enforcement is replaced by a higher degree of completeness (i.e., specificity) in the cooperation agreements.

5.6 Discussion, Policy Recommendations and Future Research

We have presented an analysis of the long-term stability of sustainable energy partnerships between developed and developing countries and private sector investors by means of an evolutionary game theoretical model, parametrized according to an exemplary hydrogen partnership between EU and Northern African governments. As explained above, we have selected the exemplary parametrization reflecting this specific partnership since it would be well suited to contribute to the goals of the EU hydrogen strategy. Also, analyzing a specific partnership makes the results more tangible and allows us to consider the technical realities of such partnerships, which would not be reflected in a more general approach. When generalizing the results and deriving policy recommendations for the setup of sustainable energy partnerships in general, hence, the concrete threshold values regarding the incentivization of a cooperation of the participants can be different. However, the direction of the impact of the external developments and framework conditions can be generalized to a large extent, which we have also tested by means of sensitivity analyses regarding the model parametrization.

With these caveats in mind, we can derive six overarching conclusions and policy recommendations for the setup of long-term stable sustainable energy partnerships. Firstly, stand-alone improvements in the business case underlying the sustainable energy partnerships do not lead to long-term stable partnerships in any case. This includes external developments such as increases in energy prices, decreases in the levelized costs of energy, or decreases in capital costs. Hence, it is crucial for the long-term success of such partnerships that both the cooperation agreement and the PPPs are carefully designed. Secondly, carbon price increases only incentivize the cooperation of private sector investors if very high prices are introduced immediately in both the EU and the African countries. Thirdly, any factors, which increase costs within the partnership should be avoided. This is, especially, import and export tariffs on energy and tariffs on foreign direct investments between the participating countries since those factors have a dampening effect on the likelihood of cooperation of the involved parties. However, avoiding all of these costs does not suffice to incentivize the players to cooperate. Fourthly, general development aids aiming at improving the institutional conditions within the African countries and, thus, making energy sales and the administration of PPPs more efficient, are not an adequate instrument to incentivize cooperation, since non-targeted payments would be necessary to an extent, which disincentivizes the EU governments to cooperate. Fifthly, a co-investment of all participating governments and the private sector investors is crucial for their long-term incentivization to cooperate, since otherwise, windfall environmental, social, and economic benefits can be realized, which disincentivizes long-term cooperation. Lastly, availability-based PPPs are generally the preferrable setup. On the one hand, private sector actors are incentivized to cooperate as the risk associated with the energy projects is mainly borne by the governments (i.e., availability payments are not subject to a randomized component). On the other hand, as governments bear the risk and collect the initial revenues from the energy projects, their interest to cooperate is higher in the long run, as they have an interest in recovering their initial investments.

Limitations of our research result from the methodological choice and from the model setup. We have selected a game theoretical setup in which three groups of players interact strategically and whose decision-making is based on the decision-making of the other players. Following approaches from literature on international investment and trade relations in the oil and gas industry, e.g., Araujo and Leoneti (2018), research on international environmental agreements based on Barro (1994) and research on transnational PPPs, e.g., Yu et al. (2018), the presented constellation is pre-determined to be investigated by means of game theory. However, selecting this methodology omits aspects, such as the private sector investors facing multiple alternative investment options which can contribute to maximize the payoffs of their entire portfolio. Also, selecting an evolutionary game theoretical approach allows to consider the long-term stability of the investigated partnership in a setup of an infinite number of subsequent games, under the assumption of bounded rationality, in which the decision-making of the players depends on their experience from the previous rounds of the game. While both aspects adequately match the goal of our research, the assumptions underlying the game also might determine the games' outcomes. Further limitations result from the concrete setup of the tripartite evolutionary game. Firstly, the presented model setup consists of three groups of players. This implies two assumptions: The players within the groups, such as the private investors, are assumed to exhibit sufficiently comparable characteristics regarding their payoffs and strategic rationales that they can be summarized under one group of players with one common payoff function, whereas other stakeholders are not accounted for in the model. This is, for instance, the case for the general public, which also plays a role in the success of energy partnerships. Secondly, many interdependencies are reflected in the model setup, albeit not all of them, and not in the greatest possible depth. For instance, the decreases in the levelized costs of hydrogen are modeled as exogenous developments. Hence, costs for research and development and the resulting innovations are assumed to be borne by players outside the modeled game and the role of endogenous innovation is not accounted for. This leads to limitations within the assessibility of innovation as one important factor within the success of a hydrogen economy in general, including the role of intellectual property. Finally, the parametrization of the model is based on different data sets from literature. While we have accounted for ranges in the parameter values by means of sensitivity analyses, for some parameters, as indicated within the respective paragraphs, an in-depth determination of the values would be beneficial.

Avenues for future research result from the limitations stated. Firstly, it would be insightful to take alternative model approaches, which allows the incorporation of distinct interrelations, and compare the results to the present ones. This is especially the case for methodological approaches, which allow a more detailed reflection of decision-making dynamics within the groups of players, such as the private sector actors optimizing their portfolios and considering multiple investment alternatives outside the sustainable energy partnerships. Also, deploying another game theoretical model based, e.g., on the assumption of a fully rational behavior of the players can be interesting. Secondly, a model setup incorporating a more granular and additional selection of players can be insightful, e.g., an incorporation of the public as a fourth player into the game. Also, assessing differences within the groups of players can be insightful, e.g., in our exemplary setup, a more granular modeling of the African countries, since in the present setup, for instance, tensions amongst the African governments are not accounted for.

Also, the private sector actors include many different types of stakeholders, ranging from construction companies to financial investors. Breaking down this group of players and assessing the sub-groups allows for a large variety of additional insights, e.g., regarding efficient financing conditions. Finally, an in-depth assessment of specific interdependencies reflected in the model on a high level can be insightful, especially regarding the role of endogenous innovation and intellectual property.

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Appendix D

New Green Alliances: Requirements to Implement Long-Run International Sustainable Energy Partnerships

D.1 Detailed Payoff Functions

Table D.50: Detailed Composition Variables of the Payoff Functions

Variable	Unit	Description	Composition
$INV^{i}_{H2an,k}(t)$	EUR/a	Annual infrastructure investments for hydrogen sales on the EU (African) markets	$(x^{i}_{PR,EGk} + x^{i}_{PR,AGk} + x^{i}_{EGk} + x^{i}_{EGk})INV^{i}_{H2an,k}(t)$
$INV^{i}_{H2cum,k}(t)$	EUR	Infrastructure stock	$\int_0^t INV^{i}_{H2an,k}(t)(1 + d_{H2})(1 + c_{WACCi})$
$INV^{i}_{H2,k}(t)$	EUR	Net present value (NPV) of outstanding investments	$\int_t^T \frac{INV^{i}_{H2an,k}(t)(1 + d_{H2})(1 + c_{WACCi})}{e^{r_i t}}$
$INV^{i}_{H2life,k}(t)$	EUR	Investment costs distributed to total lifetime T_{life} of the infrastructure assets	$\int_t^{Tlife} \frac{INV^{i}_{H2an,k}(t)(1 + d_{H2})(1 + c_{WACCi})T}{T_{life}}$
$INV^{i}_{H2all,k}(t)$	EUR	Sum of infrastructure stock and NPV of outstanding investments	$INV^{i}_{H2cum,k}(t) + INV^{i}_{H2,k}(t)$
$Q^{i}_{H2cum,k}(t)$	Wh (J/s)	Amount of hydrogen produced with infrastructure stock, $i \in \{EG, AG\}$	$s\alpha_Q INV^{i}_{H2cum,k}(t)$
$Q^{i}_{H2,k}(t)$	Wh (J/s)	NPV of outstanding hydrogen production, $i \in \{EG, AG\}$	$s\alpha_Q INV^{i}_{H2,k}(t)$
$Q^{i}_{H2all,k}(t)$	Wh (J/s)	Total amount of hydrogen production, $i \in \{EG, AG\}$	$Q^{i}_{H2cum,k}(t) + Q^{i}_{H2,k}(t)$
$ENV_{EGk}(t)$	EUR	Environmental benefits, EU governments	$\alpha_{ENV,EG} Q^{EG}_{H2all,k}(t)$
$ENV_{AGk}(t)$	EUR	Environmental benefits, African governments	$\alpha_{ENV,AG}\left(Q^{AG}_{H2all,k}(t) + (1 - s)Q^{EG}_{H2all,k}(t)\right)$
$SOC_{EGk}(t)$	EUR	Social benefits, EU governments	$\alpha_{SOC,EG} Q^{EG}_{H2all,k}(t)$
$SOC_{AGk}(t)$	EUR	Social benefits, African governments	$\alpha_{SOC,i}\left(Q^{AG}_{H2all,k}(t) + (1 - s)Q^{EG}_{H2all,k}(t)\right)$
$MAC_{EGk}(t)$	EUR	Macroeconomic benefits, EU governments	$\alpha_{MAC,EG}(x^{EG}_{PR,EGk} + x^{EG}_{EGk})INV^{EG}_{H2,k}(t) + (x^{AG}_{PR,EGk} + x^{AG}_{EGk})INV^{AG}_{H2,k}(t)$
$MAC_{AGk}(t)$	EUR	Macroeconomic benefits, African governments	$\alpha_{MACfix,AG}[(x^{EG}_{PR,EGk} + x^{EG}_{PR,AGk} + x^{EG}_{EGk} + x^{EG}_{AGk})INV^{EG}_{H2,k}(t) + (x^{AG}_{PR,EGk} + x^{AG}_{PR,AGk} + x^{AG}_{EGk} + x^{AG}_{AGk})INV^{AG}_{H2,k}(t)] + \alpha_{MACvar,AG}[(1 - s)(x^{EG}_{PR,EGk} + x^{EG}_{PR,AGk} + x^{EG}_{EGk} + x^{EG}_{AGk})INV^{EG}_{H2all,k}(t) + (x^{AG}_{PR,EGk} + x^{AG}_{PR,AGk} + x^{AG}_{EGk} + x^{AG}_{AGk})INV^{AG}_{H2all,k}(t)]$
$\Pi_{all,ik}(t)$	EUR	Revenues from system operation, collected by EU or African governments	$(x^{EG}_{PR,ik} + x^{EG}_{ik})\Big[s[Q^{EG}_{H2all,k}(t)w_{\Pi,EG}(p^{EG}_{H2}(t) + p^{EG}_{CO2}(t)) - w_{cvar}C_{var,EGk}(t)] + (1 - s)[Q^{EG}_{H2all,k}(t) * (w_{\Pi,AG}\alpha_{\Pi,DA}\beta_{\Pi,DA}DA_{EGk})(p^{AG}_{H2}(t) + p^{AG}_{CO2}(t)) - w_{cvar}C_{var,EGk}(t)(1 - w_{cOMtr})]\Big] + (x^{AG}_{PR,ik} + x^{AG}_{ik})[Q^{AG}_{H2all,k}(t)(w_{\Pi,AG}\alpha_{\Pi,DA}\beta_{\Pi,DA}DA_{EGk})(p^{AG}_{H2}(t) + p^{AG}_{CO2}(t)) - w_{cvar}C_{var,AGk}(t)]$
$T_{nat,ik}(t)$	EUR	Governments taxes on hydrogen sales, $i \in \{EG, AG\}$	$\tau_{nat,ik}\Pi_{PRall,ik}(t)$
$T_{intl,EGk}(t)$	EUR	Import tariffs on hydrogen of EU governments	$\tau_{intl,EGk}\Pi_{PRall,EGk}(t)$
$T_{intl,AGk}(t)$	EUR	Export tariffs on hydrogen and tariffs of foreign direct investment of African governments	$\tau_{intl,var,AGk}\Pi_{PRall,AGk}(t) + \tau_{intl,fix,AGk}\left(x^{EG}_{PR,EGk}INV^{EG}_{H2all,k}(t) + x^{AG}_{PR,EGk}INV^{AG}_{H2all,k}(t)\right)$

$\Pi_{PRall,k}^{EG}(t)$	EUR	Revenues collected by private sector investors from sales to EU markets	$s\left[Q_{H2all,k}^{EG}(t)w_{\Pi,EG}\left(p_{h2,EG}(t)+p_{CO2\Delta,EG}(t)+s_{var,EG}(t)\right)-\left(x_{PR,EGk}^{EG}+x_{PR,AGk}^{EG}\right)INV_{H2life,k}^{EG}(t)-w_{cvar}C_{var,EGk}(t)\right]$
$\Pi_{PRall,k}^{AG}(t)$	EUR	Revenues collected by private sector investors from sales to African markets	$\left(w_{\Pi,AG}\alpha_{\Pi,DA}\beta_{\Pi,DA}DA_{EGk}\right)\left[Q_{H2all,k}^{AG}(t)+(1-s)Q_{H2all,k}^{EG}(t)\right]\left(p_{H2}^{EG}(t)+p_{CO2}^{EG}(t)+s_{var,EG}(t)\right)-\left(x_{PR,EGk}^{AG}+x_{PR,AGk}^{AG}\right)INV_{H2life,k}^{AG}(t)-(1-s)\left(x_{PR,EGk}^{EG}+x_{PR,AGk}^{EG}\right)INV_{H2life,k}^{EG}(t)-w_{cvar}(1-w_{cOMtr})\left[C_{var,AGk}(t)-(1-s)C_{var,EGk}(t)\right]$
$C_{var,ik}(t)$	EUR	Variable costs from operation and maintenance of the infrastructure assets, $i \in \{EG, AG\}$	$\alpha_{cOM}(t)c_{WACCi}(t)\left(INV_{H2cum,k}^{i}(t)+INV_{H2life,k}^{i}(t)\right)$
$P_{ik}(t)$	EUR	Penalties for non-compliance with PPP contracts, $i \in \{EG, AG, PR\}$	$\beta_{enf,i}g\left(w_{P,EG}^{EG}\left(x_{PR,EGk}^{EG}INV_{H2all,k}^{EG}(t)+x_{PR,EGk}^{AG}INV_{H2all,k}^{AG}(t)\right)+\left(w_{P,EG}^{AG}\alpha_{P,DA}\beta_{P,DA}DA_{EGk}\right)\left(x_{PR,AGk}^{EG}INV_{H2all,k}^{EG}(t)+x_{PR,AGk}^{AG}INV_{H2all,k}^{AG}(t)\right)\right)$
$R_{ik}(t)$	EUR	Availability payments of governments to private sector investors, $i \in \{EG, AG\}$	$\alpha_{R,i}\left[w_{cvar}\left(s\left(x_{PR,ik}^{EG}+x_{ik}^{EG}\right)C_{var,EGk}(t)+(1-s)\left(x_{PR,ik}^{EG}+x_{ik}^{EG}\right)C_{var,EGk}(t)(1-w_{cOMtr})+\left(x_{PR,ik}^{AG}+x_{ik}^{AG}\right)C_{var,AGk}(t)\right)+x_{PR,ik}^{EG}INV_{H2life,k}^{EG}(t)+x_{PR,ik}^{AG}INV_{H2life,k}^{AG}(t)\right]$
$S_{var,ik}(t)$	EUR	Variable subsidies $i \in \{EG, AG\}$	$s_{var,i}(t)\left(x_{ik}^{EG}Q_{H2all,k}^{EG}(t)+x_{ik}^{AG}Q_{H2all,k}^{AG}(t)\right)$
$TC_{adm,ik}(t)$	EUR	Transaction costs for the administration of the energy partnership, $i \in \{EG, AG\}$	$\int_t^T \frac{TC_{adman,ik}(t)}{e^{r_i t}}$
$TC_{mon,ik}(t)$	EUR	Transaction costs for the monitoring of the energy partnership, $i \in \{EG, AG\}$	$\int_t^T \frac{TC_{monan,ik}(t)}{e^{r_i t}}$
$TC_{enf,ik}(t)$	EUR	Transaction costs for the enforcement of the energy partnership, $i \in \{EG, AG\}$	$\int_t^T \frac{TC_{enfan,ik}(t)}{e^{r_i t}}$
$TC_{PPP,ik}(t)$	EUR	PPP transaction costs for the private investors, $i \in \{PR\}$	$\int_t^T \frac{TC_{PPPan,ik}(t)}{e^{r_i t}}$
$\Delta CO2^{i}$	tCO2e	Carbon emissions avoided by replacing fossil fuels with green hydrogen in EU markets	$\left[\kappa_{NG}^{i}CO2_{NG}^{i}+\kappa_{Diesel}^{i}CO2_{Diesel}^{i}+\left(\kappa_{Heat}^{i}+\kappa_{Store}^{i}\right)CO2_{el}^{i}\right]-CO2_{H2}^{i}$
$\alpha_{ENV,i}$	EUR/Wh	Environmental benefit per unit of hydrogen energy	$p_{CO2}^{i}(t)\Delta CO2^{i}$

Note: Order of appearance in equations. SI units displayed.

Table D.51: Parameters in the Payoff Functions

Symbol	Unit	Parameter description	Specification
c_{WACCi}	%	Parameter describing the cost of capital (weighted average cost of capital)	
$CO2^{i}_{Diesel}$	tCO2e/GWh	Carbon intensity diesel	
$CO2^{i}_{el}$	tCO2e/GWh	Carbon intensity electricity	
$CO2^{i}_{H2}$	tCO2e/GWh	Carbon intensity hydrogen	
$CO2^{i}_{NG}$	tCO2e/GWh	Carbon intensity natural gas	
d_{H2}	%	Depreciation rate infrastructure investments	$d_{H2} \in [0,1]$
g	%	Penalties agreed in PPP contract as a share of investment volume	$g \in [0,1]$
DA_{EG}	Bn. EUR/a	Development aid paid by the EU to the African governments	$DA_{EG} \geq 0$
INV^{i}_{H2an}	Bn. EUR/a	Annual investments into infrastructure assets under the sustainable energy partnerships for sales of the energy on the EU or African markets	
$p^{i}_{CO2}(t = 0)$	Bn. EUR/tCO2e	Carbon price for EU and African governments in first round	
$p^{i}_{H2}(t = 0)$	Bn. EUR/GWh	Sales price for hydrogen in the EU (African) markets in first round	
r_i	%	Discount rate	$r_i \in [0,1]$
s	%	Share of max. hydrogen volumes sellable to the EU markets sold to the EU markets	$s \in [0,1]$
$1 - s$	%	Share of max. hydrogen volumes sellable to the EU markets sold to the African markets	
$s_{var,i}$	n.a.	Rate of variable subsidies paid by EU (African) governments to the private sector	
T	a	Time until build-up of all infrastructure assets to reach policy goals in time	$T \geq 0$
T_{life}	a	Average total lifetime of infrastructure assets, including annual re-investment	$T_{life} \geq 0$
$TC_{adman,i}(t = 0)$	Bn. EUR/a	Annual transaction costs for administration of cooperation agreements in first round	
$TC_{monan,i}(t = 0)$	Bn. EUR/a	Annual transaction costs for PPP monitoring in first round	
$TC_{PPP,PR}(t = 0)$	Bn. EUR/a	Annual transaction costs for administration of PPPs in first round	
$w^{EG}_{P,EG}$	%	Likelihood that the EU penalties can be enforced and are paid by the EU actors	$w^{EG}_{GP,EG} \in [0,1]$
$w^{AG}_{P,EG}$	%	Likelihood that the Northern African penalties can be enforced and are paid by the Northern African actors	$w^{AG}_{GP,EG} \in [0,1]$
$w^{EG}_{P,AG}$	%	Likelihood that the EU penalties can be enforced and are paid by the Northern African actors	$w^{EG}_{GP,AG} \in [0,1]$
$w^{AG}_{P,AG}$	%	Likelihood that the Northern African penalties can be enforced and are paid by the Northern African actors	$w^{AG}_{GP,AG} \in [0,1]$
w^{EG}_{π}	%	Efficiency of hydrogen sales to EU markets (likelihood that $\Pi_{PR,EG}$ materialize)	$w_{\pi,EG} \in [0,1]$
w^{AG}_{π}	%	Efficiency of hydrogen sales to African markets without development aid (likelihood that $\Pi_{PR,AG}$ materialize)	$\left(w_{\pi,AG} + w_{\pi,DA}\right) \in [0,1]$
$w_{\pi,DA}$	%	Improvements due to development aid in efficiency of hydrogen sales to African markets	
$x^{EG}_{PR,EG}$	%	Share of European private sector actors’ investment in total investment for sales to EU markets	$x^{EG}_{PR,EG} + x^{EG}_{PR,AG} + x^{EG}_{EG} + x^{EG}_{AG} = 1$
$x^{EG}_{PR,AG}$	%	Share of Northern African private sector actors’ investment in total investment for sales to EU markets	
x^{EG}_{EG}	%	Share of EU governments’ investment in total investment for sales to EU markets	
x^{EG}_{AG}	%	Share of African governments’ investment in total investment for sales to EU markets	
$x^{EG}_{PR,AG}$	%	Share of European private sector actors’ investment in total investment for sales to Northern African markets	$x^{AG}_{PR,EG} + x^{AG}_{PR,AG} + x^{AG}_{EG} + x^{AG}_{AG} = 1$
$x^{AG}_{PR,AG}$	%	Share of African private sector actors’ investment in total investment for sales to Northern African markets	
x^{AG}_{EG}	%	Share of EU governments’ investment in total investment for sales to Northern African markets	
x^{AG}_{AG}	%	Share of Northern African governments’ investment in total investment for sales to Northern African markets	
α_{cOM}	%	Operational expenses, expressed as share of infrastructure investment	
$\alpha_{MAC,i}$	Bn. EUR/GWh	Dependency of EU (Northern African) governments’ macroeconomic benefits on INV_{H2}	
$\alpha_{P,DA}$	%	Improvement factor for efficiency of government penalties by Northern African governments due to development aid	$\alpha_R \in [0,1]$
α_Q	Bn. EUR/GWh	Investment costs per hydrogen generation unit	
α_R	%	Parameter determining the amount of availability payments to private sector actors	
$\alpha_{SOC,i}$	Bn. EUR/GWh	Dependency of EU (Northern African) governments’ social benefits on INV_{H2}	

$\alpha_{\pi,DA}$	%	Improvement factor for efficiency of hydrogen sales to African markets due to development aid	
β_{enf}	%	Allocation of enforcement responsibilities of PPP contract to EU governments	$\beta_{enf} \in [0,1]$
$1 - \beta_{enf}$	%	Allocation of enforcement responsibilities of PPP contract to Northern African governments	
$\beta_{P,DA}$	%	DA allocation to improvements in GP efficiency in African markets	$\beta_{GP,DA} \in \left[0,1 - \beta_{\pi,DA}\right]$
β_{π}	%	Shares of Π_{EG} potentially allocated to EG	$\beta_{\pi} \in [0,1]$
$1 - \beta_{\pi}$	%	Shares of Π_{EG} potentially allocated to AG	$\beta_{enf} \in [0,1]$
$\beta_{\pi,DA}$	%	Development aid allocation to improvements in hydrogen sales efficiency in Northern African markets	$\beta_{\pi,DA} \in \left[0,1 - \beta_{GP,DA}\right]$
η_{TC}^{i}	%	Efficiency of transaction costs for EU (Northern African) governments	$\eta_{TC}^{i} \in [0,1]$
κ_{Diesel}^{i}	%	Share of hydrogen applications in heavy-duty transport in hydrogen capacity potentially covered by EU-Africa partnership	
κ_{Heat}^{i}	%	Share of hydrogen applications in industry processes in hydrogen capacity potentially covered by EU-Africa partnership	$\kappa_{Diesel}^{i} + \kappa_{Heat}^{i} + \kappa_{NG}^{i} + \kappa_{Store}^{i} \leq 1$
κ_{NG}^{i}	%	Share of hydrogen applications in heat in hydrogen capacity potentially covered by EU-Africa partnership	
κ_{Store}^{i}	%	Share of hydrogen applications in energy storage in hydrogen capacity potentially covered by EU-Africa partnership	
$\tau_{intl,var}^{i}$	%	Tariff rate for imports (exports) of hydrogen to EU (from Northern African) markets	
$\tau_{intl,fix}^{i}$	%	Tariff rate for outbound (inbound) foreign direct investment from EU (to Northern African) markets	
τ_{nat}^{i}	%	Tax rate set by EU (Northern African) governments for hydrogen sold to EU (Northern African) markets	

Note: In alphabetical order.

D.2 Payoffs Under the Different Strategic Choices

Table D.52: Payoffs Under the Different Strategic Choices

Payoff Comp.	**Strategic Choices**			
W_{ik}	{1,1,1}	{1,0,1}	{0,1,1}	{0,0,1}
	$\sum_{EG,AG} W_i$	$\sum_{EG,AG} (x^i_{PR,EG} + x^i_{PR,AG} + x^i_{EG})W_i$	$\sum_{EG,AG} (x^i_{PR,EG} + x^i_{PR,AG} + x^i_{AG})W_i$	$\sum_{EG,AG} (x^i_{PR,EG} + x^i_{PR,AG})W_i$
	{1,1,0}	{1,0,0}	{0,1,0}	{0,0,0}
	$\sum_{EG,AG} (x^i_{EG} + x^i_{AG})W_i$	$\sum_{EG,AG} x^i_{EGk}W_i$	$\sum_{EG,AG} x^i_{AGk}W_i$	0
P_{ik}	{1,1,1}	{1,0,1}	{0,1,1}	{0,0,1}
	0	$\sum_{EG,AG} x^i_{AG}\, P_{AG}$	$\sum_{EG,AG} x^i_{EG}\, P_{EG}$	$\sum_{EG,AG} (x^i_{EG} + x^i_{AG})\, P_i$
	{1,1,0}	{1,0,0}	{0,1,0}	{0,0,0}
	$\sum_{EG,AG} (x^i_{PR,EG} + x^i_{PR,AG})P_{PR}$	$\sum_{EG,AG} (x^i_{PR,EG} + x^i_{PR,AG})P_{PR} + \sum_{EG,AG} x^i_{AG}\, P_{AG}$	$\sum_{EG,AG} (x^i_{PR,EG} + x^i_{PR,AG})P_{PR} + \sum_{EG,AG} x^i_{EG}\, P_{EG}$	0
DA_{EGk}	{1,1,1}	{1,0,1}	{0,1,1}	{0,0,1}
	DA_{EGk}	DA_{EGk}	0	0
	{1,1,0}	{1,0,0}	{0,1,0}	{0,0,0}
	DA_{EGk}	DA_{EGk}	0	0
TC_{ik}	{1,1,1}	{1,0,1}	{0,1,1}	{0,0,1}
	$\sum_{EG,AG,PR} TC_i$	$\sum_{EG,PR} TC_i$	$\sum_{AG,PR} TC_i$	TC_{PR}
	{1,1,0}	{1,0,0}	{0,1,0}	{0,0,0}
	$\sum_{EG,AG} TC_i$	TC_{EG}	TC_{AG}	0
$TC_{enf,ik}$	{1,1,1}	{1,0,1}	{0,1,1}	{0,0,1}
	0	$\sum_{EG,PR} TC_{enf,i}$	$\sum_{AG,PR} TC_{enf,i}$	$TC_{enf,PR}$
	{1,1,0}	{1,0,0}	{0,1,0}	{0,0,0}
	$\sum_{EG,AG} TC_{enf,i}$	$TC_{enf,EG}$	$TC_{enf,AG}$	0
Π^i_{PRk}	{1,1,1}	{1,0,1}	{0,1,1}	{0,0,1}
	$\sum_{EG,AG} \Pi^i_{PR}$	$\sum_{EG,AG} (x^i_{PR,EG} + x^i_{PR,AG} + x^i_{EG})\Pi^i_{PR}$	$\sum_{EG,AG} (x^i_{PR,EG} + x^i_{PR,AG} + x^i_{AG})\Pi^i_{PR}$	$\sum_{EG,AG} (x^i_{PR,EG} + x^i_{PR,AG})\Pi^i_{PR}$
	{1,1,0}	{1,0,0}	{0,1,0}	{0,0,0}
	$\sum_{EG,AG} (x^i_{EG} + x^i_{AG})\Pi^i_{PR}$	$\sum_{EG,AG} x^i_{EG}\Pi^i_{PR}$	$\sum_{EG,AG} x^i_{AG}\Pi^i_{PR}$	0
$\pm R_{ik}$	{1,1,1}	{1,0,1}	{0,1,1}	{0,0,1}
	$\sum_{EG,AG} R_i$	$\sum_{EG,AG} (x^i_{PR,EG} + x^i_{PR,AG} + x^i_{EG})R_i$	$\sum_{EG,AG} (x^i_{PR,EG} + x^i_{PR,AG} + x^i_{AG})R_i$	$\sum_{EG,AG} (x^i_{PR,EG} + x^i_{PR,AG})R_i$
	{1,1,0}	{1,0,0}	{0,1,0}	{0,0,0}
	0	0	0	0
T^i_{PRk}	{1,1,1}	{1,0,1}	{0,1,1}	{0,0,1}
	$\sum_{EG,AG} T^i_{PR}$	$\sum_{EG,AG} (x^i_{PR,EG} + x^i_{PR,AG} + x^i_{EGk})T^i_{PR}$	$\sum_{EG,AG} (x^i_{PR,EG} + x^i_{PR,AG} + x^i_{AGk})T^i_{PR}$	$\sum_{EG,AG} (x^i_{PR,EGk} + x^i_{PR,AGk})T^i_{PR}$
	{1,1,0}	{1,0,0}	{0,1,0}	{0,0,0}
	$\sum_{EG,AG} (x^i_{EG} + x^i_{AG})T^i_{PR}$	$\sum_{EG,AG} x^i_{EG}T^i_{PR}$	$\sum_{EG,AG} x^i_{AG}T^i_{PR}$	0
$S_{var,ik}$	{1,1,1}	{1,0,1}	{0,1,1}	{0,0,1}
	$S_{var,EG} + S_{var,AG}$	$S_{var,EG}$	$S_{var,AG}$	0
	{1,1,0}	{1,0,0}	{0,1,0}	{0,0,0}
	0	0	0	0

Note: Strategic choices of $\{EG, AG, PR\}$, with 1 representing *cooperate*, 0 representing *not cooperate*. For {1,1,1}, $k = 1$; for {1,0,1}, $k = 2$; for {0,0,0}, $k = 8$. TC_{ik} excl. $TC_{enf,ik}$ (see Table D.50).

D.3 Model Parametrization

Table D.53: Model Parametrization and Initial Values of Variables

Symbol	Specification	Initial value	Value, min	Value, max	Unit	Sources
$c_{WACCi}(t=0)$	$c_{WACCi} \in [0,1]$	0.045	See *c.p.* analyses	See *c.p.* analyses	n.a.	Bundesbank (2023)
$CO2^{i}_{Diesel}$	n.a.	900	800	1,000	tCO2e/GWh	Calculated based on ICCT (2012), Umweltbundesamt (2016)
$CO2^{i}_{el}$	n.a.	2,100	900	2,300	tCO2e/GWh	Calculated based on ICCT (2012), Umweltbundesamt (2016)
$CO2^{i}_{H2}$	n.a.	10	5	15	tCO2e/GWh	Calculated based on ICCT (2012), Umweltbundesamt (2016)
$CO2^{i}_{NG}$	n.a.	720	620	820	tCO2e/GWh	Calculated based on ICCT (2012), Umweltbundesamt (2016)
d_{H2}	$d_{H2} \in [0,1]$	0.10	0.05	0.15	n.a.	IEA (2022)
DA_{EG}	$DA_{EG} \geq 0$	0	See *c.p.* analyses	See *c.p.* analyses	Bn. EUR/a	Initial assumption
g	$g \in [0,1]$	14.30	See *c.p.* analyses	See *c.p.* analyses	n.a.	Initial assumption
INV^{EG}_{H2an}	$INV^{EG}_{H2an} \geq 0$	11.37	8.08	15.07	Bn. EUR/a	Calculated based on data sets from IRENA (2017; 2018; 2021), Timmerberg and Kaltschmitt (2019), van Wijk et al. (2019), Timmerberg (2020), IEA (2020), and ICCT (2022)
INV^{AG}_{H2an}	$INV_{H2,AG,cum} \geq 0$	9.03	4.50	14.30	Bn. EUR/a	
p^{EG}_{CO2}	n.a.	0.0000001	0.00000006	0.0000002	Bn. EUR/tCO2e	World Bank (2023)
p^{AG}_{CO2}	n.a.	0.00	0.00	0.00	Bn. EUR/tCO2e	World Bank (2023)
$p^{EG}_{H2}(t=0)$	n.a.	0.000052	0.000037 and *c.p.* analyses	0.000082 and *c.p.* analyses	Bn. EUR/GWh	Calculated based on Destatis (2022), EC (2022)
$p^{AG}_{H2}(t=0)$	n.a.	0.000030	0.000028 and *c.p.* analyses	0.000032 and *c.p.* analyses	Bn. EUR/GWh	Calculated based on globalpetrolprices (2023)
r_i	$r_i \in [0,1]$	0.05	0.01	0.09	n.a.	Bundesbank (2023)
s	$s \in [0,1]$	1.00	0.00	1.00	n.a.	Initial assumption
$s_{var,EG}$	n.a.	0.00	See *c.p.* analyses	See *c.p.* analyses	Bn. EUR/GWh	Initial assumption
$s_{var,AG}$	n.a.	0.00	See *c.p.* analyses	See *c.p.* analyses	Bn. EUR/GWh	Initial assumption
T		8	8	8	a	EC (2019; 2020)
T_{life}		40	20	50	a	IEA (2022)
$TC_{adman,EG}(t=0)$	$TC_{adm,EG} \geq 0$	0.004	0.003	0.006	Bn. EUR/a	Calculated based on OECD (2018)
$TC_{adman,AG}(t=0)$	$TC_{adm,AG} \geq 0$	0	0	0.006	Bn. EUR/a	Calculated based on OECD (2018)
$TC_{monan,i}(t=0)$	$TC_{mon} \geq 0$	0.05	0.03	0.07	n.a.	Yahara et al. (2020)
$TC_{monan,i}(t=0)$	$TC_{enf} \geq 0$	0.03	0.01	0.05	n.a.	Yahara et al. (2020)
$TC_{PPP,PR}(t=0)$	$TC_{PPP,PR} \geq 0$	0.04	0.02	0.06	n.a.	Yahara et al. (2020)
$w^{EG}_{P,EG}$	$w^{EG}_{P,EG} \in [0,1]$	0.71	0.69	0.73	n.a.	Calculated based on World Bank (2021)
$w^{AG}_{P,EG}$	$w^{AG}_{P,EG} \in [0,1]$	0.54	0.52	0.56	n.a.	Calculated based on World Bank (2021)
$w^{EG}_{P,AG}$	$w^{EG}_{P,AG} \in [0,1]$	0.19	0.17	0.21	n.a.	Calculated based on World Bank (2021)
$w^{AG}_{P,AG}$	$w^{EG}_{P,AG} \in [0,1]$	0.38	0.36	0.40	n.a.	Calculated based on World Bank (2021)
w^{EG}_{π}	$w^{EG}_{\pi} \in [0,1]$	0.95	0.93	0.97	n.a.	Calculated based on World Bank (2021)
w^{AG}_{π}	$w^{AG}_{\pi} \in [0,1]$	0.70	0.68	0.72	n.a.	Calculated based on World Bank (2021)
$w_{\pi,DA}$	n.a.	0.00	0.00	0.00	n.a.	Initial assumption
$x^{EG}_{PR,EG}$	$x^{EG}_{PR,EG} + x^{EG}_{PR,AG} + x^{EG}_{EG} + x^{EG}_{AG} = 1$	0.45	See *c.p.* analyses	See *c.p.* analyses	n.a.	Initial assumption, based on EIB (2022)
$x^{EG}_{PR,AG}$		0.05	See *c.p.* analyses	See *c.p.* analyses	n.a.	
x^{EG}_{EG}		0.50	See *c.p.* analyses	See *c.p.* analyses	n.a.	
x^{EG}_{AG}		0.00	See *c.p.* analyses	See *c.p.* analyses	n.a.	
$x^{AG}_{PR,EG}$	$x^{AG}_{PR,EG} + x^{AG}_{PR,AG} + x^{AG}_{EG} + x^{AG}_{AG} = 1$	0.45	See *c.p.* analyses	See *c.p.* analyses	n.a.	Initial assumption, based on EIB (2022)
$x^{AG}_{PR,AG}$		0.05	See *c.p.* analyses	See *c.p.* analyses	n.a.	
x^{AG}_{EG}		0.50	See *c.p.* analyses	See *c.p.* analyses	n.a.	
x^{AG}_{AG}		0.00	See *c.p.* analyses	See *c.p.* analyses	n.a.	
α_{cOM}		0.025	See *c.p.* analyses	See *c.p.* analyses	n.a.	IRENA (2017; 2018; 2021), Timmerberg and

						Kaltschmitt (2019), van Wijk et al. (2019), Timmerberg (2020), IEA (2020), and ICCT (2022)
$\alpha_{MAC,EG}$	n.a.	0.22	(0.61)	1.07	n.a.	Calculated based on World Bank (2022)
$\alpha_{MAC,AG,fix}$	n.a.	0.28	(0.70)	1.26	n.a.	Calculated based on African Business (2022), World Bank (2022)
$\alpha_{MAC,AG,var}$	n.a.	0.000002	0.000001	0.000003	Bn. EUR/GWh	Calculated based on African Business (2022)
$\alpha_{P,DA}$	n.a.	0.00001	See *c.p.* analyses	See *c.p.* analyses	w_P^{AG}/(Bn. EUR)	Initial assumption
α_Q	n.a.	320.43	241.87	450.84	GWh/(Bn. EUR)	Calculated based on Irena (2017, 2018), van Wijk et al. (2019), Timmerberg (2020)
α_R	$\alpha_R \in [0,1]$	0.75	0.70	0.80	n.a.	Calculated based on Yahara et al. (2020), World Bank (2021)
$\alpha_{SOC,EG}$	n.a.	0,00012	0.00002	0.00023	Bn. EUR/GWh	Calculated based on Swinand et al. (2019)
$\alpha_{SOC,AG}$	n.a.	0.00007	0.00004	0.00010	Bn. EUR/GWh	Calculated based on ETF (2014), Bhagwat and Olczak (2020), Trading Economics (2022)
$\alpha_{\pi,DA}$	n.a.	0.00001	See *c.p.* analyses	See *c.p.* analyses	w_π^{AG}/(Bn. EUR)	Initial assumption
β_{enf}	$\beta_{enf} \in [0,1]$	0.45	See *c.p.* analyses	See *c.p.* analyses	n.a.	Initial assumption
$\beta_{P,DA}$	$\beta_{P,DA} \in \left[0,1-\beta_{\pi,DA}\right]$	0.50	See *c.p.* analyses	See *c.p.* analyses	n.a.	Initial assumption
β_π	$\beta_\pi \in [0,1]$	0.45	See *c.p.* analyses	See *c.p.* analyses	n.a.	Initial assumption
$\beta_{\pi,DA}$	$\beta_{\pi,DA} \in [0,1]$	0.45	See *c.p.* analyses	See *c.p.* analyses	n.a.	Initial assumption
η_{TC}^{EG}	$\eta_{TC}^{EG} \in [0,1]$	0.75	See *c.p.* analyses	See *c.p.* analyses	n.a.	Calculated based on OECD (2018), Yahara et al. (2020)
η_{TC}^{AG}	$\eta_{TC}^{AG} \in [0,1]$	0.45	See *c.p.* analyses	See *c.p.* analyses	n.a.	
κ_{Diesel}^{EG}	$\kappa_{Diesel}^{i} + \kappa_{Heat}^{i} + \kappa_{NG}^{i} + \kappa_{Store}^{i} \leq 1$	0.25	0.15	0.35	n.a.	Calculated based on Agora, 2021, BCG (2021a,b)
κ_{Heat}^{EG}		0.00	0.00	0.00	n.a.	
κ_{NG}^{EG}		0.75	0.65	0.85	n.a.	
κ_{Store}^{EG}		0.00	0.00	0.00	n.a.	
κ_{Diesel}^{AG}		0.27	0.27	0.27	n.a.	Calculated based on Bhagwat and Olczak (2020)
κ_{Heat}^{AG}		0.21	0.21	0.21	n.a.	
κ_{NG}^{AG}		0.24	0.24	0.24	n.a.	
κ_{Store}^{AG}		0.28	0.28	0.28	n.a.	
$\eta_{TC,EG}$	$\eta_{TC}^{EG} \in [0,1]$	0	See *c.p.* analyses	See *c.p.* analyses	n.a.	Initial assumption
$\eta_{TC,AG}$	$\eta_{TC}^{AG} \in [0,1]$	0	See *c.p.* analyses	See *c.p.* analyses	n.a.	Initial assumption
$\tau_{intl,var}^{EG}$	n.a.	0.0000005	0.0000005	0.0000005	Bn. EUR/GWh	EC (2003)
$\tau_{intl,fix}^{EG}$	n.a.	0.00	See *c.p.* analyses	See *c.p.* analyses	n.a.	Initial assumption
$\tau_{intl,var}^{AG}$	n.a.	0.00	See *c.p.* analyses	See *c.p.* analyses	n.a.	Initial assumption
$\tau_{intl,fix}^{AG}$	n.a.	0.00	See *c.p.* analyses	See *c.p.* analyses	n.a.	Initial assumption
τ_{nat}^{EG}	n.a.	0.21	0.21	0.21	n.a.	Calculated based on PwC (2022), Tax Foundation (2022)
τ_{nat}^{AG}	n.a.	0.25	0.25	0.25	n.a.	Calculated based on PwC (2022), Tax Foundation (2022)

Note: Parameters in alphabetical order. Min. and Max. values denote minimum and maximum values for the parameters found in the literature and are tested as part of the sensitivity analyses. Calculations are provided in the supplementary material (available upon request). Rounded values shown.

D.4 *Ceteris Paribus* Analyses

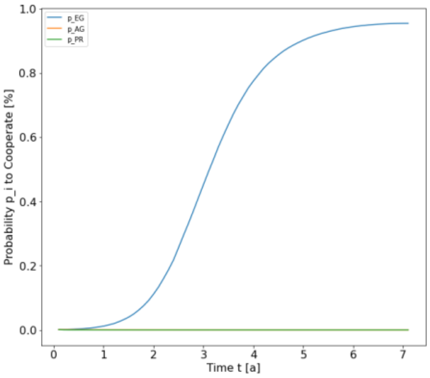
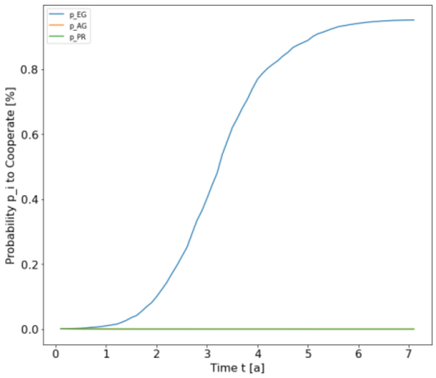
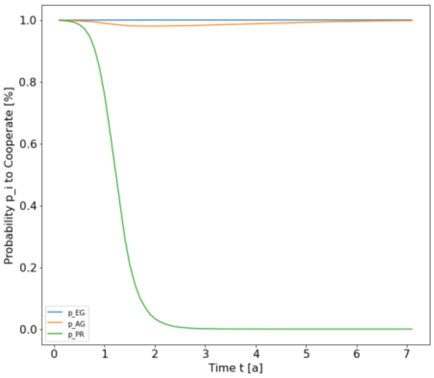
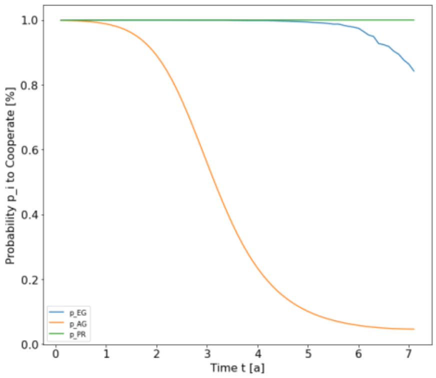
<table>
<tr><th>Initial Probability</th><th>Long-term Cooperation Outcomes Under (a) Concession Contracts</th><th>Long-term Cooperation Outcomes Under (b) Availability-based PPPs</th></tr>
<tr><td>(a), (b)
$p_{EG1,init}$
$= 0.001$
$p_{AG1,init}$
$= 0.001$
$p_{PR1,init}$
$= 0.001$</td><td>
</td><td>
</td></tr>
<tr><td>(a), (b)
$p_{EG1,init}$
$= 0.999$
$p_{AG1,init}$
$= 0.999$
$p_{PR1,init}$
$= 0.999$</td><td>
</td><td>
</td></tr>
</table>

Figure D.35: Model Results—Initial Parametrization—Sensitivity Analyses

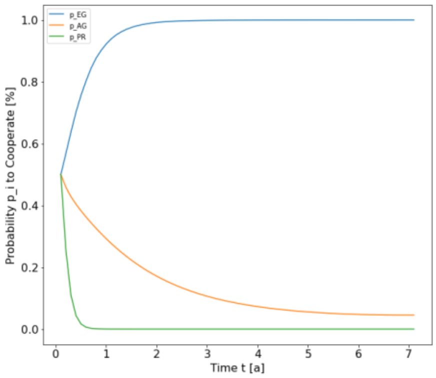
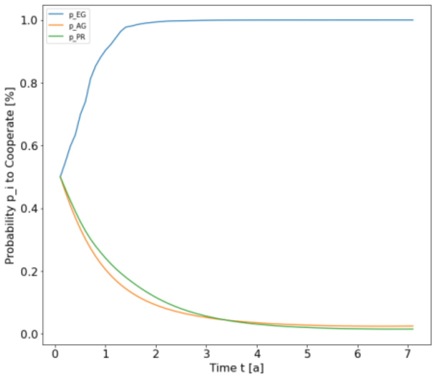
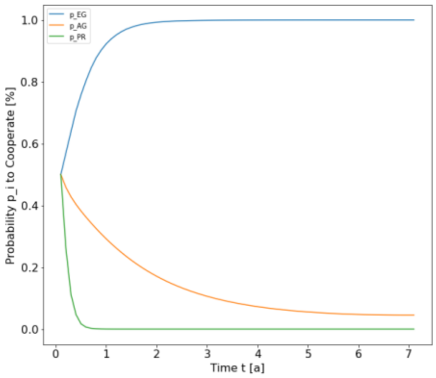
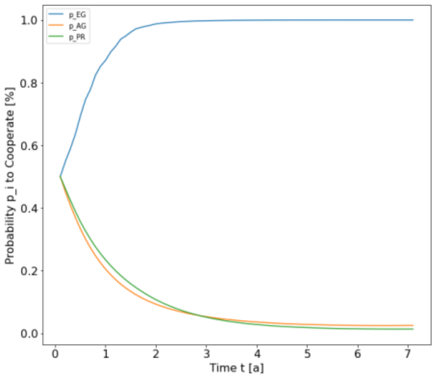
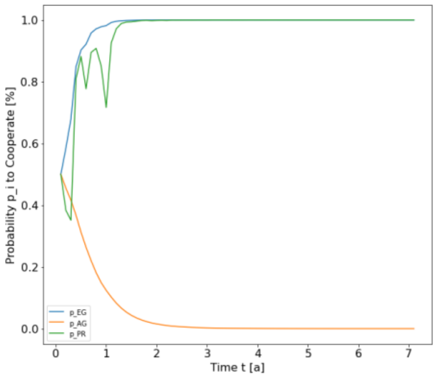
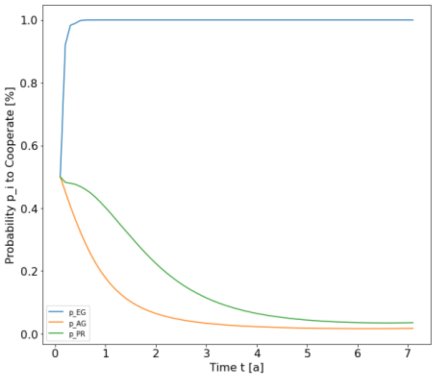
<table>
<tr><th>C.p. Changed Parameters</th><th>Long-term Cooperation Outcomes Under (a) Concession Contracts</th><th>Long-term Cooperation Outcomes Under (b) Availability-based PPPs</th></tr>
<tr><td>Hydrogen price increase, immediate (realistic)
(a), (b)
$p_{H2}^{EG}(t = 0)$
$= p_{H2}^{EG}(t = T)$
$= 82$
EUR/kWh
$p_{H2}^{AG}(t = 0)$
$= p_{H2}^{AG}(t = T)$
$= 31$
EUR/kWh</td><td>
</td><td>
</td></tr>
<tr><td>Hydrogen price increase, successive (realistic)
(a), (b)
$p_{H2}^{EG}(t = 0)$
$= 52$
EUR/kWh
$p_{H2}^{EG}(t = T)$
$= 82$
EUR/kWh
$p_{H2}^{AG}(t = 0)$
$= 30$
EUR/kWh
$p_{H2}^{AG}(t = T)$
$= 32$
EUR/kWh</td><td>
</td><td>
</td></tr>
<tr><td>Hydrogen price increase, immediate (threshold)
(a), (b)
$p_{H2}^{EG}(t = 0)$
$= p_{H2}^{EG}(t = T)$
$= 1{,}560$
EUR/kWh
$p_{H2}^{AG}(t = 0)$
$= p_{H2}^{AG}(t = T)$
$= 900$
EUR/kWh</td><td>
</td><td>
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Figure D.36: Model Results—Changes in External Influencing Factors—Hydrogen Prices

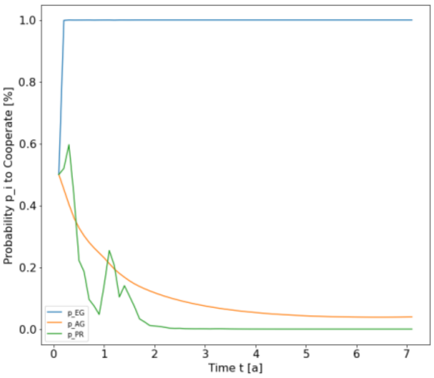
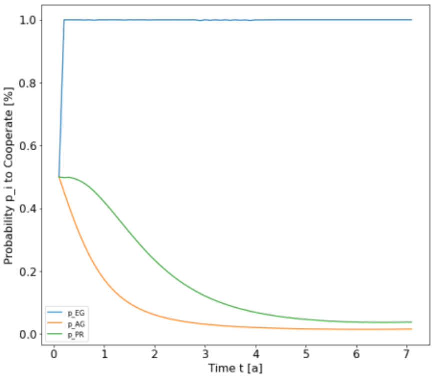
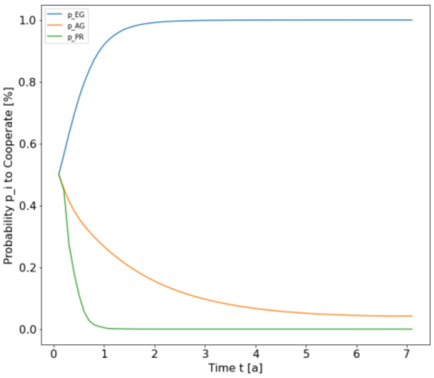
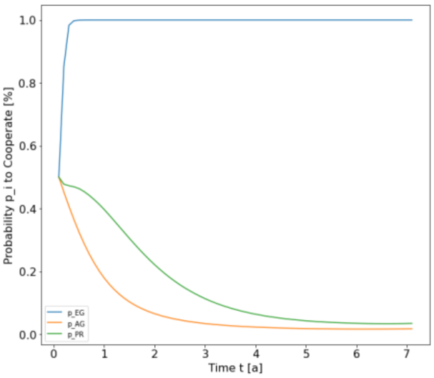
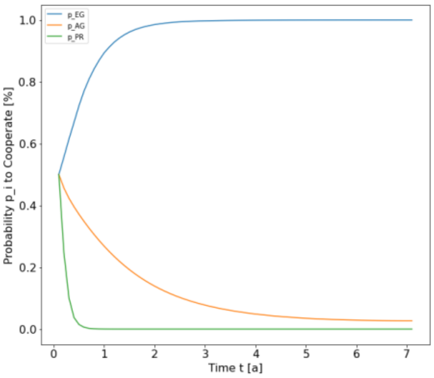
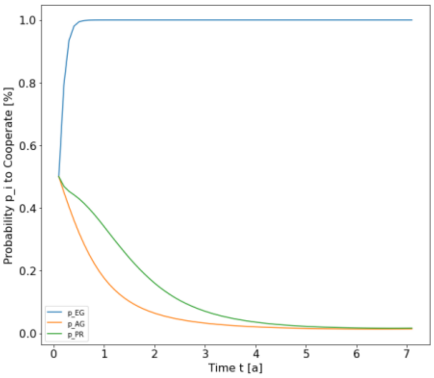
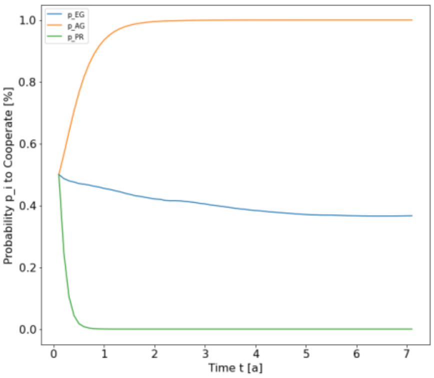
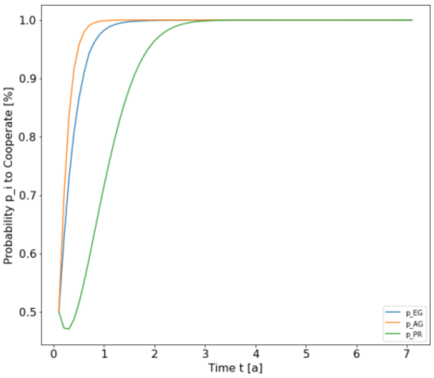
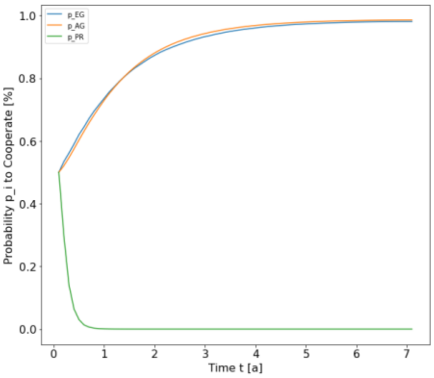
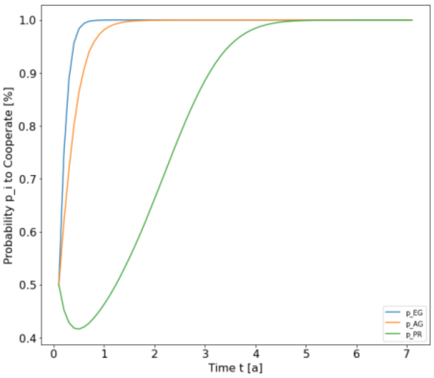
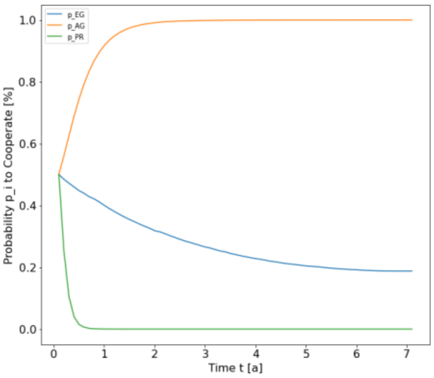
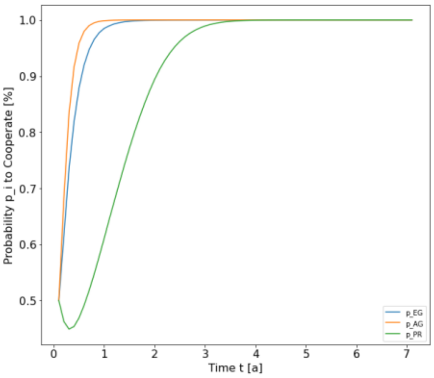
C.p. **Changed Parameters**	**Long-term Cooperation Outcomes Under (a) Concession Contracts**	**Long-term Cooperation Outcomes Under (b) Availability-based PPPs**
Carbon price increase only in EU (a), (b) $p_{CO2}^{EG} = 7{,}000$ EUR/tCO2e $p_{CO2}^{AG} = 0.00$		
Carbon price increase only in African countries (a), (b) $p_{CO2}^{EG} = 100$ EUR/tCO2e $p_{CO2}^{AG} = 7{,}000$		

Figure D.37: Model Results—Changes in External Influencing Factors—Carbon Prices

C.p. changed parameters	Long-term cooperation outcomes under (a) concession contracts	Long-term cooperation outcomes under (b) availability-based PPPs
Initial parametrization (a), (b) $x_{PR,EG}^{EG} = 0.45$ $x_{PR,AG}^{EG} = 0.05$ $x_{EG}^{EG} = 0.50$ $x_{AG}^{EG} = 0.00$ $x_{PR,EG}^{AG} = 0.45$ $x_{PR,AG}^{AG} = 0.05$ $x_{EG}^{AG} = 0.50$ $x_{AG}^{AG} = 0.00$		
African governments' equal co-investment (a), (b) $x_{PR,EG}^{EG} = 0.45$ $x_{PR,AG}^{EG} = 0.05$ $x_{EG}^{EG} = 0.25$ $x_{AG}^{EG} = 0.25$ $x_{PR,EG}^{AG} = 0.45$ $x_{PR,AG}^{AG} = 0.05$ $x_{EG}^{AG} = 0.25$ $x_{AG}^{AG} = 0.25$		
African governments' moderate co-investment (a), (b) $x_{PR,EG}^{EG} = 0.35$ $x_{PR,AG}^{EG} = 0.05$ $x_{EG}^{EG} = 0.425$ $x_{AG}^{EG} = 0.175$ $x_{PR,EG}^{AG} = 0.35$ $x_{PR,AG}^{AG} = 0.05$ $x_{EG}^{AG} = 0.425$ $x_{AG}^{AG} = 0.175$		
All equal (a), (b) $x_{PR,EG}^{EG} = 0.25$ $x_{PR,AG}^{EG} = 0.25$ $x_{EG}^{EG} = 0.25$ $x_{AG}^{EG} = 0.25$ $x_{PR,EG}^{AG} = 0.25$ $x_{PR,AG}^{AG} = 0.25$ $x_{EG}^{AG} = 0.25$ $x_{AG}^{AG} = 0.25$		

Mainly EU private investment
(a), (b)
$x_{PR,EG}^{EG} = 0.90$
$x_{PR,AG}^{EG} = 0.00$
$x_{EG}^{EG} = 0.05$
$x_{AG}^{EG} = 0.05$
$x_{PR,EG}^{AG} = 0.90$
$x_{PR,AG}^{AG} = 0.00$
$x_{EG}^{AG} = 0.05$
$x_{AG}^{AG} = 0.05$

Only EU governments
(a), (b)
$x_{PR,EG}^{EG} = 0.00$
$x_{PR,AG}^{EG} = 0.00$
$x_{EG}^{EG} = 1.00$
$x_{AG}^{EG} = 0.00$
$x_{PR,EG}^{AG} = 0.00$
$x_{PR,AG}^{AG} = 0.00$
$x_{EG}^{AG} = 1.00$
$x_{AG}^{AG} = 0.00$

Only EU and African governments
(a), (b)
$x_{PR,EG}^{EG} = 0.00$
$x_{PR,AG}^{EG} = 0.00$
$x_{EG}^{EG} = 0.50$
$x_{AG}^{EG} = 0.50$
$x_{PR,EG}^{AG} = 0.00$
$x_{PR,AG}^{AG} = 0.00$
$x_{EG}^{AG} = 0.50$
$x_{AG}^{AG} = 0.50$

Only African governments
(a), (b)
$x_{PR,EG}^{EG} = 0.00$
$x_{PR,AG}^{EG} = 0.00$
$x_{EG}^{EG} = 0.00$
$x_{AG}^{EG} = 1.00$
$x_{PR,EG}^{AG} = 0.00$
$x_{PR,AG}^{AG} = 0.00$
$x_{EG}^{AG} = 0.00$
$x_{AG}^{AG} = 1.00$

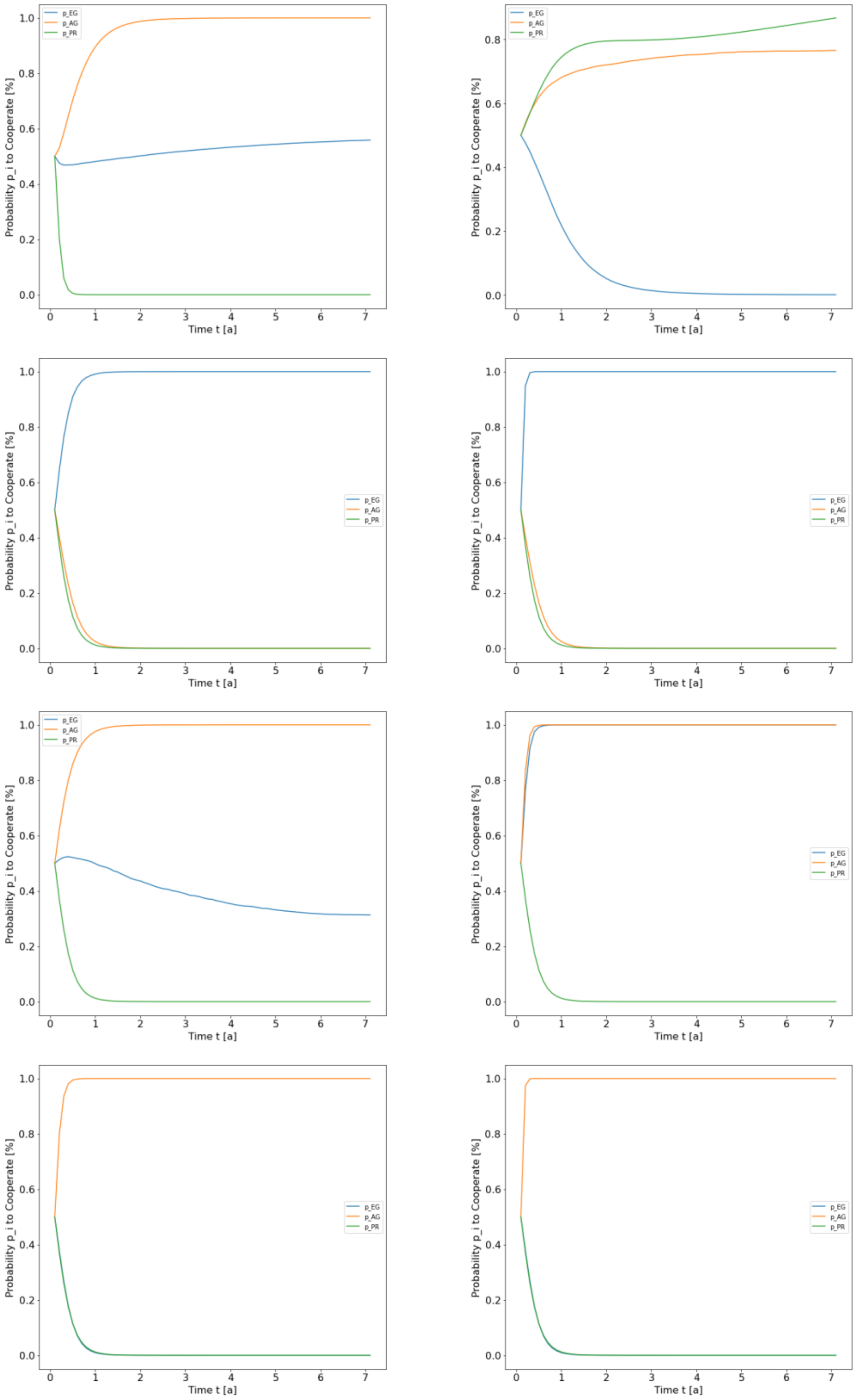


Figure D.38: Model Results—Changes in the PPP Setup—Distribution of Investment

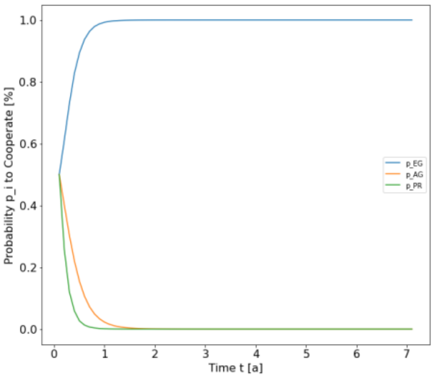
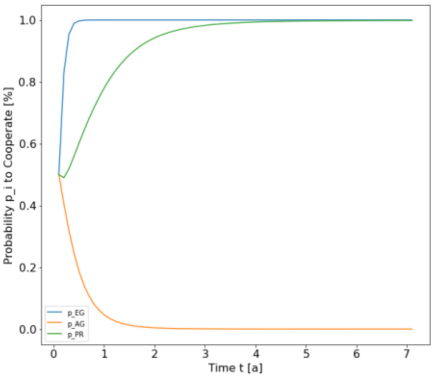
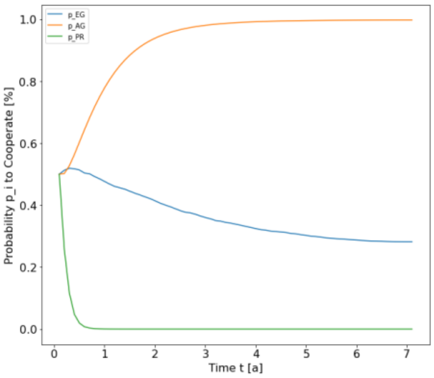
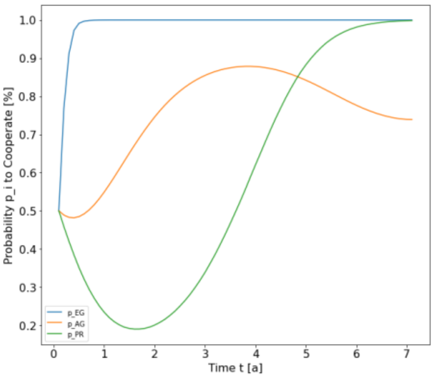
C.p. **changed parameters**	**Long-term cooperation outcomes under (a) concession contracts**	**Long-term cooperation outcomes under (b) availability-based PPPs**
Full responsibility of EU governments (a), (b) $\beta_{enf} = 1.0$ $\beta_{\pi} = 1.0$		
Full responsibility of African governments (a), (b) $\beta_{enf} = 0.0$ $\beta_{\pi} = 0.0$		

Figure D.39: Model Results—Changes in the PPP Setup—Distribution of Responsibilities

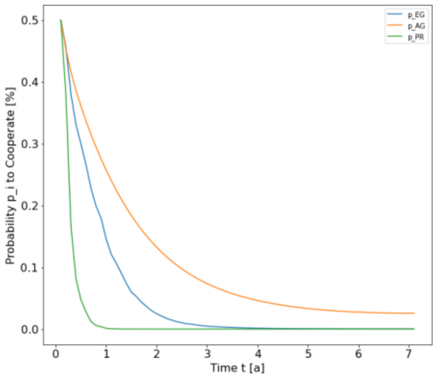
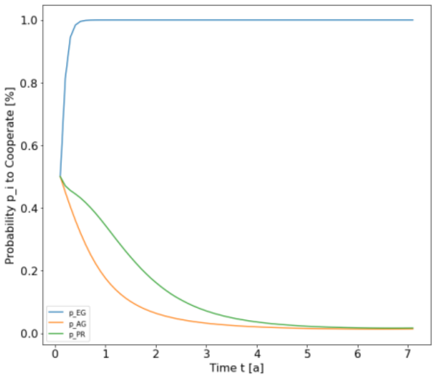
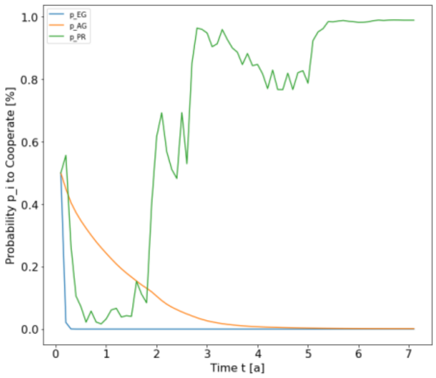
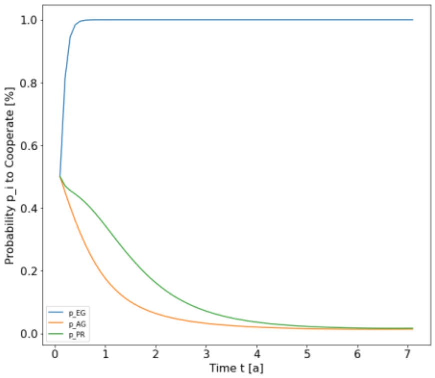
C.p. **changed parameters**	**Long-term cooperation outcomes under (a) concession contracts**	**Long-term cooperation outcomes under (b) availability-based PPPs**
Variable subsidies I (a), (b) $s_{var,EG}$ $= 500\%$ $s_{var,AG}$ $= 500\%$		
Variable subsidies II (a), (b) $s_{var,EG}$ $= 4{,}000\%$ $s_{var,AG}$ $= 500\%$		

Figure D.40: Model Results—Changes in the PPP Setup—Variable Subsidies