# Dual Sourcing under Risky Public Procurement*

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**Abstract**

This paper examines the provision of a public service subject to a risk of disruption in a dynamic setting. To hedge against this risk, a public authority may use a dual sourcing policy. Instead of awarding the entire production to one supplier, he may split it between two suppliers. If the primary supplier is disrupted, a part of production may still be provided by the secondary. However, dual sourcing increases the procurement cost since a more costly supplier may be awarded part of the production. The public authority thus faces a trade-off when deciding upon the procurement policy. This trade-off is analysed under asymmetry of information on the secondary supplier's cost. We first determine the optimal choice of the appropriate set of suppliers. Then, we specify the optimal part of production awarded to each selected supplier. Finally, we extend our model to consider the influence of lobbying on the public authority's choice of procurement policy.

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## 1 Introduction

One of the major challenges in the provision of public services is the management of the risk of disruption through an appropriate public procurement policy. Disruption, defined as a major breakdown in production, may occur due to catastrophic events as natural disasters, terrorist attacks and political crises. In the aftermath of the March 2011 earthquake and tsunami in Japan, some nuclear power plants have been shut down and construction of nuclear plants has been put on hold. It entailed a major regional disruption of electricity. The Fukushima disaster has brought new attention on the vulnerability of nuclear

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energy systems which can also be threatened by terrorist attacks. To illustrate, suspected explosives was found at Ringhals nuclear power plant in southwest Sweden in June 2012.[1] Another illustrative example of energy systems subject to potential disruption is the gas supply in the European Union (EU), threatened by political crises. Indeed, natural gas has become a political leverage for producing countries, especially for Russia after the EU's 2004 enlargement to Eastern Europe. In 2008-2009, the Russian gas supplier, Gazprom, has decided to cut gas supply to Europe through Ukraine. More broadly, a large share of European or US energy supply originates from politically instable regions in the Middle East, the Caucasus and Central Asia. To hedge against such risk is thus necessary for both developed and developing countries since important disruptions would cause serious economic upheaval.

The aim of this paper is to determine the optimal public procurement policy in presence of risk of disruption. Sole sourcing, through the dependence on only one supplier, can increase exposure to risk of the provision of a public service. Instead of awarding the entire production to one single supplier, a public authority may split it between two suppliers. Dual sourcing provides insurance against disruptions. If the production of one supplier is disrupted, i.e. the supplier is suddenly unable to produce the public service, a part of the production may still be provided by a backup supplier. For example, the threats to the present worldwide energy systems (based essentially on nuclear and fossil energy) may bolster the rationale for deploying renewable energies such as solar, wind, hydro and geothermal energy to provide insurance against a major shortage of electricity.[2] However, the public authority faces a trade-off when deciding upon the optimal procurement policy: a secondary supplier protects the production against disruptions, but it could also increase the procurement cost since a more costly supplier may be awarded part of production.

The public procurement policy is, in this paper, characterized by two key decisions: the choice of the appropriate set of suppliers (sole versus dual sourcing) and the quantity to be produced by each selected supplier. In order to understand the fundamental economic determinants of these decisions, we consider a two-period model of public procurement with two potential suppliers. The primary supplier is unreliable in that her production is subject to random disruption at the second period. The secondary one is perfectly reliable, but more costly. We allow the model to integrate a system of compensation among suppliers. The public authority may shift a part of the default production to the secondary supplier, which depends on her ability to increase her production at the second period. However, this ability is limited; she cannot deliver the entire default production. Under these circumstances, the public authority has to determine the optimal public

[1] Ringhals nuclear plant is the largest power plant in Scandinavia and its four reactors produce about 20 percent of all electricity in Sweden.

[2] Renewables can enhance energy security by increasing the diversity of electricity sources, and through local generation, its resistance to central shocks. See Olz, Sims and Kirchner (2007) for more details.

procurement policy. To do so, he will trade-off between the cost due to supply disruption and the cost of contracting out a part of production to a more costly supplier. However, the determination of the optimal policy is complicated by the fact that the public authority may lack information about the backup supplier's cost. While we discuss the choice between sole and dual sourcing, our paper is more focused on the choice of the share of production awarded to each supplier in case of dual sourcing, i.e. the relative use of the primary supplier and the secondary supplier once both have been selected.

The secondary supplier's ability to deliver the default production is one of the key determinants of the optimal public procurement policy. We show that the public authority chooses dual sourcing when the marginal benefit of the default production ensured by the secondary firm is larger than the marginal cost of awarding her a part of the production. Furthermore, when the part of the default production that she may deliver decreases, the disruption cost increases and it becomes harder to ensure the security of the provision of the public service.[3] The optimal share of production is then to rely more on the secondary supplier to ensure a backup production in case of disruption. However, the cost of doing so is inflated under asymmetry of information due to the backup supplier's incentive to misrepresent her cost.

We first extend the model to allow for the possibility that the probability of disruption depends on the share of production. Two situations are considered. First, the higher the primary supplier's part of production, the lower her reliability. In this case, a decreased use of the primary supplier and an increased use of the secondary supplier is a better procurement strategy. In addition to ensuring a backup production, dual sourcing may help reduce the probability of disruption. Second, the higher the primary supplier's part of production, the lower her probability of disruption. Therefore, to improve the primary supplier's reliability, the secondary supplier's part of production is downward distorted. The scope of dual sourcing is thus reduced.

Finally, the model is extended to examine the influence of lobbying on the determination of public procurement policy. The secondary supplier attempts to influence procurement strategy in favor of dual sourcing to increase the rent she receives due to her informational advantage over the public authority. To do so, she offers a monetary transfer to the public authority. However, the latter is privately informed about the weight he gives to this transfer with respect to social welfare. In this part of the paper, we show how the transfer and therefore the procurement strategy, depends on the public authority's private information.

As discussed above, this paper aims to contribute to the literature that examines dual

[3] The disruption cost corresponds to the loss incurred by the public authority when the primary supplier fails to provide her part of the production due to the occurrence of catastrophic events disruption.

sourcing in procurement. Anton and Yao (1989, 1992) are two early contributions to the literature comparing the performance of sole sourcing and dual sourcing. Anton and Yao (1989) consider the case in which the suppliers know each other's costs. They show that splitting production reduces the production costs when suppliers have strictly convex costs, but provides suppliers powerful incentives to collude. Anton and Yao (1992) extend their previous model to allow for asymmetric information among the suppliers about each other's cost. As collusion becomes harder to sustain, dual sourcing may lead to lower procurement costs than sole sourcing. Our model differs in two ways from Anton and Yao's papers. First, we assume that returns to scale are constant. Second, we consider optimal mechanisms. From this point of view, our paper is close to Auriol and Laffont (1992), Dana and Spier (1994) and McGuire and Riordan (1995). They analyze the market structure, i.e. sole versus dual sourcing, under asymmetric information about firms' cost. McGuire and Riordan (1995) focus on the particular context in which firms produce differentiated products. We rather assume that products are perfectly substitutable as in Auriol and Laffont (1992) and Dana and Spier (1994). The key idea of these two papers is the role played by the duopolistic structure to reduce information cost. On the contrary, we show that dual sourcing induces information cost since a costly information rent should be given to the privately informed backup supplier. Moreover, these papers restrict their analysis to a static setting. In this paper, we rather determine the optimal procurement strategy considering the dynamics of procurement as Klotz and Chatterjee (1995). Contrary to them, we do not consider dual sourcing as a means to maintain competition in later auctions. In our model, dual sourcing may be chosen by the public authority to hedge against the risk of disruption and therefore to ensure the security of the provision of public services.[4]

Managing the risk of disruption is a growing element of concern in supply chains. Berger et al. (2004) are among the first to incorporate supplier risk into the selection of the optimal number of suppliers. Furthermore, Ruiz-Torres and Mahmoodi (2006) not only examine the supplier selection problem, but also the corresponding volume allocation for each selected supplier. Yu et al. (2009) propose a method to opt for single or dual sourcing based on the disruption probability, where both suppliers have similar characteristics in terms of reliability and cost as in our paper. However, these papers do not consider the problem of asymmetric information about suppliers' cost.

Finally, our paper is related to the lobbying literature such as Grossman and Helpman (1994). Indeed, our model considers the possibility for a supplier to make monetary contributions in order to influence the incumbent public authority's choice of procurement policy. As Le Breton and Salanié (2003), we consider an environment where decision

[4]In other context, Engel and Wambach (2006) examines a public procurement problem subject to the risk of bankruptcy. They show how multi-sourcing strategy can be better than a standard auction.

makers are privately informed on the weight that they give to social welfare with respect the value of the lobbyists' contributions. However, contrary to them, we do not consider the competition between two special interest groups to influence the decision maker. In our model, only one supplier is tempted to buy the favor of the public authority.

The paper is organized as follows. Section 2 describes the model of public procurement. In Section 3, we present the benchmark case in which the probability of disruption is exogenous. The optimal procurement policy is characterized both under complete and incomplete information. In Section 4, we examine the implications of the probability of disruption being endogenous. Section 5 analyzes the influence of lobbying on the procurement policy. Section 6 concludes.

# 2 The Model of Public Procurement

We consider a two-period model of public procurement. A public authority, also called the principal, must procure one unit of a perfectly divisible service at each period. The service can be produced by two potential risk neutral suppliers (either by supplier A, by supplier B or by both). Supplier A (resp. supplier B) is awarded a perfectly substitutable share $(1-\alpha)$ (resp. $\alpha$) of the production of the service, where $\alpha \in [0,1]$. We focus on the full spectrum of sourcing strategies from sole sourcing to dual sourcing. In sole sourcing, the principal orders from only one of the two suppliers, which has sufficient capacity to produce the entire service. In dual sourcing, the principal simultaneously sources from both suppliers.[5] These two sourcing strategies represent a long-term relationship, in which the principal commits to allocate the same part of the production to the suppliers for both periods.

The cost for supplier A (resp. supplier B) of producing $(1-\alpha)$ (resp. $\alpha$) is given by $\theta_A(1-\alpha)$ (resp. $\theta_B\alpha$).[6] The cost parameter $\theta_k$, $k = A$, $B$, denotes their respective constant marginal cost, fixed over time. Contrary to the marginal cost $\theta_A$ which is common knowledge, the marginal cost $\theta_B$ is privately known by supplier B.[7] The cost $\theta_B$ can take only two values $\underline{\theta}$ and $\overline{\theta}$ with respective probabilities $v$ and $1-v$. We denote $\Delta\theta = \overline{\theta} - \underline{\theta}$, the spread of uncertainty. This cost $\theta_k$ is linked to the technology used which is subject to

[5] The cost of managing two different suppliers is neglected, but could be added on top of our model without changing the internal mechanics.

[6] We ignore the fixed costs which play no other role than justifying the existence of a single supplier.

[7] We can compare the main supplier A to an incumbent and the backup supplier B to an entrant. So, the simple observation of supplier A's past performances justifies that the public authority has better information about her cost than about supplier B's one. For the sake of simplicity, we consider that her cost was perfectly revealed over time and she can thus no longer benefit from her informational advantage over the public authority.

a random disruption. A disruption of supplier $k$'s production may occur at the beginning of the second period with a publicly known probability $p_k$. The supplier is modeled as either on (available) or off (disrupted).

We make the following assumptions about the suppliers' marginal cost and their probability to be disrupted.

Assumption 1 : Supplier A has a cost advantage, $\theta_A < \underline{\theta} < \overline{\theta}$.

Assumption 2 : Supplier A has a higher probability to suffer from disruption, $p_A > p_B$.[8] For the sake of simplicity, we consider that supplier B is perfectly reliable, i.e. the probability to be disrupted $p_B$ is equal to zero. Then, we denote $p_A \equiv p$.

Assumption 3 : If supplier A's technology is disrupted, supplier B may compensate for some part of the default production $(1-\alpha)$ in addition to her own production $\alpha$. In this case, supplier B's share of the production at the second period $\widehat{\alpha}(\alpha)$ is such that:

$$\widehat{\alpha}(\alpha) = \alpha + a(1-\alpha).$$

For notational simplicity, $\widehat{\alpha}(\alpha)$ is denoted $\widehat{\alpha}$ in the following. This system of compensation among suppliers is introduced by means of the "production flexibility" parameter, $a$, where $a \in [0,1)$. "Production flexibility" represents supplier B's ability to increase her production at the second period. We assume that supplier B's ability to compensate is limited; she cannot deliver the entire default production. Note that if the public authority awards the entire production to supplier A, supplier B is still able to deliver the part $a$ of the production in case of disruption. It means that she may survive at the second period without producing at the first period.[9]

For concreteness, we may interpret supplier A as centralized conventional energy systems such as nuclear or fossil fuel and supplier B as renewable energy systems. The two suppliers are heterogeneous differing in their marginal costs of production and their likelihoods of disruption. Renewable energies are considered more costly, but more reliable. Indeed, the utilization of renewable resources could be economically unattractive due to availability of cheaper conventional energy and higher cost of energy generation.[10] However, the renewable energies mix encompassing a variety of technologies available in

[8] If the less costly supplier is also the more reliable, the public authority will award her the entire production. In order to focus on the interesting cases, we restrict attention to parameter values that satisfy Assumption 2.

[9] To contract only with the supplier A at the first period doesn't mean that the supplier B won't be available if it might need it at the second period, except for $a = 0$. We abstract from the role of dual sourcing keeping the supplier alive to promote competition in later periods as it was suggested by Greer and Liao (1986) and Klotz and Chatterjee (1995). Supplier B can survive producing on the behalf of other publics authorities for example.

[10] The nuclear energy is less costly if we consider its marginal cost of production. If we take in consideration the cost of building the infrastructure and therefore the long run incremental cost, this assumption is not so obvious.

perpetuity such as solar, wind, hydroelectric, biomass and geothermal energy ensures the reliability of energy supply. First, renewable energies mix can contribute to the pursuit of energy independence for a country, so free from political risk. Second, their decentralized nature contributes to the resistance of the energy system to central shocks as natural disasters and terrorist attacks. Furthermore, their diversity contributes to achieving security of energy supply since disruption of any one source will have a smaller impact on overall renewable energy supply.[11] Finally, as these technologies are newly established, their cost is not yet perfectly publicly known.

The value for the risk neutral public authority of the public service is common knowledge. With probability $(1-p)$, both suppliers are available, so the entire service is provided. In this case, we let the principal's surplus be denoted such that: $S(1) \equiv S$. With probability $p$, supplier A is not available at the second period, so the service is only partially provided by supplier B. The surplus is henceforth denoted $S(\widehat{\alpha})$. Its marginal value is positive and strictly decreasing with the part of the production of the service bought by the principal, $S(.)' > 0$ and $S(.)'' < 0$, and satisfies the conditions $S(0) = 0$ and $S'(1) = 0$.

To ensure the suppliers' participation, the production of the public service must yield at least as much utility as the outside option level, normalized to zero. The public authority maintains supplier A at zero utility level. To accept working for him, she must only receive the reimbursement of cost $\theta_A(1-\alpha)$ at each period. For the sake of clarity, we do not explicit her utility level in the rest of the paper, its value being null. However, the principal has to induce supplier B not to misrepresent her marginal costs. To do so, he must pay a monetary transfer $t$ to her, encompassing the reimbursement of her cost. This transfer depends on the supplier's marginal cost and her part of the production. With probability $(1-p)$, supplier B's utility level is then $U(\theta_B, \alpha) = t(\theta_B, \alpha) - \theta_B \alpha$ at each period. With probability $p$, her utility level becomes $U(\theta_B, \widehat{\alpha}) = t(\theta_B, \widehat{\alpha}) - \theta_B \widehat{\alpha}$ if she produces at the first period or $U(\theta_B, a) = t(\theta_B, a) - \theta_B a$ if not.

The public authority designs the procurement contract based on the part of production produced $\alpha$, $\widehat{\alpha}$ or $a$ and the transfer $t$ received by supplier B. For notational simplicity, the transfer is denoted such that: $\underline{t} \equiv t(\underline{\theta}, \underline{\alpha})$, $\widehat{\underline{t}} \equiv t(\underline{\theta}, \widehat{\underline{\alpha}})$, $\underline{t}(a) \equiv t(\underline{\theta}, a)$, $\overline{t} \equiv t(\overline{\theta}, \overline{\alpha})$, $\widehat{\overline{t}} \equiv t(\overline{\theta}, \widehat{\overline{\alpha}})$ and $\overline{t}(a) \equiv t(\overline{\theta}, a)$. A transfer-part of production pair is specified for each type of supplier B, namely: $\{(\underline{\alpha}, \underline{t}), (\widehat{\underline{\alpha}}, \widehat{\underline{t}}), (a, \underline{t}(a))\}$ for supplier $\underline{\theta}$ and $\{(\overline{\alpha}, \overline{t}), (\widehat{\overline{\alpha}}, \widehat{\overline{t}}), (a, \overline{t}(a))\}$ for supplier $\overline{\theta}$.

As already mentioned, the public authority is able to commit on contracts for the

[11] Using renewable energy mix implies that if the wind dies down, solar energy can take over. If skies aren't sunny, hydroelectric could be used instead. If there is a drought, provision may get back to wind or solar energy and so on. The aim of renewable energy mix is to avoid being too reliant on one source and suffering from energy shortage.

whole duration of the relationship. At the beginning of the first period (but after the supplier has learned her marginal cost), the principal can offer a contract settling all future exchanges which cannot be reneged on.[12] The public authority and the suppliers use a common discount factor, $\delta > 0$.

To describe the dynamic of the relationship between the public authority and the suppliers, let us detail the timing of the contracting game as follows.

*At the first period:* Supplier B discovers her marginal cost. The public authority chooses the optimal sourcing strategy and offers a contract to the supplier. She accepts or refuses the contract (if she refuses, she gets her reservation utility). The first part of the contract is implemented.

*At the second period:* The nature draws the state of the nature: (a) with a probability $(1-p)$, supplier A is available, the same share of the production than the first period is provided by both suppliers ; (b) with a probability $p$, supplier A is disrupted and supplier B may compensate only for some part of the production. The second part of the contract is implemented.

# 3 Procurement Policy under Exogenous Probability of Disruption

In this section, we assume that the probability of disruption is exogenous. As previously discussed, disruptions of the provision of the public service may occur due to natural disasters, political risks and acts of terrorism.

## 3.1 Complete Information

Let us first consider the complete-information benchmark in which the public authority observes supplier B's marginal cost. His problem is then to maximize social welfare under supplier B's participation constraint such that:[13]

$$\underset{\{t,\alpha\}}{Max}\{S-\theta_A(1-\alpha)-\theta_B\alpha-U(\theta_B,\alpha)$$
$$+\delta[(1-p)[S-\theta_A(1-\alpha)-\theta_B\alpha-U(\theta_B,\alpha)]+p[S(\widehat{\alpha}(\alpha))-\theta_B\widehat{\alpha}(\alpha)-U(\theta_B,\widehat{\alpha})]]\}$$

[12] Once the public authority has contracted with the secondary supplier, he cannot break the contract if there is no disruption and give back all the production to the primary supplier. Also, once he has contracted only with the primary supplier, he cannot decide to contract with the second one to award her the default production in case of disruption.

[13] Social welfare corresponds to social value of trade minus the rent of the suppliers. The public authority is only concerned about consumers' surplus, not about supplier's profit.

subject to $U(\theta_B, \alpha) + \delta[(1-p)U(\theta_B, \alpha) + pU(\theta_B, \widehat{\alpha})] \geq 0$.[14]

Social welfare encompasses the full spectrum of procurement strategies from sole sourcing to dual sourcing. The public authority can decide to award the entire production to the main supplier A ($\alpha = 0$), to the backup supplier B ($\alpha = 1$) or to split it between both suppliers ($1 > \alpha > 0$).

In order to better understand the role of the backup supplier in the public service provision, social welfare can be rewritten explicitly both in terms of investment $I$ and return $R$. The investment corresponds to the cost of contracting out a certain part of production to the most reliable but most costly supplier. The return corresponds to the backup production in case of disruption. Actually, opting for supplier B refers to an insurance. The program of maximization (P1) becomes:

$$\underset{\{t,\alpha\}}{Max}\{S - \theta_A - I + \delta[(1-p)(S - \theta_A) + p[S(a) - \theta_B a - U(\theta_B, a) + R]]\}$$

subject to $U(\theta_B, \alpha) + \delta[(1-p)U(\theta_B, \alpha) + pU(\theta_B, \widehat{\alpha})] \geq 0$ and $U(\theta_B, a) \geq 0$.

Supplier B's ability to compensate for some portion of the default production without producing at the first period appears more clearly in this expression of social welfare. If the principal only contracts with supplier A at the first period, supplier B will thus provide the production $a$ at the cost $\theta_B a$ and will receive the rent $U(\theta_B, a)$.

The investment $I$ corresponds to the cost that the public authority incurs using the backup supplier from the first period. It is defined as:

$$I = [(\theta_B - \theta_A)\alpha + U(\theta_B, \alpha)](1 + \delta) \tag{1}$$

Contracting with supplier B for the part $\alpha$ of the production instead of allocating it to supplier A is costly for the principal. In addition, the public authority has to give the information rent to supplier B, $U(\theta_B, \alpha)$. Furthermore, once the contract is concluded (at the first period), the public authority cannot choose to abandon the backup supplier B if supplier A has not been disrupted (at the second period). So, the investment is paid for both periods.

The return on investment $R$ is:

$$R = [S(\widehat{\alpha}) - \theta_B\widehat{\alpha} - U(\theta_B, \widehat{\alpha})] - [S(a) - \theta_B a - U(\theta_B, a)] + [(\theta_B - \theta_A)\alpha + U(\theta_B, \alpha)] \tag{2}$$

The first terms in brackets in equation (2) corresponds to social welfare of splitting the provision of the public service between two suppliers in case of disruption. If the provision

[14] To obtain supplier B's participation, the public authority must ensure that her utility level is non-negative. In this setting, only the participation constraint matters for the principal since the supplier can be forced to reveal her cost and then to produce the corresponding share of production.

from supplier A is disrupted, the public authority can shift partially his outsourcing to supplier B in addition to her previous production. The latter will thus provide the production $\widehat{\alpha}$ at the cost $\theta_B\widehat{\alpha}$ and will receive the rent $U(\theta_B, \widehat{\alpha})$. However, to obtain the return on investment $R$, we have to subtract the second bracketed term. It refers to social welfare from the backup production $a$ ensured by supplier B if she does not produce at the first period. Finally, $R$ encompasses the reimbursement of second part of the investment, which is partially reversible in case of disruption.[15] It is represented by the bracketed term on the right-hand side of equation (2).

In order to determine the optimal public procurement policy, the public authority should trade-off the cost of contracting with supplier B with the benefits from securing the production of the public service. In other words, contracting only with cheapest supplier A for all of the production process costs less, but by doing so, the public authority is accepting the risk of disruption.

Under complete information, the public authority maintains supplier B at her status quo utility level fixed at zero.[16] The participation constraints are thus binding, at the optimum. When supplier B produces at the first period, it is defined as:

$$U(\theta_B, \alpha) + \delta[(1-p)U(\theta_B, \alpha) + pU(\theta_B, \widehat{\alpha})] = 0 \tag{3}$$

and when she does not, as:

$$U(\theta_B, a) = 0.$$

Then, by substituting $\alpha$ into $\widehat{\alpha}$, the principal maximizes expected social welfare with respect to $\alpha$ and we obtain the first-best part of production $\alpha^{FB}$. The next proposition summarizes the solution of the public authority's problem (P1). The proof is straightforward and omitted.

**Proposition 1** *: Under complete information, the optimal procurement policy entails:*

- *For $S'(a) > \theta_B + (\theta_B - \theta_A)\frac{1+\delta(1-p)}{\delta p(1-a)}$, dual sourcing is the optimal procurement policy. The first-best part of the production awarded to the backup supplier $\alpha^{FB}$ is given by:*

$$S'(\widehat{\alpha}(\alpha^{FB})) = \theta_B + (\theta_B - \theta_A)\frac{1+\delta(1-p)}{\delta p(1-a)}. \tag{4}$$

- *Otherwise, sole sourcing from the main supplier is optimal and $\alpha^{FB}$ is null.*

[15] The initial cost of investment is sunk at the first period through dual sourcing, but if the supplier A is disrupted at the second period, sourcing from both suppliers is not anymore possible.

[16] Under complete information, agents do not have the possibility to mimic other agents. The incentive problem thus vanishes and only the participation constraint needs to be considered. However, as suppliers' rent is socially costly, the principal minimizes it to zero.

We denote $\underline{\alpha}^{FB}$ (resp. $\overline{\alpha}^{FB}$) the solutions corresponding to $\theta_B = \underline{\theta}$ (resp. $\theta_B = \overline{\theta}$).

The public authority chooses dual sourcing when the marginal benefit of the backup production $a$ is larger than the marginal cost of splitting the production between both suppliers. Increasing the backup production beyond $a$ implies that the principal has to give up a part of the production to supplier B at the first period such as $\alpha^{FB} > 0$. This strategy is more valuable as secondary supplier's ability to increase her production reduces. However, the public authority never awards her the entire production at equilibrium. Since the surplus satisfies $S'(1) = 0$, it results that $\alpha^{FB} < 1$. On the contrary, when the benefit to increase the production beyond $a$ is lower than its marginal cost, the public authority prefers opting for sole sourcing from supplier A. In this case, he benefits only from the production $a$ in case of disruption. While we have discussed the choice between sole and dual sourcing, we focus more on the optimal share of production awarded to each supplier in case of dual sourcing, i.e. the relative use of supplier A and supplier B once both have been selected.

From equation (4), we see that the first-best part of the production is such that the marginal benefit of ensuring a backup production $\widehat{\alpha}$ in case of disruption is just equal to the marginal disutility of doing so. Such disutility, described by the right-hand side of the equation (4) is composed of two terms. The first term, $\theta_B$, corresponds to supplier B's marginal cost. The second one represents the cost of sourcing a part $\alpha^{FB}$ of production from the secondary supplier instead of allocating to less costly supplier A. This expression takes into account that such cost is reversible in case of disruption.

In more intuitive terms, the first-best part of the production awarded to supplier B, $\alpha^{FB}$, may be defined by the following first-order condition:

$$\frac{\partial I}{\partial \alpha} = \delta p \frac{\partial R}{\partial \alpha}.$$

Such optimal share of the production is obtained by equating the marginal investment in dual sourcing described as:

$$(\theta_B - \theta_A)(1 + \delta)$$

and its marginal return weighted by the discount factor $\delta$ and the probability of disruption $p$ as:

$$\delta p[S'(\widehat{\alpha}(\alpha^{FB}))(1 - a) + (\theta_B - \theta_A)].$$

The public authority trades-off the cost of making a contracting arrangement with supplier B (investment $I$) with the benefits from ensuring the security of the production of the public service (return $R$).

We now examine the reaction of the first-best part of production $\alpha^{FB}$ to changes in the parameters of the model. We begin our comparative static analysis with the effect of supplier B's ability to compensate for the default production on the share of production. Using (4), we obtain:

$$\partial\alpha^{FB}/\partial a < 0.$$

The proof is presented in Appendix A. As previously discussed, even if the public authority awards the entire production to supplier A, supplier B is still able to deliver the part $a$ of the production in case of disruption. So, if the backup production $a$ increases, awarding a part of production to supplier B at the first period is less necessary to ensure the provision of the public service. On the contrary, when $a$ decreases, the disruption cost increases and the best sourcing strategy is to rely more on supplier B. We then examine the way in which the first-best part of production $\alpha^{FB}$ depends on the other parameters of the model $p$, $\delta$ and $\theta_k$. The proof of the following results is straightforward and hence omitted. When $p$ increases, supplier A is more likely to default and the public authority calls relatively more on supplier B, $\partial\alpha^{FB}/\partial p > 0$. It is also the case when the public authority does not discount the future, $\partial\alpha^{FB}/\partial\delta > 0$. The higher the discount factor $\delta$, the more valuable the use of supplier B. Finally, the suppliers' allocation of the production depends on their respective marginal cost. The scope of dual sourcing is more important when supplier A's marginal cost (resp. supplier B's marginal cost) increases (resp. decreases), $\partial\alpha^{FB}/\partial\theta_A > 0$ and $\partial\alpha^{FB}/\partial\theta_B < 0$. In this case, contracting with the backup supplier is less costly. Similarly, dual sourcing is increasingly favored by the principal as the supplier cost heterogeneity decreases, $\partial\alpha^{FB}/\partial(\theta_B - \theta_A) > 0$.

## 3.2 Incomplete Information

We now suppose that the public authority cannot observe supplier B's marginal cost. From the Revelation Principle, there is no loss of generality in restricting the analysis to direct revelation mechanisms which specify for each message from supplier B, $\widetilde{\theta}_B = \underline{\theta}$ or $\widetilde{\theta}_B = \overline{\theta}$, a part of the production to achieve and a net transfer from the public authority.[17] The direct revelation mechanism must be truthful, i.e. must satisfy the following incentive constraints when supplier B is awarded a part of the production at the first period:

$$\begin{aligned}
\underline{t} - \underline{\theta}\underline{\alpha} + \delta[(1-p)(\underline{t} - \underline{\theta}\underline{\alpha}) + p(\widehat{\underline{t}} - \underline{\theta}\widehat{\underline{\alpha}})] &\geq \overline{t} - \underline{\theta}\overline{\alpha} + \delta[(1-p)(\overline{t} - \underline{\theta}\overline{\alpha}) + p(\widehat{\overline{t}} - \underline{\theta}\widehat{\overline{\alpha}})] \\
\overline{t} - \overline{\theta}\overline{\alpha} + \delta[(1-p)(\overline{t} - \overline{\theta}\overline{\alpha}) + p(\widehat{\overline{t}} - \overline{\theta}\widehat{\overline{\alpha}})] &\geq \underline{t} - \underline{\theta}\underline{\alpha} + \delta[(1-p)(\underline{t} - \underline{\theta}\underline{\alpha}) + p(\widehat{\underline{t}} - \underline{\theta}\widehat{\underline{\alpha}})]
\end{aligned}$$

and the following ones when not:

$$\begin{aligned}
\underline{t} - \underline{\theta}a &\geq \overline{t} - \underline{\theta}a \\
\overline{t} - \overline{\theta}a &\geq \underline{t} - \underline{\theta}a
\end{aligned}$$

[17] See Laffont and Martimort (2002).

We denote the utilities for simplicity as: $\underline{U} \equiv U(\underline{\theta},\underline{\alpha})$, $\overline{U} \equiv U(\overline{\theta},\overline{\alpha})$, $\widehat{\underline{U}} \equiv U(\underline{\theta},\widehat{\underline{\alpha}})$, $\widehat{\overline{U}} \equiv U(\overline{\theta},\widehat{\overline{\alpha}})$, $\underline{U}(a) \equiv U(\underline{\theta},a)$ and $\overline{U}(a) \equiv U(\overline{\theta},a)$. The incentive constraints are written in terms of information rents as follows:[18]

$$\begin{aligned}
\underline{U}+\delta[(1-p)\underline{U}+p\widehat{\underline{U}}] &\geq \overline{U}+\delta[(1-p)\overline{U}+p\widehat{\overline{U}}]+\Delta\theta\overline{\alpha}+\delta[(1-p)\Delta\theta\overline{\alpha}+\Delta\theta\widehat{\overline{\alpha}}] \quad (5)\\
\overline{U}+\delta[(1-p)\overline{U}+p\widehat{\overline{U}}] &\geq \underline{U}+\delta[(1-p)\underline{U}+p\widehat{\underline{U}}]-\Delta\theta\underline{\alpha}-\delta[(1-p)\Delta\theta\underline{\alpha}+\Delta\theta\widehat{\underline{\alpha}}] \quad (6)
\end{aligned}$$

and

$$\begin{aligned}
\underline{U}(a) &\geq \overline{U}(a)+\Delta\theta a \quad (7)\\
\overline{U}(a) &\geq \underline{U}(a)-\Delta\theta a \quad (8)
\end{aligned}$$

To obtain supplier B's participation, her utility level must yield at least the outside option level. The following participation constraints must be satisfied:

$$\begin{aligned}
\underline{U}+\delta[(1-p)\underline{U}+p\widehat{\underline{U}}] &\geq 0 \text{ and } \overline{U}+\delta[(1-p)\overline{U}+p\widehat{\overline{U}}]\geq 0 \quad (9)\\
\underline{U}(a) &\geq 0 \text{ and } \overline{U}(a)\geq 0 \quad (10)
\end{aligned}$$

The principal's problem is then to choose a pair of part of production $\underline{\alpha}$ and $\overline{\alpha}$ which maximizes the expected welfare. The maximization program (P2) writes as:

$$\underset{\{(\underline{t},\underline{\alpha}),(\overline{t},\overline{\alpha})\}}{Max}\ E_{\theta^B}\{S-\theta_A-I+\delta[(1-p)(S-\theta_A)+p[S(a)-\theta_B a-U(\theta_B,a)+R]]\}$$

subject to (5), (6), (7), (8), (9) and (10).

The standard simplification in the number of constraints leaves us with four relevant constraints which are binding: $\underline{\theta}$-supplier B's incentive constraints described in equations (5) and (7) and $\overline{\theta}$-supplier B's participation constraints in (9) and (10).[19] When supplier B produces at the first period, we thus have:

$$\underline{U}+\delta[(1-p)\underline{U}+p\widehat{\underline{U}}]=\Delta\theta\overline{\alpha}+\delta[(1-p)\Delta\theta\overline{\alpha}+\Delta\theta\widehat{\overline{\alpha}}] \text{ and } \overline{U}+\delta[(1-p)\overline{U}+p\widehat{\overline{U}}]=0 \quad (11)$$

It results that $\overline{\theta}$-supplier B obtains no rent. On the contrary, $\underline{\theta}$-supplier B benefits from an information rent, generated by her informational advantage over the principal. This rent depends on the part of production allocated to $\overline{\theta}$-supplier B, $\overline{\alpha}$. So, the principal has to give up a positive rent to $\underline{\theta}$-supplier B as long as he allocates a certain level of the production to $\overline{\theta}$-supplier B. When supplier B does not produce at the first period, but supplier A is disrupted, we obtain:

$$\underline{U}(a)=\Delta\theta a \text{ and } \overline{U}(a)=0 \quad (12)$$

[18] Supplier B is given incentives to reveal her marginal cost at the first period. Indeed, the principal wants to discriminate among supplier's efficiency to leave as small a rent as possible to him.

[19] Note that the neglected $\overline{\theta}$-supplier B's incentive constraints (6), (8) and $\underline{\theta}$-supplier B's participation constraint (9) are satisfied by the solution.

While $\overline{\theta}$-supplier B gets no rent, $\underline{\theta}$-supplier B earns a rent depending on her ability to compensate for the default production. Contrary to the previous case, this production $a$ is not beyond the principal's control. Compared with the complete information framework, the public authority's optimization is altered, due to the subtraction of the expected rents given up to $\underline{\theta}$-supplier B.

The maximization of expected social welfare with respect to $(\underline{\alpha}, \overline{\alpha})$ subject to (11) and (12) can written in terms of investment and return, as:

$$\begin{array}{l} \underset{\{\underline{\alpha},\overline{\alpha}\}}{Max} \; \{ \; v \; [S - \theta_A - \underline{I} + \delta[(1-p)(S-\theta_A) + p[S(a) - \underline{\theta}a - \Delta\theta a + \underline{R}]] \\ +(1-v) \; [S - \theta_A - \overline{I} + \delta[(1-p)(S-\theta_A) + p[S(a) - \overline{\theta}a + \overline{R}]]\} \end{array}$$

Under incomplete information, when $\theta_B = \overline{\theta}$, the investment $\overline{I}$ and the return $\overline{R}$ of dual sourcing are the same than under complete information. However, when $\theta_B = \underline{\theta}$, the investment $\underline{I}$ and the return $\underline{R}$ include information rents. Inserting (11) and (12) into equations (1) and (2), we obtain:

$$\begin{array}{rcl} \underline{I} & = & (1+\delta)[(\underline{\theta} - \theta_A)\underline{\alpha} + \Delta\theta\overline{\alpha}], \\ \underline{R} & = & S(\widehat{\underline{\alpha}}) - \underline{\theta}\widehat{\underline{\alpha}} - \Delta\theta\widehat{\overline{\alpha}} - [S(a) - \underline{\theta}a - \Delta\theta a \;] + (\underline{\theta} - \theta_A)\underline{\alpha} + \Delta\theta\overline{\alpha}. \end{array}$$

By substituting $(\underline{\alpha}, \overline{\alpha})$ into $(\widehat{\underline{\alpha}}, \widehat{\overline{\alpha}})$, we maximize expected social welfare with respect to $(\underline{\alpha}, \overline{\alpha})$ and obtain the following proposition 2.

**Proposition 2** *Under incomplete information, the optimal procurement policy is as follows:*

- *For $S'(a) > S'(\widehat{\alpha}(\overline{\alpha}^{FB})) + \frac{v}{1-v}\Delta\theta\frac{1+\delta(1-ap)}{\delta p(1-a)}$, dual sourcing is optimal. The optimal menu of contracts entails no distortion of the second-best part of the production $\underline{\alpha}^{SB}$ from the first-best and a downward distortion of the second-best part of the production $\overline{\alpha}^{SB}$, determined by:*

$$S'(\widehat{\alpha}(\overline{\alpha}^{SB})) = S'(\widehat{\alpha}(\overline{\alpha}^{FB})) + \frac{v}{1-v}\Delta\theta\frac{1+\delta(1-ap)}{\delta p(1-a)}$$

- *Otherwise, sole sourcing from the main supplier is the optimal procurement policy and the second-best parts of the production $\underline{\alpha}^{SB}$ and $\overline{\alpha}^{SB}$ are null.*

The proof of proposition 2 and all later results are presented in Appendix B. In what follows, we focus our attention on settings in which dual sourcing is optimal.

As previously, there is a trade-off between the marginal cost of dual sourcing and its marginal benefit. The $\underline{\theta}$-supplier B's second-best part of the production is not distorted away from the first-best level, $\underline{\alpha}^{SB} = \underline{\alpha}^{FB}$. However, the existence of information rents leads the principal to distort downwards $\overline{\theta}$-supplier B's level of production $\overline{\alpha}^{SB}$ away from the first-best level. It results that $\overline{\alpha}^{SB} < \overline{\alpha}^{FB}$. Even if a part of the rent, $\underline{U}$, is reversible at the second period if supplier A is disrupted, the principal distorts the second-best part of production level to reduce the cost of the rent left to $\underline{\theta}$-supplier B, $\widehat{\underline{U}}$. The principal stops decreasing $\overline{\alpha}^{SB}$, until a further decrease would have a higher cost than the benefit in reducing the information rent it would bring about.

Under incomplete information, the public authority may still opt for dual sourcing but the cost of doing so is higher than under complete information, due to supplier B' incentives to misrepresent her marginal costs. The scope of using dual sourcing is thus reduced and the public authority is pushed towards a lower use of the backup supplier.

We derive simple comparative statics analysis of the effect of the informational rent on the optimal contract. As in the "classical" contract theory literature (Baron and Myerson (1982) and Laffont and Tirole (1993)), we find that the higher the probability to face $\underline{\theta}$-supplier B, the lower $\overline{\theta}$-supplier's part of the production, $\partial\overline{\alpha}^{SB}/\partial v < 0$. It is also the case as the spread of uncertainty on the supplier's cost increases, $\partial\overline{\alpha}^{SB}/\partial\Delta\theta < 0$. An infinitesimal increase in $\overline{\theta}$-supplier B's level of production (resp. decrease in $\underline{\theta}$-supplier B's level of production) also increases the information rent and the principal's expected payoff is diminished. He thus reduces $\overline{\theta}$-supplier's part of the production. Furthermore, a higher value of $a$, leading to a higher value of the rent $\widehat{\underline{U}}$, increases the distortion from the first-best of $\overline{\theta}$-supplier B level of production, $\partial\overline{\alpha}^{SB}/\partial a < 0$. Finally, when the intensity of the risk $p$ and the discount factor $\delta$ increase, the downward distortion of the level of production $\overline{\alpha}^{SB}$ due to the informational rent given up to supplier B is diminished, $\partial\overline{\alpha}^{SB}/\partial p > 0$ and $\partial\overline{\alpha}^{SB}/\partial\delta > 0$.

# 4 Procurement Policy under Endogenous Probability of Disruption

We now consider that the probability of disruption is endogenously determined by the share of production. In other words, supplier A's reliability depends on her part of production. Two cases can be distinguished. First, the probability $p$ increases as supplier A produces more. Second, the supplier A is less likely to be disrupted as her part of production increases. Variations of the probability of disruption $p$ with respect to the suppliers' part of the production $\alpha$ will be part of the discussion below.

## 4.1 Complete Information

The public authority has to choose a share of production which maximizes social welfare, considering now the probability of disruption as endogenous. In this case, the informed principal's problem (P3) is the following:

$$\underset{\{t,\alpha\}}{Max}\{S-\theta_A - I + \delta[(1-p(\alpha))(S-\theta_A) + p(\alpha)[S(a) - \theta_A a - U(\theta_B, a) + R]]\}$$

subject to $U(\theta_B,\alpha) + \delta[(1-p(\alpha))U(\theta_B,\alpha) + p(\alpha)U(\theta_B,\widehat{\alpha})] \geq 0$ and $U(\theta_B, a) \geq 0$.

The participation constraints are binding at the optimum as in section 3.1. Supplier B's rents are thus defined as follows when she produces at the first period:

$$U(\theta_B,\alpha) + \delta[(1-p(\alpha))U(\theta_B,\alpha) + p(\alpha)U(\theta_B,\widehat{\alpha})] = 0$$

and as follows when she does not:

$$U(\theta_B, a) = 0.$$

Then, we solve the public authority's problem (P3) and obtain the following proposition characterizing the optimal part of the production $\alpha^*$.

**Proposition 3** *: Under complete information, the optimal procurement policy entails:*

- *For $S'(a) > S'(\widehat{\alpha}(\alpha^{FB})) + \frac{\partial p(\alpha)}{\partial \alpha}\frac{1}{p(\alpha)(1-a)}[S-\theta_A - S(\widehat{\alpha}(\alpha)) + \theta^B\widehat{\alpha}(\alpha)]$, dual sourcing is optimal. When the probability of disruption decreases (resp. increases) with the part awarded to the backup supplier, the first-best part of the production allocated to the backup supplier $\alpha^*$ is higher (resp. lower) than in the exogenous probability of disruption case. The part $\alpha^*$ is defined, at $p = p(\alpha)$, by:*

  $$S'(\widehat{\alpha}(\alpha^*)) = S'(\widehat{\alpha}(\alpha^{FB})) + [\frac{\partial p(\alpha)}{\partial \alpha}|_{\alpha=\alpha^*}\frac{1}{p(\alpha^*)(1-a)}[S-\theta_A - S(\widehat{\alpha}(\alpha^*)) + \theta_B\widehat{\alpha}(\alpha^*)]]$$

- *Otherwise, sole sourcing from the main supplier is the optimal procurement policy and the first-best part of the production $\alpha^*$ is null.*

We denote $\underline{\alpha}^*$ the solution corresponding to $\theta_B = \underline{\theta}$ and $\overline{\alpha}^*$ to $\theta_B = \overline{\theta}$.

The extra term in the previous equation, with respect equation (4), captures the impact of the share of the production on the probability to be disrupted. Two different cases are considered. First, the higher supplier A's part of production $(1-\alpha)$, the higher her probability to be disrupted, $\partial p(\alpha)/\partial\alpha < 0$**.** In this case, the marginal cost of dual sourcing is smaller than in the benchmark case described in section 3.1. The public authority finds it more valuable to rely more on supplier B in order to reduce the risk of disruption such that $\alpha^* > \alpha^{FB}$. Second, increasing supplier A's part of production improves her reliability, $\partial p(\alpha)/\partial\alpha > 0$. In this case, the marginal cost of dual sourcing increases. The part of the production awarded to supplier B decreases such that $\alpha^* < \alpha^{FB}$. To lower the probability of disruption, the principal uses less the backup supplier with respect to the benchmark case.

We study the sustainability of such a share of production in a setting suffering from asymmetry of information on supplier B's cost.

## 4.2 Incomplete Information

We assume that supplier B is privately informed about her marginal cost of production. As in section 3.2, only $\underline{\theta}$-supplier B's incentive constraints and $\overline{\theta}$-supplier B's participation constraints are binding such as:

$$\begin{aligned} \underline{U} + \delta[(1-p(\alpha))\underline{U} + p\widehat{\underline{U}}] &= \Delta\theta\overline{\alpha} \text{ and } \overline{U} + \delta[(1-p(\alpha))\overline{U} + p\widehat{\overline{U}}] = 0 \\ \underline{U}(a) &= \Delta\theta a \text{ and } \overline{U}(a) = 0 \end{aligned}$$

We insert those expressions into the public authority's objective function:

$$\underset{\{\underline{\alpha},\overline{\alpha}\}}{Max} \;\; E_{\theta^B}\{S - \theta_A - I + \delta[(1-p(\alpha))(S-\theta_A) + p(\alpha)[S(a) - \theta_A a - U(\theta_B, a) + R]\}$$

The next proposition summarizes the solution of this program (P4).

**Proposition 4** *Under incomplete information, the optimal procurement policy is as follows:*

- *For $S'(a) > S'(\widehat{\alpha}(\overline{\alpha}^*)) + \frac{v}{1-v}\Delta\theta\frac{1+\delta(1-ap(\overline{\alpha}^{**}))}{\delta p(\overline{\alpha}^{**})(1-a)}$, dual sourcing is optimal. The optimal menu of contracts entails no distortion of the second-best part of the production $\underline{\alpha}^{**}$, and a downward distortion of the second-best part of the production $\overline{\alpha}^{**}$ from the first-best, determined as:*

$$S'(\widehat{\alpha}(\overline{\alpha}^{**})) = S'(\widehat{\alpha}(\overline{\alpha}^*)) + \frac{v}{1-v}\Delta\theta\frac{1+\delta(1-ap(\overline{\alpha}^{**}))}{\delta p(\overline{\alpha}^{**})(1-a)}$$

- *Otherwise, sole sourcing from the main supplier is the optimal procurement policy and the second-best parts of the production $\underline{\alpha}^{**}$ and $\overline{\alpha}^{**}$ are null.*

As in the previous section, the optimal procurement policy depends on the impact of the share of production on the probability of disruption. The public authority calls more (resp. less) on the backup supplier when it decreases (resp. increases) the probability of disruption. However, the complete information optimal contracts can no longer be implemented under incomplete information. At the optimal (second-best) contract, the public authority trades-off the benefit to reach allocative efficiency against the cost coming from the information rent given up to the less costly supplier B. Indeed, the rent information cost adds up to the cost of dual sourcing and then justifies downward distortions from the first-best of the part of the production achieved under asymmetric information. Relying on supplier B's backup production is less valuable for the principal. Therefore, the scope of using dual sourcing is reduced.

# 5 Procurement Policy under Lobbying

In this part of the paper, we evaluate the impact of lobbying on the choice of public procurement policy. The pure benevolence assumption is relaxed, allowing the public authority to value monetary transfers from lobbyists. His choice may be thus distorted in the direction of their interests.

## 5.1 The Model of Lobbying

In this section, we go back to the exogenous probability framework in the incomplete information case described at the section 3.2.

The public authority must choose between two procurement strategies, sole sourcing from the main supplier $a_{SS}$ and dual sourcing $a_{DS}$. Supplier A is indifferent between both strategies. Indeed, she receives no rent in both cases, $E_{\theta_A}[U(\theta_A, (1-\alpha))] = 0$. Only supplier B attempts to influence, at the beginning of the contracting game, the public authority in favor of dual sourcing defined such as in Proposition 2. While she obtains the following payoff $V_{SS}$ in case of sole sourcing:

$$V_{SS} = \delta p E_{\theta_B}[U(\theta_B, a)],$$

she obtains $V_{DS}$ in case of dual sourcing:

$$V_{DS} = E_{\theta^B}[U(\theta_B, \alpha) + \delta[(1-p)U(\theta_B, \alpha) + pU(\theta_B, \widehat{\alpha})]].$$

Supplier B receives a larger payoff if $a_{DS}$ is chosen versus $a_{SS}$ due to the fact that:

$$V_{DS} > V_{SS}$$

$$\Leftrightarrow v\Delta\theta[(1+\delta(1-p))\overline{\alpha} + \delta p\widehat{\overline{\alpha}}] > \delta p v \Delta\theta a$$

$$\Leftrightarrow v\Delta\theta\overline{\alpha}[1+\delta(1-ap)] > 0$$

We denote $W_i$, $i = SS, DS$, the social welfare if the strategy $a_i$ is chosen. Without loss of generality, we assume that the following condition defined in proposition 2 holds,

$$S'(a) \leq S'(\widehat{\alpha}(\overline{\alpha}^{FB})) + \frac{v}{1-v}\Delta\theta\frac{1+\delta(1-ap)}{\delta p(1-a)}$$

which implies that:

$$W_{SS} > W_{DS}.$$

The efficient decision is thus $a_{SS}$. Therefore, supplier B attempts to influence the procurement policy in favor of $a_{DS}$ by promising to make a non negative monetary transfer $T$ to the public authority conditionally on dual sourcing being adopted such as:

$$V_{DS} - T \geq V_{SS}$$

$$\Leftrightarrow v\Delta\theta\overline{\alpha}[1+\delta(1-ap)] \geq T$$

The transfer $T$ does not depend on the supplier's marginal cost due to the fact that it is offered at the beginning of the contracting game, before she discovers it.

As Grossman and Helpman (1994), we consider that the incumbent public authority values social welfare because it cares to be re-elected, but also monetary transfers because it can be used to finance campaign spending. Then, the public authority chooses the procurement strategy which maximizes a weighted sum of social welfare and monetary transfer, defined as:

$$\gamma W + T.$$

The parameter $\gamma$ denotes the weight on social welfare in the public authority's payoff. The latter is privately informed on $\gamma$ with $\gamma$ in $\Gamma = [\underline{\gamma}, \overline{\gamma}]$, with a cumulative distribution function $F(\gamma)$ and a density function $f(\gamma)$, both positive on $[\underline{\gamma}, \overline{\gamma}]$. Furthermore, to ensure that first order conditions are necessary and sufficient, we assume that monotone hazard rate property $(\frac{F(\gamma)}{f(\gamma)})' \geq 0$ holds.

The timing of the contracting game including lobbying unfolds as follows.

*At the first period:* Supplier B offers a monetary transfer $T$ to the public authority that she commits to pay if strategy $a_{DS}$ is chosen. Supplier B discovers her marginal cost. The public authority chooses the optimal procurement strategy between sole sourcing and dual sourcing and offers a contract to the supplier. The latter accepts or refuses the contract (if she refuses, she gets her reservation utility). The first part of the contract is implemented.

*At the second period:* The second part of the timing is described in section 2.

In the following, we determine how the public authority's private information over his sensitivity to monetary contributions may affect the participation of the backup supplier in the lobbying process and the amount of her contribution.

## 5.2 Complete Information on the Weight on Social Welfare

As a benchmark case, let us first assume that the weight on social welfare $\gamma$ is common knowledge. In this case, the public authority selects the inefficient strategy $a_{DS}$ if:

$$\gamma W_{SS} \leq \gamma W_{DS} + T$$

$$\Leftrightarrow T \geq \gamma(W_{SS} - W_{DS})$$

As supplier B's utility $(V_{DS} - T)$ decreases in the level of lobbying $T$, the constraint above is binding. Then, the supplier's transfer is defined as:

$$T^C = \{ \begin{array}{cl} \gamma(W_{SS} - W_{DS}) & \text{if } \gamma(W_{SS} - W_{DS}) \leq V_{DS} - V_{SS} \\ 0 & \text{otherwise} \end{array}$$

We denote $\underline{T}^C$ (resp. $\overline{T}^C$) the solutions when $\gamma = \underline{\gamma}$ (resp. $\gamma = \overline{\gamma}$).

The supplier B's transfer corresponds the difference between social welfare $W_{SS}$ and $W_{DS}$, weighted by the public authority's sensitivity to monetary arguments. However, supplier B attempts to influence the procurement policy in favor of $a_{DS}$ only if this transfer is lower than the difference of rents she stands to get in dual sourcing and in sole sourcing, $V_{DS} - V_{SS}$. In this case, the backup supplier lobbies to defeat sole sourcing more vigorously as the weight on social welfare $\gamma$ increases. In other words, the transfer $T^C$ increases when the public authority's sensitivity to it decreases. $T^C$ also increases when the social welfare difference $(W_{SS} - W_{DS})$ increases. When the social efficiency of sole sourcing policy $a_{SS}$ (resp. dual sourcing policy $a_{DS}$) increases (resp. decreases), supplier B has to lobby more strongly. Finally, once the supplier decides the amount of the transfer, the public authority chooses the procurement policy which maximizes his payoff.

## 5.3 Incomplete Information on the Weight on Social Welfare

We now assume that supplier B lacks information on how costly it is to influence the procurement strategy. In this case, the public authority selects the inefficient strategy $a_{DS}$ if $\gamma$ is below some threshold $\gamma_0$:

$$\gamma < \frac{T}{W_{SS} - W_{DS}} \equiv \gamma_0.$$

We suppose that $\underline{\gamma} < \gamma_0 < \overline{\gamma}$. Supplier B's payoff corresponds to:

$$\begin{aligned} V_{DS} - T \text{ if } \gamma &< \gamma_0 \\ V_{SS} \text{ if } \gamma &\geq \gamma_0 \end{aligned}$$

To determine the optimal level of transfer $T$, the firm is willing to maximize her ex ante payoff such as:

$$\underset{\{T\}}{Max}\{[V_{DS}-T]F(\gamma_0)+V_{SS}(1-F(\gamma_0))\}$$

The next proposition summarizes the solution of the supplier's problem. The assumption of monotone hazard rate ensures that the second-order condition is satisfied.

**Proposition 5** *Under uncertainty on the public authority's preferences, the optimal transfer is characterized by the following first-order condition:*

$$T^{IC}+\frac{F(\gamma_0)}{f(\gamma_0)}(W_{SS}-W_{DS})=V_{DS}-V_{SS}$$

For simplicity and in order to highlight comparative statics, we assume that $\gamma$ is drawn from the uniform distribution on [0,1]. It results that the lobbyist should pay, to influence the choice of procurement policy in favor of dual sourcing, the following monetary transfer:

$$T^{IC}=\frac{V_{DS}-V_{SS}}{2}$$

$$\Leftrightarrow T^{IC}=\frac{v\Delta\theta\overline{\alpha}[1+\delta(1-ap)]}{2}.$$

Supplier B's ability to increase her production at the second period is one of the determinants of the transfer. The lower the "production flexibility" parameter $a$, the higher the level of the transfer $T^{IC}$. As $a$ decreases, the probability of dual sourcing (without any lobbying) increases so there is less scope for lobbying. It is also the case as the risk of disruption $p$ increases and as the discount factor $\delta$ decreases. Furthermore, supplier B lobbies to defeat sole sourcing more vigorously the greater the rent she stands to obtain. So, when the probability $v$, the suppliers heterogeneity $\Delta\theta$ and the $\overline{\theta}$-supplier B level of production $\overline{\alpha}$ increase, the level of transfer $T^{IC}$ also increases.

We close this part of the paper by determining how the public authority's private information over $\gamma$ affects supplier B's monetary contribution. To do so, we compare the transfer $T^{IC}$ with the previous one, $T^{C}$, defined in section 5.2. Under complete information, when $\gamma$ is drawn from the uniform distribution on [0,1], the transfer becomes:

$$T^{C}=\frac{1}{2}(W_{SS}-W_{DS}).$$

when $\frac{1}{2}(W_{SS}-W_{DS})\leq V_{DS}-V_{SS}$.[20] In this case, we can easily show that:

$$T^{C}<T^{IC}.$$

[20] Our attention will be restricted to the most interesting case in which supplier B has interest to lobby.

Under incomplete information, the lobbyist has to give an informational rent to the public authority for his informational advantage over her. Transfer being more expensive, supplier B are less incentive to lobby and therefore, the inefficient dual sourcing strategy is less adopted.

# 6 Conclusion

Suppliers around the world may experience severe disasters causing major supply disruptions. The choice of the optimal procurement policy, in regard of the number of simultaneous suppliers and their respective share of production, is thus strategically important. Sole sourcing can increase the provision of service's exposure to the risk of disruption, but at the same time, dual sourcing presents greater procurement costs using a more costly secondary supplier. In this paper, we show that the optimal procurement policy depends mainly on the secondary supplier's ability to compensate for the default production. Dual sourcing is more (resp. less) likely to be the optimal policy as the secondary supplier's compensation for the default production decreases (resp. increases). Indeed, when the production flexibility diminishes, the disruption cost increases and it becomes harder to ensure the continuity of the provision of the service. The best sourcing strategy is then to rely more on the secondary supplier to ensure a backup production in case of disruption. A potential policy implication of our results for energy supply might be that dual sourcing should be considered as a mean of ensuring security of energy supply.[21] When the renewable energy's ability to increase its production quickly is sufficiently limited, a public authority should not to be too reliant on any conventional energy (nuclear or fossil fuel) that can be cut off due to catastrophic events. He must keep his energy sources diversified. Nowadays, the potential of renewable energies has not been fully exploited. In general, there are neither sufficiently deployed to compensate for the default production in case of disruption nor sufficiently integrated in the energy portfolio as a secondary source. Yet, through the renewable energy mix, they can contribute to the pursuit of energy independence and ensure the sustainability of the production. Therefore, promoting renewable energy systems could be strategically important in the long term as it will contribute to the security of energy supply. We also find that whatever the determination of the probability of disruption (exogenously or endogenously), asymmetric information about the backup supplier's cost reduces the scope of dual sourcing. Contrary to the

[21] Another example of public service threatened by potential supply disruption is drinking water. To hedge against this risk, it may be necessary to develop technology for alternative sources of freshwater, such as desalination technology. Opting for such a backup supply is expensive but reduces the threat of a water supply disruption as a result of an accidental or intentional (e.g. terror event) contamination. To illustrate, due to its geopolitical history, Israel have already decided to address water supply disruption by launching the Hadera seawater reverse osmosis (SWRO) desalination plant.

widespread view that dual sourcing has specific incentive properties, we show that the backup supplier's information advantage prevents the public authority from achieving the efficient share of production. Finally, even if dual sourcing is not the efficient procurement strategy from an economic point of view, it may still be adopted by the public authority. The latter may be influenced by the backup supplier who acts as a lobbyist. Her ability to do so is, however, limited when the public authority has a private information over his sensitivity to monetary contributions.

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# Appendix A

**Proof.** Comparative statics in section 3.1. The first-best part of the production awarded to the secondary supplier $\alpha^{FB}$ is given by:

$$S'(\widehat{\alpha}(\alpha^{FB}(a), a)) = \theta_B + (\theta_B - \theta_A)\frac{1 + \delta(1-p)}{\delta p(1-a)}.$$

In order to facilitate the following analysis, we denote $f(a) = \widehat{\alpha}(\alpha^{FB}(a), a)$. Therefore, we obtain:

$$S'(f(a)) = \theta_B + (\theta_B - \theta_A)\frac{1 + \delta(1-p)}{\delta p(1-a)}.$$

We derive this result with respect to $a$:

$$f'(a)\ S''(f(a)) = (\theta_B - \theta_A)\frac{1 + \delta(1-p)}{\delta p}\frac{1}{(1-a)^2}. \tag{13}$$

We have $f(a) = \widehat{\alpha}(\alpha^{FB}(a), a)$ with $\widehat{\alpha}(\alpha, a) = \alpha + a(1-\alpha)$, hence:

$$\frac{\partial f(a)}{\partial a} = \frac{\partial \alpha^{FB}(a)}{\partial a}(1-a) + (1 - \alpha^{FB}(a)).$$

Therefore, equation (13) becomes:

$$\frac{\partial \alpha^{FB}(a)}{\partial a}(1-a) + (1 - \alpha^{FB}(a))\ S''(f(a)) = \frac{(\theta_B - \theta_A)[1 + \delta(1-p)]}{\delta p(1-a)^2}$$

and we finally obtain:

$$\frac{\partial \alpha^{FB}(a)}{\partial a} = \frac{(\theta_B - \theta_A)[1 + \delta(1-p)]}{\delta p(1-a)^3 S''(f(a))} - \frac{(1 - \alpha^{FB}(a))}{(1-a)}.$$

As the surplus $S$ is concave, $S''(f(a)) \leq 0$, it results that:

$$\frac{\partial \alpha^{FB}(a)}{\partial a} \leq 0.$$

The effect of supplier B's ability to compensate for the default production $a$ on the share of production $\alpha^{FB}$ is negative. ■

# Appendix B

**Proof.** Proposition 2. The public authority solves the maximization program (P2) and we obtain for the inefficient $\overline{\theta}$-supplier B:

$$\frac{\partial \overline{I}}{\partial \overline{\alpha}} + \frac{v}{1-v}\Delta\theta(1+\delta) = \delta p[\frac{\partial \overline{R}}{\partial \overline{\alpha}} + \frac{v}{1-v}\Delta\theta a] \tag{14}$$

Inserting the derivatives of investment and returns into equation (14), we must have $\overline{\alpha}^{SB}$ such as:

$$S'(\widehat{\alpha}(\overline{\alpha}^{SB})) = \theta_B + (\theta_B - \theta_A)\frac{1+\delta(1-p)}{\delta p(1-a)} + \frac{v}{1-v}\Delta\theta\frac{1+\delta(1-ap)}{\delta p(1-a)}$$

that can be written as:

$$S'(\widehat{\alpha}(\overline{\alpha}^{SB})) = S'(\widehat{\alpha}(\overline{\alpha}^{FB})) + \frac{v}{1-v}\Delta\theta\frac{1+\delta(1-ap)}{\delta p(1-a)}$$

This new expression shows clearly that the marginal benefit of dual sourcing in incomplete information depends on its expression in the complete information. ■

**Proof.** Proposition 3. The maximization program (P3) yields:

$$\frac{\partial I}{\partial \alpha} = \delta[p(\alpha)\frac{\partial R}{\partial \alpha} - \frac{\partial p(\alpha)}{\partial \alpha}\frac{1}{p(\alpha)(1-a)}(S - \theta_A - S(a) + \theta_B a + U(\theta_B, a) - R)] \tag{15}$$

Replacing the derivatives of investment and returns into equation (15), the share of production is defined by:

$$S'(\widehat{\alpha}(\alpha^*)) = \theta_B + (\theta_B - \theta_A)\frac{1+\delta(1-p(\alpha^*))}{\delta p(\alpha^*)(1-a)} + \frac{\partial p(\alpha)}{\partial \alpha}\Big|_{\alpha=\alpha^*}\frac{1}{p(\alpha^*)(1-a)}[S - \theta_A - S(\widehat{\alpha}(\alpha^*)) + \theta_B\widehat{\alpha}(\alpha^*)]$$

This yields the following expression at $p = p(\alpha)$:

$$S'(\widehat{\alpha}(\alpha^*)) = S'(\widehat{\alpha}(\alpha^{FB})) + \frac{\partial p(\alpha)}{\partial \alpha}\Big|_{\alpha=\alpha^*}\frac{1}{p(\alpha^*)(1-a)}[S - \theta_A - S(\widehat{\alpha}(\alpha^*)) + \theta_B\widehat{\alpha}(\alpha^*)]$$

Under complete information, the marginal benefit of splitting the provision of the public service between both suppliers when the probability of disruption is endogenous depends on its expression when such probability is exogenous. ■

**Proof.** Proposition 4. The public authority solves the maximization program (P4) and we get for the inefficient $\overline{\theta}$-supplier B:

$$\frac{\partial \overline{I}}{\partial \overline{\alpha}} + \frac{v}{1-v}\Delta\theta(1+\delta) = \delta[p(\overline{\alpha})\frac{\partial \overline{R}}{\partial \overline{\alpha}} - \frac{\partial p(\overline{\alpha})}{\partial \overline{\alpha}}(S - \theta_A - S(a) + \overline{\theta}a + U(\overline{\theta}, a) - \overline{R}) + \frac{v}{1-v}p(\underline{\alpha})\Delta\theta a]$$

Substituting the derivatives of investment and returns in the previous equation, the maximization yields now:

$$\begin{aligned} S'(\widehat{\alpha}(\overline{\alpha}^{**})) &= \theta_B + (\theta_B - \theta_A)\frac{1+\delta(1-p)}{\delta p(1-a)} \\ +\frac{\partial p(\overline{\alpha})}{\partial \overline{\alpha}} &\mid_{\overline{\alpha}=\overline{\alpha}^{**}} \frac{1}{p(\overline{\alpha}^{**})(1-a)}[S-\theta_A - S(\widehat{\alpha}(\overline{\alpha}^{**})) + \theta_B\widehat{\alpha}(\overline{\alpha}^{**})] + \frac{v}{1-v}\Delta\theta\frac{1+\delta(1-ap(\overline{\alpha}^{**}))}{\delta p(\overline{\alpha}^{**})(1-a)} \end{aligned}$$

We immediately obtain the following expression:

$$S'(\widehat{\alpha}(\overline{\alpha}^{**})) = S'(\widehat{\alpha}(\overline{\alpha}^{*})) + \frac{v}{1-v}\Delta\theta\frac{1+\delta(1-ap(\overline{\alpha}^{**}))}{\delta p(\overline{\alpha}^{**})(1-a)}$$

Under the endogenous probability of disruption, the marginal benefit of dual sourcing in incomplete information depends on its expression in the complete information. ■