Public-private partnerships versus traditional procurement: Innovation incentives and information gathering*

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Abstract

A government agency wants a facility to be built and managed to provide a public service. Two different modes of provision are considered. In a public-private partnership, the tasks of building and managing are bundled, while under traditional procurement, these tasks are delegated to separate private contractors. The two modes differ in their incentives to innovate and to gather private information about future costs to adapt the service provision to changing circumstances. Depending on the potential benefits of such adaptations, the government agency's preferred mode of provision may be different from the one that should be chosen from a welfare perspective.

Keywords: Public-private partnerships; Integration versus separation; Information gathering; Incomplete contracts

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1 Introduction

In the last 15 years, public-private partnerships have become an increasingly popular method to let the private sector provide public infrastructure-based services in various sectors such as health care, education, and transportation. As has been pointed out by Hart (2003), a key property of a public-private partnership is the fact that facility construction and subsequent service provision are bundled and assigned to a single private-sector entity.[1] An often heard argument in favour of public-private partnerships is that bundling encourages innovative design solutions during the construction phase that may reduce the subsequent costs of service delivery.[2] Yet, at the same time, it has also been argued that compared to traditional procurement, the long-term relationship inherent in a public-private partnership may create particular scope for information asymmetries to develop between the public sector and the private entity. Specifically, the private-sector entity may become much better informed than the public authority about additional costs that arise in the operation stage when changes in circumstances occur.[3]

In this paper, we study how incentives to come up with innovative design solutions and incentives to acquire private information relevant for service delivery affect the performance of public-private partnerships compared to traditional procurement. It turns out that a government agency's preferred mode of provision may be different from the one that is optimal from a welfare perspective. In particular, the government agency's preferences for a public-private partnership may be too strong or too weak, depending on the importance of retaining flexibility to adapt the service provision

[1] See also Grimsey and Lewis (2004, pp. 129, 222), who point out that a defining characteristic of public-private partnerships is that the tasks of designing and building a facility as well as operating it later on are integrated within a single private-sector party, while under traditional procurement there are separate contractors for construction and management.

[2] For example, Yescombe (2007, p. 21) stresses that since the same private-sector entity is responsible for construction and operation of the facility, it will be prepared to spend more during the construction phase in order to reduce the costs to be incurred later on. Similarly, the argument that a public-private partnership encourages the private-sector entity "to plan beyond the bounds of the construction phase and incorporate features that will facilitate operations" has also been brought forward by Grimsey and Lewis (2004, p. 92).

[3] See Yescombe (2007, pp. 24, 273). The fact that in the construction phase, the private-sector entity in a public-private partnership may gain an informational advantage on the costs of future investments in service provision has also been pointed out by Chong, Huet, and Saussier (2006a,b) and De Palma, Leruth, and Prunier (2009). See also Monbiot (2002) and Vickerman (2004), who argue that the informational advantage of the private entity may allow it to exaggerate its costs.

to changing circumstances that were not yet contractible when the public-private partnership was first agreed upon.

Consider a government agency that wants a certain public good or service to be provided. Before provision can take place (stage 2), a suitable infrastructure has to be built (stage 1). For example, in order to provide health care, education, or public transportation, suitable hospitals, schools, or railroad networks have to be built. Initially, only the basic features of the good or service can be described in a contract. But after some time has passed, i.e. when the second stage is reached, it becomes clear how the basic good or service can be improved by adapting it.[4] Hence, at the beginning of the second stage, the government agency can contract for additional features that increase its benefit but also the costs of provision. For instance, advances in the field of medical research may require hospitals to meet growing service standards, e.g. to adapt to new medical equipment or to enlarge the number of operating rooms. Similarly, reforms in the educational system may necessitate that schools are restructured to turn them into all-day schools. When a government agency has contracted for the procurement of public transportation, it may later (e.g., in the light of an increased public interest in safety measures) want trains to be equipped with passenger information and surveillance technology.

At the outset, the government agency can choose between two different modes of provision. In case of a *public-private partnership*, building and service provision are bundled; i.e., the government agency contracts with a single party (a consortium) to build the infrastructure and to operate it. In contrast, under *traditional procurement* the government contracts with one party to build the infrastructure and with another party to provide the public good or service. All parties are risk-neutral and (except for the agency) they are protected by limited liability.

In the first stage, the builder provides the basic version of the infrastructure and he can exert unobservable effort to come up with an innovation, which may reduce the costs of adapting the public good or service to future needs. For example, an innovative layout of a hospital may facilitate a flexible use of rooms that may be required when in-patient treatment is increasingly substituted by ambulatory treatment.[5] Sim-

[4]The importance of keeping flexibility to adapt the service provision to new developments that were not taken into account in the original public-private partnership arrangement has also been emphasized by Cambridge Economic Policy Associates (2005), HM Treasury (2003), OECD (2008), Public Accounts Select Committee (2000), and Renda and Schrefler (2006).

[5]For instance, Grimsey and Lewis (2004, p. 121) report about the Berwick Hospital Project, in which strong efforts were made to come up with design solutions that retain the flexibility “to

ilarly, structuring school grounds in innovative ways can affect future efforts that are needed to supervise children during breaks and in the afternoons. Moreover, carefully designed trains and railway stations may reduce the efforts of security guards that may be required in the future to meet increasing needs for security.

When only a standard design was developed in the first stage, the costs of improving the service provision in the second stage by making suitable adaptations are known to be high. Yet, when the design developed in the first stage is innovative, then these costs may be lower. In this case, the costs of service improvements are initially unknown, but the party in charge of construction in the first stage may spend resources to acquire private information about these costs. For instance, a firm that came up with an innovative layout for a hospital or a school may have the opportunity to find out how much effort would be needed to restructure the building to increase the number of operating rooms or to accommodate more students. Similarly, a firm that has developed innovative designs for trains and railway stations may be in a good position to evaluate which future efforts would be required to meet more ambitious security standards.

If there were no incentive problems, the optimal mode of provision would depend on technological issues only. Specifically, if it is more expensive to let a different party be in charge of the second stage, so that the tasks in the two stages are complements, then a public-private partnership would be preferred by the government agency. This is the case if the builder has lower costs to improve the service provision in the second stage because of his specific knowledge about the characteristics of the infrastructure. In contrast, if the tasks are substitutes, such that a party different from the builder can respond to changing service provision needs at lower costs, then the government agency would prefer traditional procurement. This scenario prevails if the firm in charge of the first stage is specialized in building the infrastructure, while the firm in charge of the second stage has special skills regarding the management of service provision.

However, in the presence of incentive problems, the government agency's choice between a public-private partnership and traditional procurement is no longer determined by technological considerations only. To see this, let us first investigate the case in which no mode of provision is accompanied by technological (dis-)advantages. At

address ongoing changes in medical and health care practices, to accommodate demands for the future development of new services, and to maximise the opportunities for greater integration of in-patient care with ambulance and community-based services."

first sight, one might guess that the government agency then prefers a public-private partnership. After all, when the same party is in charge of both stages, then it might be motivated to exert effort in the first stage just because of the prospect to earn a rent in the second stage by reducing the adaptation costs that it will then have to incur. In contrast, to induce first-stage effort under traditional procurement, the party in charge of the first stage has to be directly motivated by a suitable bonus payment in case that an innovation is made, since it does not care about the second-stage adaptation costs. Yet, it turns out that in the absence of technological (dis-)advantages, the government agency prefers traditional procurement.

Given a public-private partnership, the consortium will gather information about future costs of improving the service provision with positive probability, so that it may earn a rent in the second stage when these adaptation costs are low. In contrast, under traditional procurement, there is no scope for acquiring private information, since the party in charge of the first stage does not care about the second-stage costs. Actually, there are two cases. (i) If the government agency's additional benefit from implementing the second-stage improvement is relatively small, then it offers only relatively small payments for the implementation, so that the consortium cannot earn a second-stage rent. Hence, in this case under both modes of provision first-stage effort can be induced only by directly rewarding an innovation with a suitable bonus payment. But since given a public-private partnership, the consortium may be privately informed, the relatively small payments for implementing the second-stage improvement are not always accepted. As a consequence, the government agency's additional benefit from the second-stage improvement is realized less often than under traditional procurement, where the party in charge of the second stage is never privately informed. Hence, if the government agency chooses the same first-stage bonus payment as is optimal in case of a public-private partnership, then the agency is better off under traditional procurement. Moreover, it can do even better if under traditional procurement a larger first-stage effort is induced. (ii) If the government agency's additional benefit from implementing the second-stage improvement is relatively large, then given a public-private partnership, the agency offers relatively large payments for the implementation, so that the consortium can earn a second-stage rent. Yet, the rent left to the consortium is so large that the government agency can no longer benefit from a first-stage innovation. Hence, the government agency offers no direct reward for an innovation in the first stage, while under traditional procurement it benefits from an innovation and thus induces a positive first-stage effort, which means that the government agency must be better off under traditional procurement. Note that nevertheless, the prospect to earn the second-stage rent may lead the consortium to choose a larger first-stage effort level than the one induced by the government agency under traditional procurement. In particular, this may happen when the information acquisition costs are small, such that the second-stage rent that the consortium may earn becomes large.

Given that the government agency opts for traditional procurement when technological issues are not relevant, it will prefer a public-private partnership only if traditional procurement is accompanied by sufficiently large technological disadvantages; i.e., if the complementarities between the tasks in the two stages are sufficiently strong. On the other hand, if technologically the tasks in the two stages are substitutes, then the government agency will always prefer traditional procurement.

A central question motivating our study is whether the government agency's preferred mode of provision coincides with the one that is optimal from a welfare perspective; i.e., would the agency's decision between the two modes be supported or would it be overruled by a welfare-maximizing government? Our results depend on the potential merits of adapting the service provision to future needs. (i) Consider first the case in which the additional benefit from implementing the second-stage improvements is relatively small, such that second-stage rents never occur. If the technological disadvantages of separating the two tasks are sufficiently large (resp., small), a welfare-maximizing government would agree with the agency's choice of a public-private partnership (resp., traditional procurement). However, for intermediate levels of the technological disadvantages, the agency may prefer a public-private partnership, whereas a welfare-maximizing government may opt for traditional procurement (while the opposite can never occur). The fact that the first-stage effort level is larger under traditional procurement implies that, given limited liability, also the first-stage rent is larger. Hence, traditional procurement is more attractive for a welfare-maximizing government, since it takes the rents into account, while the agency does not. (ii) Consider now the case in which the additional benefit from the second-stage adaptations is relatively large. In this case, the results depend on the costs of gathering information. If the information acquisition costs are large, so that given a public-private partnership the second-stage rent and hence also the first-stage effort incentives are small, then there are again situations in which the government agency chooses a public-private partnership while a welfare-maximizing government would opt for traditional procurement. In contrast, if the information gathering costs are small, the second-stage rent and therefore the first-stage effort given a public-private partnership become large. This makes a public-private partnership relatively more attractive for a welfare-maximizing government than for the agency, since the latter does not care about the consortium's rent. In particular, in contrast to the agency, a welfare-maximizing government may prefer a public-private partnership, even if technological issues are irrelevant or if the tasks in the two stages are substitutes. That is, even if separating the tasks has technological advantages, this may be overcompensated by the fact that given a public-private partnership, stronger incentives to exert effort in the first stage may be generated by the prospect to earn an information rent in the second stage.

There is by now a vast literature on the role of private firms in the provision of public goods.[6] Specifically, the theoretical literature on public-private partnerships has various strands. As pointed out above, we follow Hart (2003) who argues that a key property of a public-private partnership is the fact that building the infrastructure and service provision are bundled. Bundling implies that the builder internalizes the second-stage operating costs when he exerts effort in the first stage. While Hart (2003) considers a model with symmetric information, our aim is to highlight the implications of the possibility to gather private information; hence, we study a framework in which under symmetric information the mode of provision would be irrelevant in the absence of technological (dis-)advantages. In order to focus on the key question whether or not the two stages should be separated, we follow Hart (2003) in that we do not complicate the analysis by introducing the choice between public and private ownership.[7] The interaction of the mode of provision and different ownership structures under symmetric information has been studied by Bennett and Iossa (2006a,b) and Chen and Chiu (2009). A common feature of their models and our framework is that second-stage service improvements are non-contractible ex ante but become verifiable ex post. In contrast, Bentz, Grout, and Halonen (2004) study related ques-

[6] For surveys on privatization, see e.g. Vickers and Yarrow (1988), Bös (1991), Shleifer (1998), and Martimort (2006). In this literature, the focus is generally on informational asymmetries and/or contractual incompleteness (e.g., Shapiro and Willig, 1990, Laffont and Tirole, 1991, Schmidt, 1996a,b).

[7] The effects of public and private ownership on investment incentives are studied by Hart, Shleifer, and Vishny (1997), who build on the property rights approach based on incomplete contracting (Grossman and Hart, 1986; Hart and Moore, 1990; Hart, 1995). Hoppe and Schmitz (2010a) extend their model by considering a richer set of contractual arrangements. See also Besley and Ghatak (2001), Francesconi and Muthoo (2006), and Halonen-Akatwijuka and Pafilis (2009) who build on the property rights approach to analyze whether non-governmental organizations should own public goods.

tions in a complete contracting framework. Martimort and Pouyet (2008) develop a model that encompasses both traditional agency problems and property rights and they find that the important issue is not who owns the assets, but instead whether tasks are bundled or not. Iossa and Martimort (2008, 2009) provide extensions and applications of this framework, also highlighting the positive (resp., negative) effects of bundling in the presence of positive (resp., negative) externalities between the stages.[8]

The remainder of the paper is organized as follows. In the next section, the model is introduced. The two different modes of provision are studied in Section 3 (public-private partnership) and Section 4 (traditional procurement). In Section 5, we analyze which mode of provision is preferred by the government agency and whether or not a welfare-maximizer would overrule this decision. Concluding remarks follow in Section 6.

2 The model

The principal (a government agency) wants to delegate the provision of a public good or service. There are two stages. In the first stage, a suitable infrastructure has to be designed and built (task 1), while in the second stage it has to be managed and operated (task 2). At the outset, the principal can choose between two different modes of provision. Either the principal opts for a public-private partnership, i.e. she contracts with one agent (a consortium) in charge of both tasks, or she contracts with two different agents each in charge of one task (traditional procurement). The agents are protected by limited liability, their reservation utilities are zero, and all parties are risk-neutral.

An agent in charge of task 1 can build a basic version of the infrastructure, causing monetary and verifiable costs c_1. Additionally, to come up with an innovation, the agent can exert unobservable effort $e \in [0, 1]$ at non-monetary effort costs $\frac{1}{2}e^2$. The verifiable outcome of his effort is a success ($x = 1$) with probability e and a failure ($x = 0$) otherwise. A success means that an innovation has been developed that reduces the expected costs of undertaking adaptations (not yet describable in stage 1) to improve the service provision in the second stage.

Specifically, in the second stage the agent in charge of task 2 can provide a stan-

[8] On the pros and cons of bundling sequential tasks in the absence of information gathering when complete contracts can be written, see also Schmitz (2005) and the literature discussed there.

dard version of the public good or service, which entails monetary and verifiable costs c_2 and yields a benefit B to the principal. We assume that $B > c_1 + c_2$, so that at least, it is always desirable to build the basic infrastructure and to provide the standard service. Moreover, in stage 2 it is possible to contract upon the improvement of the service provision which yields an additional benefit b to the principal. If the same agent is in charge of both tasks, then the effort costs of improving the second-stage service provision are c, while they are $c + \Delta$ if a different agent is in charge of task 2. We assume that these costs are non-monetary. If there was no innovation ($x = 0$), then $c = c_h$, while $c \in \{c_l, c_h\}$ with $\Pr\{c = c_l\} = p$ if an innovation was made ($x = 1$). We normalize $0 < c_l < c_h < 1$ and we assume that $\Delta > -c_l$, which means that the costs of improving the second-stage service provision by undertaking adaptations are always strictly positive. A positive Δ implies that task 1 and implementation of the second-stage improvement are complements, while a negative Δ means that they are substitutes.[9]

If an innovation was made, initially no one knows the realization of c. However, at the end of stage 1, the agent in charge of task 1 can exert unobservable effort in order to gather information about the costs c of improving the second-stage service provision. In particular, if the agent incurs non-monetary effort costs $\gamma > 0$, then he learns the realization of c, while he remains uninformed otherwise.

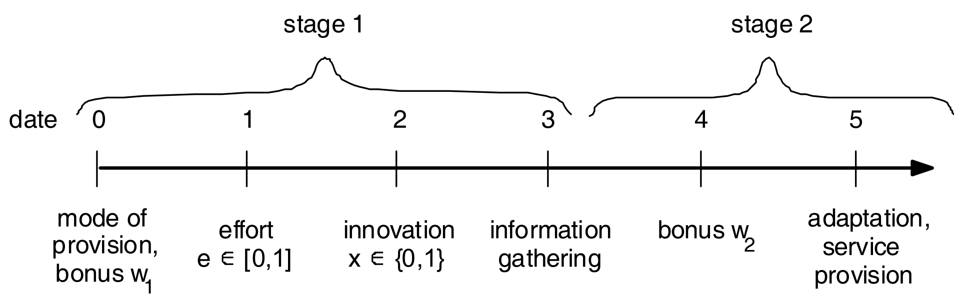

Figure 1. The sequence of events.

The sequence of events is illustrated in Figure 1. At date 0, the principal chooses the mode of provision. Consider first the case of a public-private partnership, so that the principal makes an offer to one agent (i.e., a consortium) who will be in charge of

[9]The relevance of cost complementarities for the desirability to bundle tasks has been discussed by Holmström and Milgrom (1991) and Itoh (1994). See Laffont and Martimort (2002, Section 5.2) for an excellent textbook exposition.

both tasks. In this case, at date 0 the principal offers the agent to cover his verifiable costs c_1 at date 1 and c_2 at date 5 and she offers to pay him a bonus w_1^{PPP} if an innovation is made at date 2.[10] At date 1, the agent builds the basic version of the infrastructure and decides how much effort e he wants to exert to come up with an innovation. If an innovation was made, the agent can gather information at date 3. At the beginning of the second stage, the adaptations necessary to improve the second-stage service provision become contractible and hence at date 4 the principal offers the agent to pay him a bonus w_2^{PPP} if he agrees to undertake the adaptations. At date 5, the agent provides the public good or service.

Next, consider the case of traditional procurement, so that the principal contracts with two different agents each in charge of one stage. At date 0, the principal offers agent 1 to bear the costs c_1 of building the basic infrastructure at date 1 and to pay him the bonus w_1^{TP} for an innovation at date 2. Moreover, the principal offers agent 2 to cover the costs c_2 of providing the basic version of the public good or service at date 5.[11] Agent 1 exerts effort e at date 1 and may gather information at date 3. At date 4, the second-stage service improvement becomes contractible and the principal offers to pay agent 2 the bonus w_2^{TP} if he agrees to implement it. Finally, at date 5, agent 2 provides the public service.

In order to simplify the exposition, we make the following assumptions.

Assumption 1 *(i)* $\gamma < p(E[c] - c_l)$.

(ii) $b > E[c]$.

The assumptions rule out uninteresting cases. Specifically, Assumption 1(i) excludes the case in which information gathering is prohibitively expensive. If this assumption were violated, an agent would never gather information and the optimal mode of provision would depend only on straightforward technological considerations; i.e., a public-private partnership would be preferred whenever Δ is positive. Moreover, if Assumption 1(ii) were violated, it turns out that the second-stage service improvement would never be implemented given a public-private partnership.

The first-best benchmark. Consider for a moment a first-best world in which the effort decisions and the information gathered are verifiable. Then the choice between a public-private partnership and traditional procurement is based on their technological

[10] Note that at date 0, the parties are symmetrically informed, so that an agent will always accept a contract that ensures that his expected payoff is at least equal to his reservation utility zero.

[11] The precise date of the contract offer to agent 2 is irrelevant, as long as it is made until date 4.

(dis-)advantages only. Hence, if $\Delta > 0$ a public-private partnership is chosen, if $\Delta < 0$ traditional procurement is chosen, and if $\Delta = 0$ the mode of provision is irrelevant.

Consider the case in which a public-private partnership is optimal, $\Delta \geq 0$. Suppose first that $b \geq c_h$. Then no information gathering occurs,[12] and at date 1 the first-best effort level is $e^{FB} = \arg\max e(b - E[c]) + (1-e)(b - c_h) - \frac{1}{2}e^2 = c_h - E[c]$. Next, suppose that $E[c] < b < c_h$ which implies that the stage-2 improvement will not be implemented if no innovation was made ($x = 0$). If $x = 1$, then information gathering is optimal whenever $p(b - c_l) - \gamma \geq b - E[c]$. Observe that in the case that information is gathered, the second-stage improvement is implemented only if $c = c_l$, so that the first-best date-2 effort level is $e^{FB} = p(b - c_l)$. In the case that, after an innovation, information gathering does not occur, the second-stage improvement is always implemented, such that $e^{FB} = b - E[c]$.

Consider now the case in which traditional procurement is optimal, $\Delta \leq 0$. Suppose that $b \geq c_h + \Delta$. Then no information is gathered, the second-stage service improvement is always implemented, and $e^{FB} = c_h - E[c]$. Next, suppose that $E[c] < b < c_h + \Delta$. If $p(b - c_l - \Delta) - \gamma \geq b - E[c] - \Delta$, then it is optimal to gather information and the stage-2 improvement is implemented whenever $c = c_l$, such that $e^{FB} = p(b - c_l - \Delta)$. Otherwise, information gathering does not take place, the stage-2 improvement is always implemented, and $e^{FB} = b - E[c] - \Delta$.

3 Public-private partnership

3.1 No innovation at date 2 ($x = 0$)

Suppose first that there was no success at date 2 ($x = 0$), so that the effort costs of implementing a second-stage service improvement are $c = c_h$. Note that then there is no scope for information gathering at date 3. At date 4, if $b \geq c_h$, the principal asks the agent to implement the stage-2 improvement and she offers him to reimburse him for his effort costs, $w_2^{PPP} = c_h$. The agent will always accept the offer. If $b < c_h$, then the improvement will not be implemented. Hence, if $x = 0$,

[12] Note that information gathering can be productive only if $b < c_h$. Otherwise, implementation of the improvement is known to be always ex post efficient, so that information gathering is a rent-seeking activity only. In different contexts, productive information gathering has been studied by Aghion and Tirole (1997), Lewis and Sappington (1997), Crémer, Khalil, and Rochet (1998a), Kessler (1998), and Khalil, Kim, and Shin (2006), while socially undesirable information gathering has been addressed by Crémer and Khalil (1992), Crémer, Khalil, and Rochet (1998b), Schmitz (2006), and Hoppe and Schmitz (2010b).

the implementation of the second-stage service improvement occurs whenever it is ex post efficient. At date 2, the principal's continuation payoff is $B - c_2 + [b - c_h]^+$, where $[b - c_h]^+ := \max\{b - c_h, 0\}$, and the agent's continuation payoff is zero.

3.2 An innovation at date 2 ($x = 1$)

Next, suppose that at date 2 there was a success ($x = 1$), so that $c = c_l$ with probability p and $c = c_h$ with probability $1 - p$. The agent will agree to implement the second-stage service improvement whenever the principal's offer w_2^{PPP} is weakly larger than his effort costs c (resp., his expected costs $E[c]$) if he is informed (resp., uninformed). Hence, at date 4, the principal will choose among the offers c_l, $E[c]$, and c_h only.

Lemma 1 *In equilibrium, at date 4 the principal chooses* $w_2^{PPP} \in \{c_l, E[c], c_h\}$*. Given that the agent is informed with probability* $\pi \in [0, 1]$*, the principal's expected date-5-profit is* $B - c_2 + \pi p[b - c_l]$ *if* $w_2^{PPP} = c_l$*, it is* $B - c_2 + (\pi p + 1 - \pi)[b - E[c]]$ *if* $w_2^{PPP} = E[c]$*, and it is* $B - c_2 + b - c_h$ *if* $w_2^{PPP} = c_h$*.*

Proof. If $0 \leq w_2^{PPP} < c_l$, then the agent would reject the offer and the principal's profit would be $B - c_2$. If $c_l \leq w_2^{PPP} < E[c]$, only an informed agent with costs $c = c_l$ would accept the offer, so that the best the principal can do is to offer $w_2^{PPP} = c_l$, yielding an expected profit of $B - c_2 + \pi p[b - c_l] \geq B - c_2 + \pi p[b - w_2^{PPP}]$. Since $b > c_l$, the offer $w_2^{PPP} = c_l$ also strictly dominates offers $w_2^{PPP} < c_l$. If $E[c] \leq w_2^{PPP} < c_h$, then both an uninformed agent and an informed agent with costs c_l would accept, so that the principal offers $w_2^{PPP} = E[c]$, which leads to an expected profit of $B - c_2 + (\pi p + 1 - \pi)[b - E[c]] \geq B - c_2 + (\pi p + 1 - \pi)[b - w_2^{PPP}]$. If $c_h \leq w_2^{PPP}$, then the offer would always be accepted and the principal chooses $w_2^{PPP} = c_h$, since $B - c_2 + b - c_h \geq B - c_2 + b - w_2^{PPP}$. ■

At date 3, the agent will mix between gathering and not gathering information and at date 4, the principal will mix between different offers. To see this, note that the agent can gain by gathering information only if he is offered $w_2^{PPP} = E[c]$ with strictly positive probability. Yet, if he always gathered information, the principal would never offer $E[c]$. Moreover, if the agent never gathered information, the principal would always offer $E[c]$, but then the agent's best response would be to gather information (due to Assumption 1(i)). Hence, in equilibrium the agent must be indifferent between gathering and not gathering information, and the principal must offer $w_2^{PPP} = E[c]$ with a probability strictly between zero and one.

Lemma 2 *In equilibrium, the probability that the agent gathers information at date 3 is* $0 < \pi < 1$.

Proof. First, suppose that π were equal to 1. Then the principal would never offer $w_2^{PPP} = E[c]$, because $w_2^{PPP} = c_l$ would yield a larger expected profit. But if the agent anticipated that the principal would offer either $w_2^{PPP} = c_l$ or $w_2^{PPP} = c_h$, he would have no incentive to undertake costly information gathering (since he could always reject the offer c_l and accept the offer c_h).

Next, suppose that π were equal to 0. Then the principal would offer $w_2^{PPP} = E[c]$, so that without information gathering the agent's expected date-5-payoff would be 0. Yet, if he deviated and gathered information, he would accept the offer if and only if $c = c_l$, so that his expected payoff would be larger, $p(E[c] - c_l) - \gamma > 0$. ■

Lemma 3 *There exists no equilibrium in which the principal plays a pure strategy; i.e., at date 4 she must mix between at least two of the three wage offers* c_l, $E[c]$, *and* c_h.

Proof. If the principal always offers $w_2^{PPP} = c_l$, then the agent could never earn a rent and would therefore never gather information ($\pi = 0$), which contradicts Lemma 2. If the principal always offers $w_2^{PPP} = E[c]$, the agent's payoff is 0 if he does not gather information, while it is $p(E[c] - c_l) - \gamma > 0$ otherwise, so the agent would always gather information ($\pi = 1$), contradicting Lemma 2. If the principal always offers $w_2^{PPP} = c_h$, then the agent would always accept without information gathering ($\pi = 0$), which is in contradiction to Lemma 2. ■

Let the probability that the principal offers $w_2^{PPP} = c_l$ be denoted by α_l and let α_h be the probability that she offers $w_2^{PPP} = c_h$ (hence, she offers $w_2^{PPP} = E[c]$ with probability $1 - \alpha_l - \alpha_h$).

If the principal's benefit b from implementing the second-stage service improvement is relatively small, the principal mixes between the offers c_l and $E[c]$. In this case, the expected second-stage rent of the agent is zero. To see this, recall that the agent must be indifferent between gathering and not gathering information. If the agent does not gather information, he will accept the offer $E[c]$ only, so that his expected effort costs will be reimbursed without leaving him a rent. In contrast, if the principal's benefit b is sufficiently large, she mixes between the offers c_h and $E[c]$. If now the agent does not gather information, he enjoys a rent when the offer is c_h and he is of the low type ($c = c_l$). Since the agent must be indifferent between gathering and not gathering information, his expected second-stage rent is hence $\alpha_h (c_h - E[c])$.

Proposition 1 *Let $\tilde{b} > c_h$ be implicitly defined by $\frac{(\tilde{b}-E[c])^2}{\tilde{b}-pc_l-(1-p)E[c]} = \frac{c_h-E[c]}{1-p}$.*

(i) If $E[c] < b < \tilde{b}$, then in equilibrium the agent gathers information with probability $\pi = \frac{b-E[c]}{b-pc_l-(1-p)E[c]}$ and the principal mixes between the wage offers $w_2^{PPP} = c_l$ and $w_2^{PPP} = E[c]$, where $\alpha_l = 1 - \frac{\gamma}{p(E[c]-c_l)}$. Hence, at date 2 the principal's expected continuation payoff is $B - c_2 + \Pi$, where $\Pi := \frac{b-E[c]}{b-pc_l-(1-p)E[c]}p[b-c_l]$, and the agent's expected continuation payoff is 0.

(ii) If $b \geq \tilde{b}$, then in equilibrium the agent gathers information with probability $\pi = \frac{c_h-E[c]}{(1-p)(b-E[c])}$ and the principal mixes between the wage offers $w_2^{PPP} = c_h$ and $w_2^{PPP} = E[c]$, where $\alpha_h = 1 - \frac{\gamma}{p(E[c]-c_l)}$. Thus, at date 2 the principal's expected continuation payoff is $B - c_2 + b - c_h$ and the agent's expected continuation payoff is $\alpha_h (c_h - E[c]) = c_h - E[c] - \frac{\gamma}{1-p}$.

Proof. Note that $\frac{d}{db}\frac{(b-E[c])^2}{b-pc_l-(1-p)E[c]} = \frac{(b-E[c])^2+2p(b-E[c])(E[c]-c_l)}{(b-pc_l-(1-p)E[c])^2}$ is strictly positive for $b > E[c]$. Hence, the LHS of $\frac{(b-E[c])^2}{b-pc_l-(1-p)E[c]} = \frac{c_h-E[c]}{1-p}$ is strictly increasing in b for $b > E[c]$. Moreover, the LHS is smaller than the RHS for $b = c_h$ and it goes to infinity for $b \to \infty$, so that given continuity there must exist a unique $\tilde{b} > c_h$.

Recall that the case $\alpha_l + \alpha_h = 1$ cannot occur in equilibrium, since the agent would have no incentives to gather information (see Lemma 2). Hence, according to Lemma 3, the principal must be indifferent between offering c_l and $E[c]$ or between offering c_h and $E[c]$.

(i) According to Lemma 1, the principal's expected profit given the offer $w_2^{PPP} = c_l$ is $B - c_2 + \pi p[b - c_l]$ and her expected profit given the offer $w_2^{PPP} = E[c]$ is $B - c_2 + (\pi p + 1 - \pi)[b - E[c]]$. Hence, she is indifferent between the offers c_l and $E[c]$ if the agent gathers information with probability $\pi = \frac{b-E[c]}{b-pc_l-(1-p)E[c]} \in (0,1)$. Moreover, an offer of $E[c]$ is more profitable than offering $w_2^{PPP} = c_h$ (yielding an expected profit $B - c_2 + b - c_h$) if $\pi \leq \frac{c_h-E[c]}{(1-p)(b-E[c])}$. Given that $\pi = \frac{b-E[c]}{b-pc_l-(1-p)E[c]}$, the latter condition is equivalent to $b \leq \tilde{b}$.

In equilibrium, the principal must mix between the offers c_l and $E[c]$ such that the agent is indifferent between gathering and not gathering information. Suppose the agent does not gather information. Then he will accept the principal's offer only if it is $w_2^{PPP} = E[c]$, so that his expected payoff is 0. Next, suppose the agent gathers information. Then he will accept the principal's offer whenever he is of the low type $c = c_l$, such that his expected payoff is $p(1 - \alpha_l)(E[c] - c_l) - \gamma$. Hence, the agent is indifferent between gathering and not gathering information if $\alpha_l = 1 - \frac{\gamma}{p(E[c]-c_l)}$.

(ii) The principal's expected profit when she offers $w_2^{PPP} = E[c]$ is $B - c_2 + (\pi p + 1 - \pi)[b - E[c]]$, while her expected profit given $w_2^{PPP} = c_h$ is $B - c_2 + b - c_h$. Thus, she is indifferent between offering $E[c]$ and c_h if the agent gathers information with probability $\pi = \frac{c_h - E[c]}{(1-p)(b-E[c])} > 0$. Note that $\pi < 1$ whenever $b > \frac{c_h - pE[c]}{1-p}$, which is always the case if $b \geq \tilde{b}$. In order to see this, one can check that $\frac{(b-E[c])^2}{b-pc_l-(1-p)E[c]} < \frac{c_h - E[c]}{1-p}$ for $b = \frac{c_h - pE[c]}{1-p}$.

Moreover, an offer of $E[c]$ is more profitable than offering $w_2^{PPP} = c_l$ (which yields an expected profit $B - c_2 + \pi p[b - c_l]$) if $\pi \leq \frac{b-E[c]}{b-pc_l-(1-p)E[c]}$. Given that $\pi = \frac{c_h - E[c]}{(1-p)(b-E[c])}$, the latter condition is equivalent to $b \geq \tilde{b}$.

We now characterize how in equilibrium the principal must mix between c_h and $E[c]$. Suppose the agent does not gather information. Then he will always accept the principal's offer, so that his expected payoff is $\alpha_h (c_h - E[c])$. Next, suppose the agent gathers information. Then he will always accept the principal's offer except when he is of the high type ($c = c_h$) and the offer is $w_2^{PPP} = E[c]$. Hence, his expected payoff is $p[\alpha_h c_h + (1-\alpha_h)E[c] - c_l] - \gamma$. The agent is indifferent between gathering and not gathering information if $\alpha_h = 1 - \frac{\gamma}{p(E[c]-c_l)}$.

Finally, in the special case where $b = \tilde{b}$, the principal is indifferent between offering c_l, $E[c]$, and c_h when the agent gathers information with probability $\pi = \frac{c_h - E[c]}{(1-p)(b-E[c])}$. In this case, there are multiple equilibria. The principal offers $E[c]$ with probability $\frac{\gamma}{p(E[c]-c_l)}$, while the probabilities that she offers c_l or c_h must add up to $1 - \frac{\gamma}{p(E[c]-c_l)}$. Note that in all equilibria the principal makes the same expected profit, while the equilibrium in which $\alpha_h = 1 - \frac{\gamma}{p(E[c]-c_l)}$ is the best one for the agent, so that we assume that they coordinate on the latter one. ■

Observe that the probability with which the agent gathers information is a function of the principal's benefit b, since the agent's behavior must ensure that the principal is indifferent between making different offers. Specifically, consider the case where the benefit b is relatively small ($b < \tilde{b}$), such that the principal mixes between the offers c_l and $E[c]$. Suppose now that b increases, which implies that the offer $E[c]$ would become more attractive for the principal (since the offer c_l is more often rejected than the offer $E[c]$) if the agent did not change his information gathering probability. Hence, the agent must increase the information gathering probability, which in turn increases the attractiveness of the offer c_l, since in case of an informed agent both offers are accepted with probability p. Next, consider the case where the benefit b is relatively large ($b \geq \tilde{b}$), so that the principal mixes between the offers $E[c]$ and c_h. If b increases, the principal would prefer to offer c_h (which is always accepted), unless the agent decreases his information gathering probability (since in case of an uninformed agent, both offers $E[c]$ and c_h are accepted).

Note also that the probability with which the principal mixes between her offers is a function of the agent's information gathering costs γ, because the offers must be such that the agent is indifferent between gathering and not gathering information. In particular, when it becomes more expensive to gather information (γ increases), information gathering must become more useful, which is the case if the probability of an offer $E[c]$ increases.

Finally, consider the principal's expected profit $B - c_2 + \Pi$ in the case that the benefit is relatively small, $b < \tilde{b}$, such that the principal mixes between the offers c_l and $E[c]$. Note that $B - c_2 + \Pi$ must be larger than the profit $B - c_2 + b - c_h$ that she would make if she made the offer c_h. Moreover, $\Pi < b - E[c]$ must hold, because the principal's expected profit is $B - c_2 + \Pi$, regardless of whether she offers c_l or $E[c]$, and an offer of $E[c]$ is not always accepted by the agent.

Remark 1 *(i) If $E[c] < b < \tilde{b}$, then the probability π that the agent gathers information is increasing in b.*

(ii) If $b \geq \tilde{b}$, then the probability π that the agent gathers information is decreasing in b.

(iii) The probability with which the principal makes the offer $E[c]$ is increasing in the agent's information gathering costs γ.

(iv) $b - c_h < \Pi < b - E[c]$.

Proof. The proof is straightforward. ■

3.3 The effort decision at date 1

Consider now the agent's effort decision at date 1. Observe that the agent can be motivated to exert effort for two different reasons. First, the principal can directly reward the agent by offering to pay him a bonus $w_1^{PPP} > 0$ in case an innovation is made ($x = 1$). Second, investment incentives can arise indirectly when the agent anticipates to enjoy a second-stage rent whenever he comes up with an innovation in the first stage. Recall that if the principal's benefit b from implementing the second-stage service improvement is relatively small ($b < \tilde{b}$), then the agent does not obtain a second-stage rent. Yet, in this case the principal will offer a direct reward, because her expected second-stage profit when an innovation is made is $B - c_2 + \Pi$, which is larger than $B - c_2 + [b - c_h]^+$, her profit when there was no innovation. In contrast, if b is sufficiently large ($b \geq \tilde{b}$), the principal's (expected) second-stage profit is always $B - c_2 + b - c_h$, regardless of whether or not there was an innovation in the first stage. This implies that the principal offers the agent no direct reward ($w_1^{PPP} = 0$). However, the agent exerts effort at date 1 because of the prospect to earn the expected second-stage rent $c_h - E[c] - \frac{\gamma}{1-p}$ when he comes up with an innovation at date 2.

Proposition 2 *(i) If $E[c] < b < \tilde{b}$, then the principal offers a bonus $w_1^{PPP} = \frac{1}{2}\left(\Pi - [b - c_h]^+\right)$, so that at date 1 the agent chooses the effort level $e_i^{PPP} = w_1^{PPP}$. The expected payoffs at date 0 are $B - c_1 - c_2 + [b - c_h]^+ + \left(e_i^{PPP}\right)^2$ for the principal and $\frac{1}{2}\left(e_i^{PPP}\right)^2$ for the agent. Thus, the expected welfare is $B - c_1 - c_2 + [b - c_h]^+ + \frac{3}{2}\left(e_i^{PPP}\right)^2$.*

(ii) If $b \geq \tilde{b}$, then the principal offers no direct reward for an innovation ($w_1^{PPP} = 0$). At date 1, the agent chooses $e_{ii}^{PPP} = c_h - E[c] - \frac{\gamma}{1-p}$. The expected payoffs at date 0 are $B - c_1 - c_2 + b - c_h$ for the principal and $\frac{1}{2}(e_{ii}^{PPP})^2$ for the agent. Hence, the expected welfare is $B - c_1 - c_2 + b - c_h + \frac{1}{2}(e_{ii}^{PPP})^2$.

Proof. (i) In this case, the agent obtains no rent in the second stage. Hence, given that the principal has offered to pay him a bonus $w_1^{PPP} \geq 0$ whenever an innovation is made ($x = 1$), at date 1 the agent chooses $e_i^{PPP} = \arg\max_{e \in [0,1]} e w_1^{PPP} - \frac{1}{2}e^2 = \min\{w_1^{PPP}, 1\}$. Note that the principal will never choose $w_1^{PPP} > 1$, hence $e_i^{PPP} = w_1^{PPP}$. Recall that the principal's continuation payoff if $x = 1$ is $B - c_2 + \Pi$, while it is $B - c_2 + [b - c_h]^+$ if $x = 0$. The principal thus offers the bonus w_1^{PPP} that maximizes her expected profit $B - c_1 - c_2 + w_1^{PPP}\left(\Pi - w_1^{PPP}\right) + (1 - w_1^{PPP})[b - c_h]^+$, so that $w_1^{PPP} = \frac{1}{2}\left(\Pi - [b - c_h]^+\right)$. Note that $w_1^{PPP} < 1$, because $\Pi - [b - c_h]^+ < b - E[c] - [b - c_h]^+ \leq c_h - E[c] < 1$. The payoffs then follow immediately.

(ii) In this case, the principal's expected continuation payoff is $B - c_2 + b - c_h$ regardless of whether or not there was a success. Hence, at date 0 the principal will not offer a bonus to the agent for an innovation ($w_1^{PPP} = 0$). However, the agent still has incentives to exert effort since if $x = 1$ he expects to get the second-stage rent $c_h - E[c] - \frac{\gamma}{1-p}$. Thus, the agent chooses $e_{ii}^{PPP} = \arg\max e\left(c_h - E[c] - \frac{\gamma}{1-p}\right) - \frac{1}{2}e^2 = c_h - E[c] - \frac{\gamma}{1-p}$. The payoffs again follow immediately. ■

4 Traditional procurement

In the second stage, agent 2 provides a basic version of the good or service. In addition, if there was no innovation in the first stage ($x = 0$), then at date 4, whenever $b \geq c_h + \Delta$, the principal will offer agent 2 the payment $w_2^{TP} = c_h + \Delta$ for implementing the second-stage service improvement. The agent will accept the offer as he is reimbursed for his effort costs. If agent 1 came up with an innovation in the first stage ($x = 1$), then whenever $b \geq E[c] + \Delta$, the principal will offer agent 2 the payment $w_2^{TP} =$

$E[c] + \Delta$ for implementation of the service improvement. Agent 2 will accept the offer since he is uninformed about the realization of c.

Consider next agent 1's incentives to exert effort at date 1. Under traditional procurement, agent 1 knows that he will not be in charge of task 2 in the second stage, and hence he can be incentivized to exert effort only by the bonus payment w_1^{TP}. Moreover, knowing that the information he can gather is not relevant for him, agent 1 does not engage in costly information gathering.

Proposition 3 *At date 0, the principal offers the bonus* $w_1^{TP} = \frac{1}{2}([b - E[c] - \Delta]^+ - [b - c_h - \Delta]^+)$. *At date 1, the agent chooses the effort level* $e^{TP} = w_1^{TP}$. *The expected payoffs at date 0 are* $B - c_1 - c_2 + [b - c_h - \Delta]^+ + (e^{TP})^2$ *for the principal,* $\frac{1}{2}(e^{TP})^2$ *for agent 1, and* 0 *for agent 2. Thus, the expected welfare is* $B - c_1 - c_2 + [b - c_h - \Delta]^+ + \frac{3}{2}(e^{TP})^2$.

Proof. At date 1, agent 1 chooses $e^{TP} = \arg\max_{e\in[0,1]} ew_1^{TP} - \frac{1}{2}e^2 = \min\{w_1^{TP}, 1\}$. The principal will offer a bonus $w_1^{TP} \leq 1$, so that $e^{TP} = w_1^{TP}$. In particular, she sets $w_1^{TP} = \arg\max w_1 \left([b - E[c] - \Delta]^+ - w_1\right) + (1 - w_1)\,[b - c_h - \Delta]^+$. Hence, $e^{TP} = \frac{1}{2}\left([b - E[c] - \Delta]^+ - [b - c_h - \Delta]^+\right)$. Note that $0 \leq e^{TP} < 1$. The payoffs then follow immediately. ■

5 Public-private partnership versus traditional procurement

We can now analyze the principal's date-0 decision regarding the mode of provision. Suppose first that traditional procurement has no technological (dis-)advantages compared to a public-private partnership; i.e., $\Delta = 0$. Then due to incentive considerations, the principal will always prefer traditional procurement. To see this, consider first the case where the benefit b is relatively small ($b < \tilde{b}$), so that given a public-private partnership, the agent would not get a second-stage rent. This means that under both modes of provision, the principal extracts the (expected) total surplus generated in stage 2. While for $x = 0$ this surplus is $B - c_2 + [b - c_h]^+$ under both modes, for $x = 1$ it is $B - c_2 + b - E[c]$ under traditional procurement, but it is only $B - c_2 + \Pi$ given a public-private partnership. Hence, if under traditional procurement the principal set the same bonus w_1 as in case of a public-private partnership (thereby inducing the same first-stage effort level), she would be better off under traditional procurement. Moreover, she can increase her expected profit under traditional procurement even further by inducing $e^{TP} > e_i^{PPP}$.

Consider now the case where the benefit b is relatively large ($b \geq \tilde{b}$). Given a public-private partnership, the principal's second-stage payoff is $B - c_2 + b - c_h$ regardless of whether an innovation was made or not. In contrast, under traditional procurement, the principal's second-stage payoff is $B - c_2 + b - c_h$ if no innovation was made, while it is $B - c_2 + b - E[c]$ otherwise. Hence, if the principal set the first-stage bonus w_1^{TP} equal to zero, her expected profit would be the same under both modes of provision. Actually, the principal sets $w_1^{TP} > 0$, such that her expected profit under traditional procurement is strictly larger.

Given that the principal prefers traditional procurement when technological matters are not relevant, she finds this mode of provision even more attractive when it comes along with technological advantages (i.e., when $\Delta < 0$). On the other hand, if traditional procurement is accompanied by sufficiently strong technological disadvantages (i.e., when Δ is larger than a critical value $\tilde{\Delta} > 0$), then the principal prefers a public-private partnership. Note that $\tilde{\Delta} < b - E[c]$, because if $\Delta \geq b - E[c]$, the principal could never benefit from implementation of the second-stage improvement under traditional procurement, while given a public-private partnership, she benefits from the fact that the improvement is implemented with strictly positive probability.

Proposition 4 *There exists a unique cut-off value $\tilde{\Delta} \in (0, b - E[c])$ such that the principal prefers a public-private partnership for $\Delta \geq \tilde{\Delta}$ and traditional procurement otherwise.*

Proof. (i) Consider the case $E[c] < b < \tilde{b}$. According to Propositions 2 and 3, the principal's expected profit is larger in case of a public-private partnership than in case of traditional procurement if $D_i^{pr}(\Delta) := [b - c_h]^+ + \frac{1}{4}\left(\Pi - [b - c_h]^+\right)^2 - [b - c_h - \Delta]^+ - \frac{1}{4}([b - E[c] - \Delta]^+ - [b - c_h - \Delta]^+)^2 \geq 0$. Note that $D_i^{pr}(\Delta) = [b - c_h]^+ + \frac{1}{4}\left(\Pi - [b - c_h]^+\right)^2 - [b - c_h - \Delta] - \frac{1}{4}(c_h - E[c])^2$ for $\Delta \leq b - c_h$, $D_i^{pr}(\Delta) = [b - c_h]^+ + \frac{1}{4}\left(\Pi - [b - c_h]^+\right)^2 - \frac{1}{4}(b - E[c] - \Delta)^2$ for $b - c_h < \Delta \leq b - E[c]$, and $D_i^{pr}(\Delta) = [b - c_h]^+ + \frac{1}{4}\left(\Pi - [b - c_h]^+\right)^2$ for $\Delta > b - E[c]$.

Observe that $D_i^{pr}(0) < 0$. To see this, note that $\Pi < b - E[c]$ and hence $D_i^{pr}(0) = \frac{1}{4}\left(\Pi - [b - c_h]\right)^2 - \frac{1}{4}(c_h - E[c])^2 < 0$ if $b \geq c_h$ and $D_i^{pr}(0) = \frac{1}{4}\Pi^2 - \frac{1}{4}(b - E[c])^2 < 0$ if $b < c_h$. Moreover, observe that $D_i^{pr}(b - E[c]) = [b - c_h]^+ + \frac{1}{4}\left(\Pi - [b - c_h]^+\right)^2 > 0$. Furthermore, $D_i^{pr}(\Delta)$ is continuous and strictly increasing for $\Delta < b - E[c]$. Thus, there exists a unique $\tilde{\Delta}$ such that $D_i^{pr}(\tilde{\Delta}) = 0$, so that the claim follows immediately from a straightforward intermediate value argument.

(ii) Consider the case $b \geq \tilde{b}$. The principal prefers a public-private partnership if $D_{ii}^{pr}(\Delta) := b - c_h - [b - c_h - \Delta]^+ - \frac{1}{4}([b - E[c] - \Delta]^+ - [b - c_h - \Delta]^+)^2 \geq 0$. Observe that $D_{ii}^{pr}(\Delta) = \Delta - \frac{1}{4}(c_h - E[c])^2$ for $\Delta \leq b - c_h$, $D_{ii}^{pr}(\Delta) = b - c_h - \frac{1}{4}(b - E[c] - \Delta)^2$ for $b - c_h < \Delta \leq b - E[c]$, and $D_{ii}^{pr}(\Delta) = b - c_h$ for $\Delta > b - E[c]$. Note that $D_{ii}^{pr}(0) = -\frac{1}{4}(c_h - E[c])^2 < 0$ and $D_{ii}^{pr}(b - E[c]) = b - c_h > 0$. Moreover, $D_{ii}^{pr}(\Delta)$ is continuous and strictly increasing for $\Delta < b - E[c]$. Hence, there exists a unique $\tilde{\Delta}$ such that $D_{ii}^{pr}(\tilde{\Delta}) = 0$ and the claim follows immediately. ■

We now investigate which one of the two modes of provision leads to a larger expected welfare (measured by the parties' expected total surplus). Consider first the case in which the benefit b is relatively small, $b < \tilde{b}$. In this case, if neither mode of provision brings about technological (dis-)advantages ($\Delta = 0$), traditional procurement yields a larger welfare. To see this, recall that we already know that in this case the principal's expected profit is larger under traditional procurement. Moreover, regardless of the mode of provision, the agent cannot earn a second-stage rent, while the first-stage rent under traditional procurement is larger than under a public-private partnership, since $e^{TP} > e_i^{PPP}$. Hence, a public-private partnership leads to a larger welfare only if the technological disadvantage of traditional procurement, Δ, is larger than a critical value $\bar{\Delta} > 0$. Note that $\bar{\Delta} < b - E[c]$, because if $\Delta \geq b - E[c]$, the principal could never benefit from implementing the stage-2 improvement under traditional procurement, implying $e^{TP} = 0$ and thus a rent of zero, so that under a public-private partnership the agent is better off and, according to Proposition 4, the principal makes a larger profit.

Next, consider the case in which the benefit is relatively large, $b \geq \tilde{b}$. Now a public-private partnership can yield a larger welfare even in the absence of any technological (dis-)advantages. If $\Delta = 0$, the principal is better off under traditional procurement, but this may be overcompensated by the fact that the agent's rent given a public-private partnership can be larger than the agents' rent under traditional procurement. This is because in the case $b \geq \tilde{b}$, the public-private partnership effort level e_{ii}^{PPP} (which is motivated by the prospect to earn the second-stage rent $c_h - E[c] - \frac{\gamma}{1-p}$) is larger than the effort level under traditional procurement e^{TP} (which is induced by the first-stage bonus payment) whenever the information gathering costs are sufficiently small (such that the expected second-stage rent is large).[13]

Observe that given a public-private partnership, the agent's rent is decreasing in γ. Since the principal's profit is independent of γ, the expected welfare given a public-private partnership is decreasing in γ as well. Hence, the larger is γ, the larger has to be the technological disadvantage of traditional procurement, Δ, for a public-private

[13] Specifically, if $\Delta = 0$, then $e_{ii}^{PPP} > e^{TP}$ whenever $\gamma < \frac{1}{2}(1-p)(c_h - E[c])$.

partnership to yield a larger welfare level.

Proposition 5 *(i) Consider the case $E[c] < b < \tilde{b}$. There exists a unique cut-off value $\bar{\Delta} \in (0, b - E[c])$ such that a public-private partnership yields a larger expected welfare level than traditional procurement if and only if $\Delta \geq \bar{\Delta}$.*

(ii) Consider the case $b \geq \tilde{b}$. There exists an increasing threshold function $\bar{\Delta}(\gamma)$ such that a public-private partnership leads to a larger expected welfare than traditional procurement if and only if $\Delta \geq \bar{\Delta}(\gamma)$.

Proof. (i) The expected welfare given a public-private partnership is larger than under traditional procurement if $D_i^{wf}(\Delta) := [b - c_h]^+ + \frac{3}{8}\left(\Pi - [b - c_h]^+\right)^2 - [b - c_h - \Delta]^+ - \frac{3}{8}([b - E[c] - \Delta]^+ - [b - c_h - \Delta]^+)^2 \geq 0$. Note that $D_i^{wf}(\Delta) = [b - c_h]^+ + \frac{3}{8}\left(\Pi - [b - c_h]^+\right)^2 - [b - c_h - \Delta] - \frac{3}{8}(c_h - E[c])^2$ for $\Delta \leq b - c_h$, $D_i^{wf}(\Delta) = [b - c_h]^+ + \frac{3}{8}\left(\Pi - [b - c_h]^+\right)^2 - \frac{3}{8}(b - E[c] - \Delta)^2$ for $b - c_h < \Delta \leq b - E[c]$, and $D_i^{wf}(\Delta) = [b - c_h]^+ + \frac{3}{8}\left(\Pi - [b - c_h]^+\right)^2$ for $\Delta > b - E[c]$.

Note that $D_i^{wf}(0) < 0$. To see this, observe that $\Pi < b - E[c]$ and thus $D_i^{wf}(0) = \frac{3}{8}\left(\Pi - [b - c_h]\right)^2 - \frac{3}{8}(c_h - E[c])^2 < 0$ if $b \geq c_h$ and $D_i^{wf}(0) = \frac{3}{8}\Pi^2 - \frac{3}{8}(b - E[c])^2 < 0$ if $b < c_h$. Moreover, notice that $D_i^{wf}(b - E[c]) = [b - c_h]^+ + \frac{3}{8}\left(\Pi - [b - c_h]^+\right)^2 > 0$. Furthermore, $D_i^{wf}(\Delta)$ is continuous and strictly increasing for $\Delta < b - E[c]$. Hence, there exists a unique $\bar{\Delta}$ such that $D_i^{wf}(\bar{\Delta}) = 0$, so that the claim follows immediately.

(ii) Given Propositions 2 and 3, a public-private partnership leads to a larger expected welfare than traditional procurement if $D_{ii}^{wf}(\Delta, \gamma) := b - c_h + \frac{1}{2}(c_h - E[c] - \frac{\gamma}{1-p})^2 - [b - c_h - \Delta]^+ - \frac{3}{8}([b - E[c] - \Delta]^+ - [b - c_h - \Delta]^+)^2 \geq 0$. Observe that $D_{ii}^{wf}(\Delta, \gamma) = \Delta + \frac{1}{2}(c_h - E[c] - \frac{\gamma}{1-p})^2 - \frac{3}{8}(c_h - E[c])^2$ for $\Delta \leq b - c_h$, $D_{ii}^{wf}(\Delta, \gamma) = b - c_h + \frac{1}{2}(c_h - E[c] - \frac{\gamma}{1-p})^2 - \frac{3}{8}(b - E[c] - \Delta)^2$ for $b - c_h < \Delta \leq b - E[c]$, and $D_{ii}^{wf}(\Delta, \gamma) = b - c_h + \frac{1}{2}(c_h - E[c] - \frac{\gamma}{1-p})^2$ for $\Delta > b - E[c]$.

Consider any given $\gamma \in (0, p(E[c] - c_l))$. Note that $D_{ii}^{wf}(\Delta, \gamma)$ is continuous and strictly increasing in Δ for $\Delta < b - E[c]$. Moreover, $D_{ii}^{wf}(b - E[c], \gamma) > 0$ and $D_{ii}^{wf}(\Delta, \gamma) < 0$ for Δ sufficiently small. Hence, there exists a $\bar{\Delta}(\gamma)$ such that $D_{ii}^{wf}(\bar{\Delta}(\gamma), \gamma) = 0$. Observe that if $\bar{\Delta}(\gamma) \leq -c_l$, then a public-private partnership leads to a larger expected welfare than traditional procurement for all admissible values of Δ. On the other hand, if $\bar{\Delta}(\gamma) > -c_l$, then there exist admissible values $\Delta < \bar{\Delta}(\gamma)$ such that traditional procurement leads to a larger expected welfare than a public-private partnership.

Next, we want to show that $\bar{\Delta}(\gamma)$ is strictly increasing for all $\gamma \in (0, p(E[c] - c_l))$. To see this, observe that $D_{ii}^{wf}(\Delta, \gamma)$ is strictly decreasing in γ for all $\gamma \in (0, p(E[c] -$

c_l)). Now consider $\gamma_1 < \gamma_2$, so that $D_{ii}^{wf}(\bar{\Delta}(\gamma_1), \gamma_1) = 0 > D_{ii}^{wf}(\bar{\Delta}(\gamma_1), \gamma_2)$. Since $D_{ii}^{wf}(\bar{\Delta}(\gamma_2), \gamma_2) = 0$ and $D_{ii}^{wf}(\Delta, \gamma)$ is strictly increasing in Δ, this implies that $\bar{\Delta}(\gamma_1) < \bar{\Delta}(\gamma_2)$. ■

Consider the case where the benefit is relatively small, $b < \tilde{b}$. From Propositions 4 and 5 we know that traditional procurement (resp., a public-private partnership) is better for the principal and also for the welfare level if $\Delta \leq 0$ (resp., $\Delta \geq b - E[c]$). Hence, consider now $\Delta \in (0, b - E[c])$.

Suppose first that neither mode of provision leads to technological (dis-)advantages ($\Delta = 0$). We have already seen that in this case, the principal's expected profit as well as agent 1's expected rent are larger under traditional procurement, so that compared to a public-private partnership, traditional procurement is even more attractive from a welfare perspective than from the principal's point of view. Now consider traditional procurement and an increase in Δ, which reduces the principal's profit, while with regard to agent 1's rent, two cases have to be distinguished.

If $b \leq c_h$, then the principal implements the second-stage improvement if and only if there was an innovation at date 2 (because otherwise the implementation would cost her $c_h + \Delta > b$). But this implies that Δ will be incurred if and only if $x = 1$, so that the marginal return of the agent's date-1 effort and hence also his rent decrease in Δ. Hence, when $\Delta = 0$, the welfare gap between traditional procurement and a public-private partnership is larger than the profit gap, while the former shrinks faster than the latter when Δ increases. In fact, these two aspects offset each other, such that the critical values of Δ above which traditional procurement becomes inferior from a profit and a welfare perspective coincide.[14]

If $b > c_h$, the agent's rent is independent of Δ as long as $\Delta \leq b - c_h$. To see this, observe that then under traditional procurement, the principal implements the stage-2 improvement regardless of whether or not there was an innovation at date 2. Hence, the additional costs Δ will be incurred in any situation such that the marginal return of the agent 1's effort and thus his rent do not depend on Δ. As a consequence, when Δ increases, the welfare gap and the profit gap between traditional procurement

[14] Specifically, if no innovation is made, the principal's second-stage profit under both modes of provision is $B - c_2$. If an innovation is made, the principal's second-stage profit under traditional procurement is $B - c_2 + b - E[c] - \Delta$, while it is $B - c_2 + \Pi$ given a public-private partnership. Hence, whenever $\Delta < b - E[c] - \Pi$, the principal is better off under traditional procurement, and she will induce a larger first-stage effort level by offering a bonus $w_1^{TP} > w_1^{PPP}$, implying first-stage rents $\frac{1}{2}(e^{TP})^2 > \frac{1}{2}(e_i^{PPP})^2$. Thus, in this case, whenever the principal prefers traditional procurement, this mode of provision also yields a larger welfare.

and a public-private partnership shrink by the same amount; but since the former is larger than the latter, there are values of Δ such that the principal already prefers a public-private partnership, while the welfare level is still larger under traditional procurement (see Figure 2).

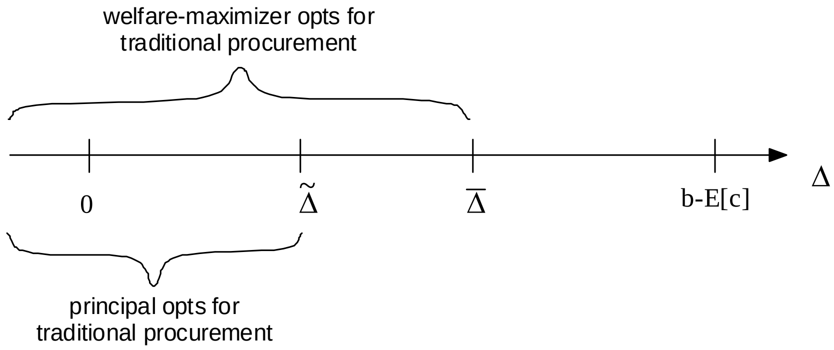

Figure 2. In the region $\Delta \in (\tilde{\Delta}, \bar{\Delta})$, the principal's preferred mode of provision deviates from the welfare-maximizer's choice.

Consider now the case where the benefit is relatively large, $b \geq \tilde{b}$. In this case there do not only exist situations in which the principal prefers a public-private partnership while traditional procurement is desirable from a welfare perspective, but there exist also situations in which the principal is better off under traditional procurement, while expected welfare is larger given a public-private partnership. As an illustration, consider Figure 3. Recall that the principal prefers a public-private partnership whenever $\Delta > \tilde{\Delta}$, while the welfare level is larger given a public-private partnership whenever $\Delta > \bar{\Delta}(\gamma)$. We already know that for $\Delta = 0$, the principal prefers traditional procurement regardless of the information gathering costs γ. But if γ is small, then given a public-private partnership the effort level and the agent's rent are relatively large, so that even for $\Delta = 0$ a public-private partnership may yield a larger welfare level. Yet, if γ increases, the agent's rent given a public-private partnership and hence its welfare advantage decrease such that region I, in which the principal's preferred decision to choose traditional procurement would be overruled by a welfare-maximizer, shrinks. If the information gathering costs are sufficiently large ($\gamma > \hat{\gamma}$), there exist again values of Δ such that the principal prefers a public-private partnership, while traditional procurement yields a larger welfare level (region II).

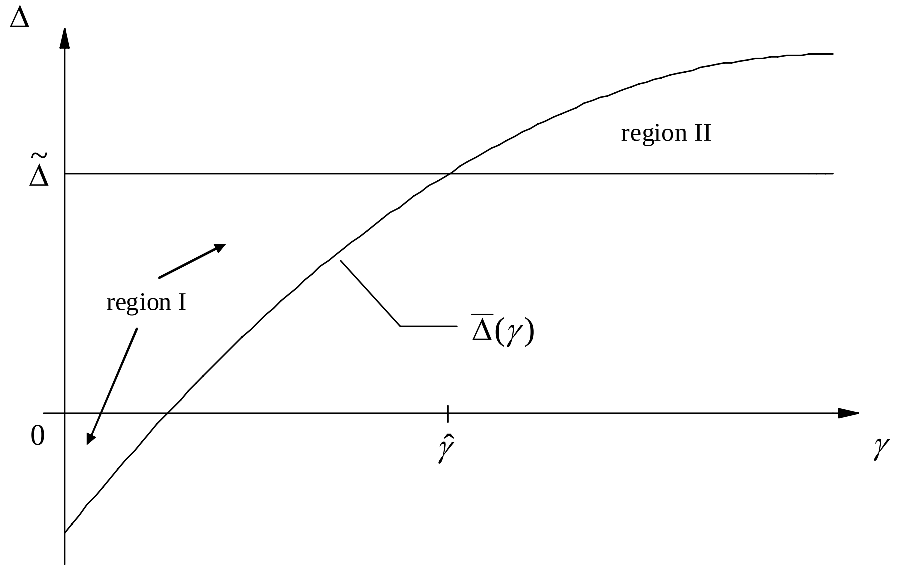

Figure 3. The principal opts for a public-private partnership for $\Delta \geq \tilde{\Delta}$, while a welfare-maximizer opts for a public-private partnership for $\Delta \geq \bar{\Delta}(\gamma)$.

Proposition 6 *(i) Consider the case $E[c] < b < \tilde{b}$. If $b \leq c_h$, then $\tilde{\Delta} = \bar{\Delta} = b - E[c] - \Pi$, so that the principal prefers a public-private partnership (resp., traditional procurement) whenever the expected welfare is larger given a public-private partnership (resp., traditional procurement). If $b > c_h$, then $\tilde{\Delta} < \bar{\Delta}$, so that for $\Delta \in (\tilde{\Delta}, \bar{\Delta})$ the principal prefers a public-private partnership while expected welfare would be larger given traditional procurement.*

(ii) Consider the case $b \geq \tilde{b}$. There exists a critical value $\hat{\gamma}$ defined by $\bar{\Delta}(\hat{\gamma}) = \tilde{\Delta}$. If $\gamma < \hat{\gamma}$, then $\bar{\Delta}(\gamma) < \tilde{\Delta}$, so that for $\Delta \in (\bar{\Delta}(\gamma), \tilde{\Delta})$ the principal prefers traditional procurement while expected welfare would be larger given a public-private partnership. If $\gamma > \hat{\gamma}$, then $\tilde{\Delta} < \bar{\Delta}(\gamma)$, so that for $\Delta \in (\tilde{\Delta}, \bar{\Delta}(\gamma))$ the principal prefers a public-private partnership while expected welfare would be larger given traditional procurement.

Proof. (i) Consider first the case $b \leq c_h$. Recall that $\tilde{\Delta} > 0$ and $\bar{\Delta} > 0$. Thus, $D_i^{pr}(\Delta) = \frac{2}{3} D_i^{wf}(\Delta) = \frac{1}{4}\Pi^2 - \frac{1}{4}(b - E[c] - \Delta)^2$, so that $\tilde{\Delta} = \bar{\Delta} = b - E[c] - \Pi$.

Consider next the case $b > c_h$. Note that $\tilde{\Delta} \in (0, b - c_h)$ if $D_i^{pr}(b - c_h) = b - c_h + \frac{1}{4}\left(\Pi - [b - c_h]\right)^2 - \frac{1}{4}(c_h - E[c])^2 > 0$, and $\tilde{\Delta} \in [b - c_h, b - E(c))$ otherwise. Moreover, $\bar{\Delta} \in (0, b - c_h)$ if $D_i^{wf}(b - c_h) = b - c_h + \frac{3}{8}\left(\Pi - [b - c_h]\right)^2 - \frac{3}{8}(c_h - E[c])^2 > 0$, and $\bar{\Delta} \in [b - c_h, b - E(c))$ otherwise. Observe that $D_i^{pr}(b - c_h) > D_i^{wf}(b - c_h)$.

Now suppose $D_i^{wf}(b - c_h) > 0$, which implies $D_i^{pr}(b - c_h) > 0$, so that $\tilde{\Delta}$ and $\bar{\Delta}$ lie in the interval $(0, b - c_h)$. In this case, $\bar{\Delta} - \tilde{\Delta} = \frac{1}{8}(c_h - E[c])^2 - \frac{1}{8}(\Pi - (b - c_h))^2 > 0$.

Suppose next that $D_i^{wf}(b - c_h) \leq 0$ and $D_i^{pr}(b - c_h) > 0$. Then $\tilde{\Delta} \in (0, b - c_h)$ and $\bar{\Delta} \in [b - c_h, b - E(c))$, so that $\tilde{\Delta} < \bar{\Delta}$. Finally, suppose that $D_i^{wf}(b - c_h) \leq 0$ and $D_i^{pr}(b - c_h) \leq 0$. Consider $\Delta \in (b - c_h, b - E(c))$, where the functions $D_i^{pr}(\Delta)$ and $D_i^{wf}(\Delta)$ are strictly increasing. Recall that $D_i^{pr}(b-c_h) > D_i^{wf}(b-c_h)$ and, moreover, $D_i^{wf}(b - E[c]) > D_i^{pr}(b - E[c])$. It is straightforward to show that $D_i^{pr}(\Delta) = D_i^{wf}(\Delta)$ implies $\Delta = \hat{\Delta} := 2b - E[c] - \Pi - c_h$. The fact that $D_i^{pr}(\hat{\Delta}) = b - c_h > 0$ then implies that $\tilde{\Delta} < \bar{\Delta}$.

(ii) Recall that $\bar{\Delta}(\gamma)$ is strictly increasing; moreover, it is continuous by the implicit function theorem. Observe that $\lim_{\gamma \to 0} D_{ii}^{wf}(0, \gamma) = \frac{1}{8}(c_h - E[c])^2 > \lim_{\gamma \to 0} D_{ii}^{wf}(\bar{\Delta}(\gamma), \gamma) = 0$. Since $D_{ii}^{wf}(\Delta, \gamma)$ is strictly increasing in Δ, this means that $\lim_{\gamma \to 0} \bar{\Delta}(\gamma) < 0$. We know from Proposition 4 that $\tilde{\Delta} > 0$, hence $\lim_{\gamma \to 0} \bar{\Delta}(\gamma) < \tilde{\Delta}$.

Moreover, $\lim_{\gamma \to p(E[c]-c_l)} \bar{\Delta}(\gamma) > \tilde{\Delta}$. In order to see this, notice that $\tilde{\Delta} \in (0, b-c_h)$ if $D_{ii}^{pr}(b-c_h) = b - c_h - \frac{1}{4}(c_h - E[c])^2 > 0$ which is always the case, since $b - c_h - (c_h - E[c])^2 > 0$ holds for $b \geq \tilde{b}$ (indeed, one can check that $\frac{(b-E[c])^2}{b-pc_l-(1-p)E[c]} < \frac{c_h-E[c]}{1-p}$ for $b = c_h + (c_h - E[c])^2$). Furthermore, observe that $\lim_{\gamma \to p(E[c]-c_l)} \bar{\Delta}(\gamma) \in (0, b - c_h)$ if $\lim_{\gamma \to p(E[c]-c_l)} D_{ii}^{wf}(b - c_h) = b - c_h - \frac{3}{8}(c_h - E[c])^2 > 0$, which also is always satisfied. Hence, $\lim_{\gamma \to p(E[c]-c_l)} D_{ii}^{wf}(\bar{\Delta}(\gamma), \gamma) = \lim_{\gamma \to p(E[c]-c_l)} \bar{\Delta}(\gamma) - \frac{3}{8}(c_h - E[c])^2 = 0$, so that $\lim_{\gamma \to p(E[c]-c_l)} \bar{\Delta}(\gamma) = \frac{3}{8}(c_h - E[c])^2 > \tilde{\Delta} = \frac{1}{4}(c_h - E[c])^2$. The result then follows immediately. ■

6 Concluding remarks

When it comes to public-private partnerships, it "all revolves around incentives. In a world of 'incomplete' contracts, where it is difficult to foresee and contract about uncertain future events, it is important to get the incentive structure right" (Grimsey and Lewis, 2004, p. 247). It has often been argued that the delegation of the tasks of building, maintaining, and managing a facility to a single private contractor is the central characteristic of a public-private partnership. Indeed, bundling the tasks may provide the private contractor with strong incentives to develop a flexible design that will be particularly cost-effective in the operation stage and that can respond efficiently to changing requirements and new technologies in the future. However, as has been emphasized by Prendergast (1999), the provision of incentives can often give rise to dysfunctional responses. Given a public-private partnership, the private contractor enters into a long-term relationship with the public sector, which may create scope for the private party to engage in rent-seeking behavior. Specifically, to the best of our knowledge, the present paper is the first one that formally models the private contractor's incentives to spend resources during the construction phase in order to obtain private information, so that he will be able to extract an information rent in the management stage. While the prospect to earn an information rent in the second stage can be a source of effort incentives in the first stage, private information may also trigger ex post inefficiencies. Moreover, the resources spent to gather information are socially wasteful when it is known from the outset that the benefits of adaptations to changing circumstances outweigh their costs. In our framework, it depends on the relevance of these benefits and on the information gathering costs whether a government agency's decision for or against a public-private partnership would be supported by a welfare-maximizing authority.

To highlight the effects that bundling different tasks in a public-private partnership has on the incentives to innovate and to gather information, we have confined our attention to a very stylized model. Hence, while beyond the scope of the present paper, it might be worthwhile to extend our framework to incorporate further aspects that are also relevant when a decision between a public-private partnership and traditional procurement has to be made. For example, modelling the award procedure, explicitly taking into account contracting costs, or investigating the effects of private financing under a public-private partnership might be interesting avenues for future research.

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