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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, whereas under traditional procurement, these tasks are delegated to separate private contractors. The two provision modes differ in their incentives to innovate and to gather private information about future costs to adapt the service provision to changing circumstances. The government agency's preferred mode of provision depends on the information gathering costs, the costs of innovation efforts, and on the degree to which effort is contractible.

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

JEL Classification: D86; L33; H11

1   Introduction

In the last two decades, 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 better informed than the public authority about additional costs that may arise in the operation stage when changes in circumstances occur.[3]

In this article, we study in an incomplete contracting framework how incentives to exert innovation effort and incentives to acquire private information affect the performance of public-private partnerships compared to traditional procurement.

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. Ini-

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[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, whereas under traditional procurement there are separate contractors for construction and management.

[2]For example, Yescombe (2007, p. 21) stresses that as 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 (2006), Chong, Huet, Saussier, and Steiner (2006), 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.

tially, 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 introduce new medical treatments and 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 effort to come up with an innovation, which reduces the costs of adapting the public good or service to future needs.[5] Innovation effort is unobservable, but the government agency obtains a verifiable but noisy signal on the effort level.

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,

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[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 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." Similarly, 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.

then these costs will 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. However, in the second stage, while using the infrastructure to provide the public service, the operator learns the adaptation costs without exerting extra effort.[6] Thus, costly information gathering in the first stage is a socially wasteful activity which may be pursued for strategic reasons only.

In a first-best world in which the effort to come up with an innovation and the information gathering decision in the first stage were verifiable, the government agency would be indifferent between the two modes of provision. However, as we assume that innovation effort is a hidden action and information gathering in the first stage cannot be ruled out, the two modes of provision differ with regard to their incentive structure.

Specifically, under traditional procurement the government agency can induce innovation effort only by offering a direct reward conditional on the verifiable but noisy signal, so that the government agency must leave a limited liability rent to the builder. In contrast, in case of a public-private partnership incentives to innovate can arise indirectly when the consortium anticipates that it may enjoy a second-stage information rent if in the first stage it develops an innovation and gathers information. As a consequence, for the government agency a public-private partnership has the advantage that the indirect incentives reduce the limited liability rent which is necessary to induce innovation effort. Yet, the disadvantage of a public-private partnership is that the consortium may gather socially wasteful information which makes it more costly for the government agency to implement the second-stage service improvements.

As a result of this trade-off, it turns out that the government agency prefers a public-private partnership when the quality of the effort signal is low, such that under traditional procurement a large limited liability rent would have to be paid. In contrast, when the effort signal is very precise, the agency prefers traditional procurement. Moreover, when the information gathering costs are relatively small, a public-private partnership is the government agency's preferred mode of provision, because in this case the indirect effort incentives due to the expected information rent

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[6]Note that it is natural to assume that once an operator provides the public service and thus uses the infrastructure, he is in a better position to obtain information about the costs of improving the service provision. The assumption that relevant information becomes costlessly available to an agent after a contract is signed is common in the literature on endogenous information structures, see e.g. Crémer and Khalil (1992; 1994) and Crémer, Khalil, and Rochet (1998a).

in case of an innovation are strong. Furthermore, we allow the government agency to put some positive weight on the profits that accrue to the private contractors. An increase in this weight makes traditional procurement more attractive for the government agency, because then it suffers less from leaving a limited liability rent to a private contractor and it wants to avoid the welfare loss due to socially wasteful information gathering.

To present our central trade-off in its purest form, in the main part of the article we assume that the government agency can observe whether or not information is gathered at the end of the first stage. We show in an extension that our results are qualitatively robust when information gathering is unobservable, even though then in case of a public-private partnership the equilibrium may be in mixed strategies such that ex post inefficiencies may occur.

There is by now a vast literature on the role of private firms in the provision of public goods.[7] 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. Whereas 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 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.[8] 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 (2010). 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 re-

[7]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).

[8]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.

lated questions 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, highlighting the positive (resp., negative) effects of bundling in the presence of positive (resp., negative) externalities between the stages.[9] In more recent contributions to the literature on public-private partnerships, Iossa and Martimort (forthcoming) and Martimort and Straub (2012) analyze the costs and benefits of bundling the building and the operating stage when a productivity shock occurs between the two stages. To the best of our knowledge, our article is the first one which introduces information gathering into a public-private partnership context.[10]

The remainder of the article is organized as follows. In the next section, the model is introduced. The two different modes of provision are studied in Section 3 (traditional procurement) and Section 4 (public-private partnership). In Section 5, we analyze which mode of provision is preferred by the government agency. In Section 6, we explore the robustness of our results with regard to the unobservability of information gathering. Concluding remarks follow in Section 7. All proofs have been relegated to the appendix.

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), whereas 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

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

[10]In our model, information gathering is a strategic rent-seeking activity which has no productive value. The same assumption has first been made in otherwise standard adverse selection models by Crémer and Khalil (1992, 1994). Further contributions in which information gathering is socially wasteful include Crémer, Khalil, and Rochet (1998a), Schmitz (2006), and Hoppe and Schmitz (2010b), whereas productive information gathering has been studied by Aghion and Tirole (1997), Lewis and Sappington (1997), Crémer, Khalil, and Rochet (1998b), Kessler (1998), and Khalil, Kim, and Shin (2006).

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.

The 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 effort $e \in \{0, 1\}$ at non-monetary effort costs $e\psi$, where $\psi > 0$. We assume throughout that the effort level e is unobservable. Yet, the principal obtains a verifiable but noisy signal $\sigma \in \{0, 1\}$ on the agent's effort level. Specifically, $\Pr\{\sigma = 1 | e = 1\} = \Pr\{\sigma = 0 | e = 0\} = \pi$, where $\pi \in (1/2, 1]$ denotes the precision of the signal. The agent's effort leads to a success ($x = 1$) with probability $e\phi$ and to a failure ($x = 0$) otherwise, where the outcome x is observable but not verifiable, and $\phi \in (0, 1)$. A success means that an innovation has been developed that reduces the costs of undertaking adaptations (not yet describable in stage 1) to improve the service provision in the second stage.[11]

Specifically, in the second stage the agent in charge of task 2 can provide a standard 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 improvements of the service provision which yield an additional benefit b to the principal. Let $y \in \{0, 1\}$ denote whether or not the adaptations are implemented. The non-monetary effort costs of improving the second-stage service provision are denoted by yc. If there was no innovation ($x = 0$), then $c = c_h$, whereas $c \in \{c_l, c_m\}$ with $\Pr\{c = c_l\} = p$ if an innovation was made ($x = 1$), where $0 < c_l < c_m < c_h$. Hence, if an innovation was made, the expected adaptation costs are $E[c] = pc_l + (1 - p)c_m$. To rule out trivial cases in which implementing the adaptations is never desirable, we assume that $b \geq c_l$.

If an innovation was made, initially no one knows the realization of the adaptation costs $c \in \{c_l, c_m\}$. However, at the end of stage 1, the agent in charge of task 1 can exert effort in order to gather information about the costs c. In particular, if the agent incurs non-monetary effort costs $\gamma > 0$, then he learns the realization of c, whereas he remains uninformed otherwise. The agent in charge of the second stage uses the infrastructure to provide the service and thereby he costlessly learns the adaptation costs c before the adaptations may take place. In line with the work of Crémer

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[11]Our assumption that an innovation is observable ex post but cannot be contracted upon ex ante is in line with Aghion and Tirole's (1994a, 1994b) work on the management of innovation.

and Khalil (1992; 1994) and Crémer, Khalil, and Rochet (1998a), costly information gathering in the first stage is thus "premature," it is an unproductive rent seeking activity which may be performed for strategic reasons only.

Throughout, an agent's utility is given by the payment he gets from the principal minus his costs. Following Baron and Myerson (1982), we assume that the principal may put some weight on the utility that accrues to the agent(s). Let this weight be given by $\alpha \in [0, 1)$. Hence, if $\alpha = 0$, the principal is interested only in her benefit $B + yb$ net of her payment to the agent(s). If α goes to one, the principal's objective function approaches that of a welfare maximizer.
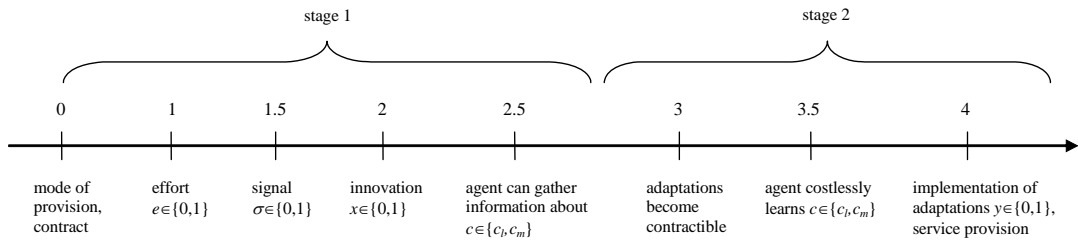

Figure 1. The sequence of events.

The sequence of events is illustrated in Figure 1. At date 0, the principal chooses the mode of provision (traditional procurement or a public-private partnership). The principal always offers to cover the verifiable costs C_1 and C_2. Moreover, at date 0 she can contractually commit to pay the agent who is in charge of the first task a reward whenever the verifiable effort signal will be favorable ($\sigma = 1$).[12] At date 1, the agent in charge of the first task builds the basic version of the infrastructure and decides how much effort e to exert to come up with an innovation. At date 1.5, the verifiable signal σ is realized, and at date 2, the parties observe whether or not an innovative infrastructure has been developed. In case of an innovation, at date 2.5 the agent who has built the infrastructure can (prematurely) learn the costs of future adaptations if he incurs information gathering costs γ. In line with Kessler (1998), in the main part of the article we assume that the principal can observe whether or not the agent has gathered information.[13]

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[12] Note that as the agent is protected by limited liability, payments to the agent cannot be negative. Hence, it is not possible to implement a penalty in case of an unfavorable signal.

[13] This assumption simplifies the exposition and thus allows us to present our main trade-off in its purest form. We analyze the case of unobservable information gathering in Section 6.

At date 3, the adaptations necessary to improve the second-stage service provision become contractible. The principal can then offer the agent in charge of the second task a payment for the implementation of the adaptations. In case of an innovation, at date 3.5 the agent costlessly learns the adaptation costs $c \in \{c_l, c_m\}$ (he learns nothing new when he has already gathered information at date 2.5). Finally, at date 4 the adaptations may take place and the agent provides the public good or service.

Note that in our model the only difference between the two modes of provision is the fact that in case of a public-private partnership, the same agent is in charge of both tasks, whereas in case of traditional procurement, two different agents are in charge of the two tasks. Thus, in a first-best world the mode of provision would be irrelevant.

The first-best benchmark. Note that costly information gathering at date 2.5 is socially wasteful, because the same information will become costlessly available at date 3.5, before the adaptations may take place. Hence, in a first-best world, the information gathering costs γ would never be incurred. Moreover, in a first-best world the adaptations would be implemented ($y^{FB}(c) = 1$) whenever $b \geq c$. Thus, the first-best effort level is $e^{FB} = 1$ if and only if

$$\phi[p(b - c_l) + (1 - p)\max\{b - c_m, 0\}] + (1 - \phi)\max\{b - c_h, 0\} - \psi \geq \max\{b - c_h, 0\}.$$

This implies that if $b \geq c_m$, then $e^{FB} = 1$ whenever $\psi \leq \phi(\min\{b, c_h\} - E[c])$. Moreover, if $b < c_m$, then $e^{FB} = 1$ whenever $\psi \leq \phi p(b - c_l)$.

Regardless of the mode of provision, the principal would implement the first-best outcome if the effort level e and the information gathering decision were verifiable. However, in the remainder of the article we assume that innovation effort e is a hidden action and premature information acquisition is not contractible. Thus, when we find that one of the two modes of provision is strictly preferred, then this must be due to incentive considerations only.

3   Traditional procurement

We first consider traditional procurement. In the second stage, the principal hires agent 2 (the operator) to use the infrastructure in order to provide a public good or service. The principal offers the agent to take over the verifiable costs C_2. Moreover, at the beginning of the second stage the adaptations that can improve the service provision become contractible. Therefore, at date 3 the principal considers to offer one of the following three contractual arrangements to the agent.

$\mathcal{A}_l$: *The agent has the option to decide at date 4 whether or not to implement the adaptations; i.e., he is free to choose $y \in \{0, 1\}$. As a compensation, the agent will get the payment $y c_l$.*

$\mathcal{A}_h$: *The agent has to implement the adaptations (i.e., he must choose $y = 1$) at date 4. As a compensation, he gets the payment c_h.*

$\mathcal{A}_{E[c]}$: *The agent has to implement the adaptations (i.e., he must choose $y = 1$) at date 4. As a compensation, he gets the payment $E[c]$.*

Suppose first that there was no success at date 2 ($x = 0$), so that the effort costs of implementing the second-stage service improvements are $c = c_h$. If the principal's benefit from the adaptations outweighs their costs ($b \geq c_h$), then at date 3 the principal offers contract $\mathcal{A}_h$ to the agent (which will be accepted by the agent, as his costs are reimbursed).[14] Otherwise, the principal will not ask the agent to implement the adaptations.

Next, suppose that there was an innovation ($x = 1$), so that at the beginning of the second stage the principal and the operator are uninformed about whether the adaptation costs are c_l or c_m. If implementing the adaptations is ex post efficient regardless of the state of nature ($b \geq c_m$), then at date 3 the principal offers contract $\mathcal{A}_{E[c]}$, which the agent will accept because his expected costs are reimbursed. If implementing the adaptations is desirable in the good state of nature only ($c_l \leq b < c_m$), then at date 3 the principal offers contract $\mathcal{A}_l$. The agent will accept the contract and after he has learnt the realization of c at date 3.5, he will implement the adaptations whenever $c = c_l$.

Note that in each case the first-best adaptation decision $y^{FB}(c)$ is implemented, and the agent gets no rent. Therefore, at date 3 the principal cannot attain a larger expected payoff. We can thus state the following result.

Lemma 1 *Consider traditional procurement. At date 3, the principal's continuation payoff is $B - C_2 + \max\{b - c_h, 0\}$ if $x = 0$, $B - C_2 + b - E[c]$ if $x = 1$ and $b \geq c_m$, and $B - C_2 + p(b - c_l)$ if $x = 1$ and $b < c_m$.*

Now consider the first stage. The principal hires agent 1 (the builder) to design and build the infrastructure. She offers the agent to bear the verifiable costs C_1. Under traditional procurement, agent 1 knows that he will not be in charge of the second stage. Hence, as the information will not be relevant for him, he does not engage in

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[14]It is straightforward to check that contract $\mathcal{A}_h$ could be equivalently replaced by a contract in which the agent can choose $y \in \{0, 1\}$ at date 4 and he gets the payment $y c_h$.

costly information gathering at date 2.5. The only possibility for the principal to induce the agent to exert innovation effort at date 1 is to offer him a contract at date 0 which promises the agent a reward conditional on the verifiable signal σ. Let $w \geq 0$ denote the payment that the principal commits to make to the agent whenever the signal is favorable ($\sigma = 1$).[15]

When the agent exerts high effort ($e = 1$), he will get the reward w with probability $\pi > 1/2$, whereas he will get the reward only with probability $1 - \pi$ when he shirks. Hence, the agent exerts high effort whenever the incentive compatibility constraint

$$\pi w - \psi \geq (1 - \pi)w$$

is satisfied. Therefore, if the principal wants to induce high effort, she sets $w^{TP} = \psi/(2\pi - 1)$,[16] so that the agent's limited liability rent is $\psi\pi/(2\pi - 1) - \psi$. Note that the more precise the signal is, the smaller is the rent that the principal must leave to the agent. Whether or not the principal actually wants to induce high effort depends on the effort costs ψ as well as on the precision π of the signal. In particular, we obtain the following result.

Proposition 1 *Consider traditional procurement.*

(i) Suppose that $b \geq c_m$. The principal induces high effort whenever

$$\psi \leq \psi^{TP}(\pi, \alpha) := \phi(\min\{b, c_h\} - E[c])\frac{2\pi - 1}{\pi - \alpha(1 - \pi)}.$$

(ii) Suppose that $b < c_m$. The principal induces high effort whenever

$$\psi \leq \tilde{\psi}^{TP}(\pi, \alpha) := \phi p(b - c_l)\frac{2\pi - 1}{\pi - \alpha(1 - \pi)}.$$

Proof. See the appendix. ∎

If the effort costs ψ are sufficiently small, the principal implements high effort. Yet, as the principal can induce high effort only by leaving a limited liability rent to the agent, high effort is not always implemented when it would be chosen in the first-best benchmark.

Observe that the threshold functions $\psi^{TP}(\pi, \alpha)$ and $\tilde{\psi}^{TP}(\pi, \alpha)$ are increasing in the precision π of the signal and in the weight α that the principal puts on the agents'

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[15] It is straightforward to show that it is never optimal to reward the agent if the signal is unfavorable ($\sigma = 0$). For an excellent textbook exposition of the standard moral hazard model with limited liability, see Laffont and Martimort (2002).

[16] Note that the principal always wants to make transfer payments to the agents as small as possible, because a payment $t > 0$ to an agent reduces the principal's payoff by $(1 - \alpha)t > 0$.

utility. In particular, if π goes to one, then the principal's decision to implement high effort approaches the first-best benchmark, because in this case the rent that is necessary to induce high effort becomes zero. The first-best benchmark is also approached if α goes to one, because then in the limit the principal becomes a welfare maximizer who does not find it costly to leave a rent to the agent.

4 Public-private partnership

Now let us consider a public-private partnership, so that the same agent is in charge of both stages. The principal offers the agent to take over the verifiable costs C_1 in the first stage and C_2 in the second stage. Suppose that there was no success at date 2 ($x = 0$), so that the effort costs of implementing the second-stage service improvements are c_h. Note that then there is no scope for information gathering at date 2.5. At date 3, the principal will implement the adaptations (by offering contract $\mathcal{A}_h$) whenever $b \geq c_h$. Next, suppose there was an innovation ($x = 1$), but the agent has not gathered information at date 2.5. Then, in analogy to the case of traditional procurement, the principal will offer the contract $\mathcal{A}_{E[c]}$ if $b \geq c_m$, and she offers the contract $\mathcal{A}_l$ otherwise. Therefore, the following result holds.

Lemma 2 *Consider a public-private partnership. If there was no innovation in the first stage or if there was an innovation but the agent has not gathered information at date 2.5, then the principal's continuation payoff at date 3 is as in the case of traditional procurement (see Lemma 1) and the agent's continuation payoff is zero.*

Now suppose that at date 2 an innovation was made ($x = 1$) and the agent has gathered information at date 2.5. Note that if the agent has learnt that his costs are c_l, then at date 3 he will agree to implement the adaptations whenever the principal offers at least the payment c_l. Similarly, if the agent has learnt that his costs are c_m, then at date 3 he will agree to implement the adaptations whenever he is offered at least c_m. Thus, at date 3 the principal offers either contract $\mathcal{A}_l$ or contract $\mathcal{A}_m$, which is defined as follows.[17]

$\mathcal{A}_m$: *The agent has to implement the adaptations (i.e., he must choose $y = 1$) at date 4. As a compensation, he gets the payment c_m.*

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[17] If the agent is informed, contract $\mathcal{A}_l$ could be equivalently replaced by a contract according to which the agent must choose $y = 1$ (as he learns nothing new after accepting the contract). Similarly, contract $\mathcal{A}_m$ could be equivalently replaced by a contract in which the agent chooses $y \in \{0, 1\}$ at date 4 and the agent gets the payment yc_m.

If the principal offers contract $\mathcal{A}_m$, the adaptations will be implemented regardless of the realization of c, and the agent enjoys an information rent $c_m - c_l$ in the good state of nature. At date 3, the principal's expected payoff then is $B - C_2 + b - c_m + \alpha p(c_m - c_l)$. If the principal offers contract $\mathcal{A}_l$, the adaptations are implemented in the good state of nature only and the agent gets no rent. At date 3, the principal's expected payoff then is $B - C_2 + p(b - c_l)$. A comparison of the expected payoffs immediately yields the following result.

Lemma 3 *Consider a public-private partnership. Suppose that there was an innovation and the agent has gathered information at date 2.5. Define*

$$\hat{b}(\alpha) := (1 - \alpha)\frac{c_m - pc_l}{1 - p} + \alpha c_m.$$

(i) If $b \geq \hat{b}(\alpha)$, then at date 3 the principal offers contract $\mathcal{A}_m$, so that her expected continuation payoff is $B - C_2 + b - c_m + \alpha p(c_m - c_l)$ and at date 2.5 the agent's expected information rent is $p(c_m - c_l) - \gamma$.

(ii) If $b < \hat{b}(\alpha)$, then at date 3 the principal offers contract $\mathcal{A}_l$, so that her expected continuation payoff is $B - C_2 + p(b - c_l)$ and the agent gets no rent.

If the benefit from implementing the adaptations is sufficiently large $(b \geq \hat{b}(\alpha))$, the principal always wants the adaptations to be undertaken. In contrast, if b is sufficiently small, the principal prefers not to implement the adaptations in the bad state in order to extract a larger part of the benefit in the good state. Note that the critical value $\hat{b}(\alpha)$ is larger than c_m. Hence, if the agent gathered information in the case $c_m < b < \hat{b}(\alpha)$, the adaptation decision would be ex post inefficient in the bad state of nature. Otherwise, ex post efficiency $(y = y^{FB}(c))$ is achieved.

Now consider the first stage. Recall that costly information gathering at date 2.5 is socially wasteful, because the information will be costlessly available at date 3.5. Yet, the agent may nevertheless engage in premature information gathering in order to gain a strategic advantage. Specifically, the agent gathers information at date 2.5 whenever an informed agent gets an information rent in the second stage, provided that the information acquisition costs are sufficiently small.

Lemma 4 *Consider a public-private partnership and suppose that there was an innovation. The agent will gather information at date 2.5 whenever (i) an informed agent gets an information rent in the second stage (i.e., $b \geq \hat{b}(\alpha)$) and (ii) the information gathering costs are smaller than the expected second-stage information rent, $\gamma \leq p(c_m - c_l)$.*

As in a public-private partnership the same agent is in charge of both stages, the agent can be motivated to exert innovation effort in the first stage for two different reasons. First, the principal can directly incentivize the agent by offering to pay him a reward $w \geq 0$ in case of a favorable signal ($\sigma = 1$). Second, investment incentives can arise indirectly when the agent anticipates that he may enjoy a second-stage information rent if he comes up with an innovation in the first stage.

Note that if information gathering is prohibitively costly ($\gamma > p(c_m - c_l)$) or if adaptations are not sufficiently important ($b < \hat{b}(\alpha)$), then according to Lemma 4 the agent will never gather information at date 2.5. In this case, we know from Lemma 2 that the principal's expected date-3 payoffs do not differ between a public-private partnership and traditional procurement. Moreover, the agent never gets a second-stage rent, so that the agent can only be motivated to exert first-stage effort through a direct reward w, just as in the case of traditional procurement. Hence, in case of a public-private partnership the principal would implement the same first-stage effort levels as under traditional procurement (see Proposition 1). As a result, at date 0 the principal would be indifferent between the two modes of provision.

Remark 1 *Consider a public-private partnership. If $\gamma > p(c_m - c_l)$ or $b < \hat{b}(\alpha)$, then there is no information gathering at date 2.5 and the principal induces the same effort levels as in case of traditional procurement, so that she is indifferent between the two modes of provision.*

In what follows, we consider the interesting case in which information gathering at date 2.5 is not prohibitively costly and in which the adaptations are sufficiently important; i.e., we make the following assumption.

Assumption 1 *(i)* $\gamma \leq p(c_m - c_l)$.

(ii) $b \geq \hat{b}(\alpha)$.

At date 1, the agent knows that he will get the direct reward w with probability π if he exerts high effort ($e = 1$); otherwise he will get the reward w with probability $1 - \pi$ only. Moreover, he knows that in case of an innovation ($x = 1$), he will gather information (which entails information gathering costs γ) and his expected second-stage information rent is $p(c_m - c_l)$. At date 1, the agent thus exerts high effort whenever the incentive compatibility constraint

$$\pi w + \phi[p(c_m - c_l) - \gamma] - \psi \geq (1 - \pi)w$$

is satisfied.

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Hence, there are two cases. If $\psi \leq \phi[p(c_m - c_l) - \gamma]$, then the prospect to earn the second-stage information rent is so attractive for the agent that he exerts high effort even in the absence of direct incentives; i.e., the principal will set $w^{PPP} = 0$. In contrast, if $\psi > \phi[p(c_m - c_l) - \gamma]$, then the indirect incentives alone are not strong enough to motivate the agent to exert high effort. In this case, if the principal wants to implement high effort, she will set $w^{PPP} = (\psi - \phi[p(c_m - c_l) - \gamma])/(2\pi - 1)$. We thus obtain the following result.

Proposition 2 *Consider a public-private partnership and let Assumption 1 be satisfied.*

(i) If $\psi \leq \phi[p(c_m - c_l) - \gamma]$, the agent always exerts high effort.

(ii) If $\psi > \phi[p(c_m - c_l) - \gamma]$, the principal implements high effort whenever

$$\psi \leq \psi^{PPP}(\pi, \alpha, \gamma) := \phi(\min\{b, c_h\} - c_m)\frac{2\pi - 1}{\pi - \alpha(1 - \pi)} + \phi[p(c_m - c_l) - \gamma].$$

Proof. See the appendix. ∎

Observe that in case (i) the first-best effort level is implemented. However, when the second-stage information rent is not large enough to let the agent choose high effort without a direct reward (case ii), then the principal may prefer to implement low effort, even when in the first-best benchmark high effort would be chosen. The threshold function $\psi^{PPP}(\pi, \alpha, \gamma)$ is increasing in π and α. Yet, in contrast to the case of traditional procurement, even if π or α go to one, the principal's decision rule to implement high effort does not converge to the first-best benchmark. If π goes to one, the first-stage limited liability rent goes to zero, but as the principal must leave a second-stage information rent to the agent, her gain from an innovation is reduced. If α goes to one, the principal's behavior approaches that of a welfare maximizer, so that in the limit payments to the agent are not costly to her. Yet, her gain from an innovation is still smaller than in the first-best benchmark, because an innovation triggers socially wasteful information gathering.[18]

Finally, observe that the threshold function $\psi^{PPP}(\pi, \alpha, \gamma)$ is decreasing in γ. If information gathering becomes more costly, the agent's indirect incentives due to the second-stage information rent decrease, so that inducing high effort requires a larger direct reward w^{PPP} and thus becomes less attractive for the principal.

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[18]Note that we have assumed that $\alpha < 1$, so that at date 3 the principal strictly prefers to offer contract $\mathcal{A}_{E[c]}$ to an uninformed agent. If α was equal to one, transfer payments to the agent would not be costly for the principal. Hence, in the second stage she would be willing to make a transfer payment $t \geq c_m$ regardless of whether or not the agent has gathered information, so that the first-best outcome would trivially be achieved.

5 Public-private partnership versus traditional procurement

We can now analyze the principal's date-0 decision regarding the mode of provision. As first-stage effort is unobservable, under traditional procurement the principal can induce high effort only by paying a direct reward conditional on the verifiable signal. As the signal is noisy, this means that the agent must get a limited liability rent in the first stage, which is costly for the principal. In contrast, in a public-private partnership the agent has an indirect incentive to exert effort in the first stage because he anticipates that in case of a success he will obtain an information rent in the second stage. Hence, on the one hand, a public-private partnership has the advantage that first-stage effort is less costly to induce, but on the other hand it has the disadvantage that implementing the second-stage adaptations is more costly for the principal because the agent has an incentive to prematurely gather private information. This trade-off is reflected by the following result.

Proposition 3 *Let Assumption 1 be satisfied. At date 0, the principal chooses between the two modes of provision as follows.*

(i) Suppose that $\psi \leq \phi[p(c_m - c_l) - \gamma]$. Define

$$\bar{\psi}(\pi, \alpha, \gamma) := \phi[(1 - \alpha)(c_m - E[c]) + \alpha\gamma]\frac{2\pi - 1}{\pi(1 - \alpha)}.$$

The principal prefers a public-private partnership if $\psi > \bar{\psi}(\pi, \alpha, \gamma)$, whereas she prefers traditional procurement if $\psi < \bar{\psi}(\pi, \alpha, \gamma)$.

(ii) Suppose that $\psi > \phi[p(c_m - c_l) - \gamma]$. Define

$$\bar{\pi}(\alpha, \gamma) := \frac{(1 - \alpha)p(c_m - c_l) + \alpha\gamma}{(1 - \alpha)p(c_m - c_l) + (1 + \alpha)\gamma}.$$

The principal prefers a public-private partnership if $\psi < \psi^{PPP}(\pi, \alpha, \gamma)$ and $\pi < \bar{\pi}(\alpha, \gamma)$. The principal prefers traditional procurement if $\psi < \psi^{TP}(\pi, \alpha)$ and $\pi > \bar{\pi}(\alpha, \gamma)$, and she is indifferent between the two modes of provision otherwise.

Proof. See the appendix. ∎

In part (i) of Proposition 3, the first-stage effort costs ψ are relatively small, so that in case of a public-private partnership the agent exerts high effort just because of the prospect to earn a second-stage information rent, even in the absence of a direct reward in the first stage (cf. Proposition 2). The principal then prefers a public-private partnership, except when the effort costs are so small that the first-stage limited liability rent that is necessary to induce effort in case of traditional

procurement becomes less costly for the principal than the second-stage information rent that she must leave to the agent in case of a public-private partnership.

In part (ii) of Proposition 3, the first-stage effort costs are larger, so that also in case of a public-private partnership the principal must pay a direct reward to the agent in order to induce high effort (although the reward can be smaller than the one that is necessary in case of traditional procurement). As long as the first-stage effort costs are small enough so that the principal induces high effort, she prefers a public-private partnership when the precision π of the signal is sufficiently small, whereas she prefers traditional procurement if the precision is large. The reason for this finding is the fact that the limited liability rent that the principal must pay to the agent in the first stage under traditional procurement is large when the quality of the signal is poor, so that in this case a public-private partnership is more attractive.
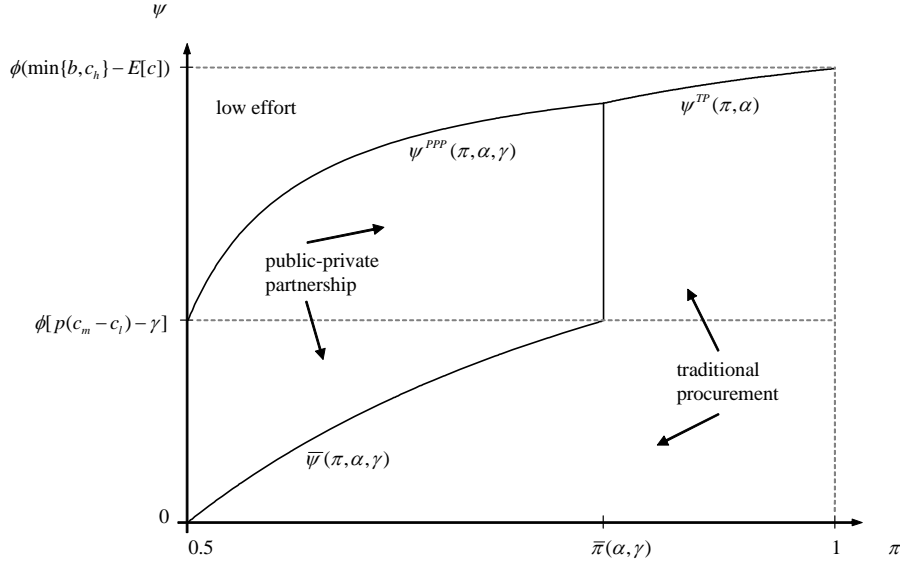

Figure 2. The principal's choice between traditional procurement and a public-private partnership. Note that high effort is first-best ($e^{FB} = 1$) whenever $\psi \leq \phi(\min\{b, c_h\} - E[c])$.

Proposition 3 is illustrated in Figure 2. Note that in the case $\psi \leq \phi[p(c_m - c_l) - \gamma]$, the principal prefers a public-private partnership (so that the agent always chooses high effort) whenever $\psi \geq \bar{\psi}(\pi, \alpha, \gamma)$, and she prefers traditional procurement (inducing high effort) otherwise. Observe that the threshold function $\bar{\psi}(\pi, \alpha, \gamma)$ is increasing in π. Intuitively, when π becomes larger, the first-stage limited liability rent that the principal must pay under traditional procurement becomes smaller, which

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makes traditional procurement more attractive. Moreover, it is straightforward to show that the threshold function $\bar{\psi}(\pi, \alpha, \gamma)$ is also increasing in α. Hence, the more weight the principal puts on the agent's utility, the larger the region in which she prefers traditional procurement. When α increases, the principal cares less about the limited liability rent, but she cares more about the fact that in case of a public-private partnership the information gathering costs are socially wasteful, so that she finds a public-private partnership less desirable. Furthermore, note that if $\alpha > 0$, then the threshold function $\bar{\psi}(\pi, \alpha, \gamma)$ is increasing in γ. The reason is that an increase in γ reduces the agent's payoff in case of a public-private partnership, so that traditional procurement becomes relatively more attractive for the principal, provided she puts a positive weight on the agent's utility.

In the case $\psi > \phi[p(c_m - c_l) - \gamma]$, Figure 1 illustrates that the principal prefers a public-private partnership whenever $\pi \leq \bar{\pi}(\alpha, \gamma)$ and traditional procurement otherwise, provided that the effort costs ψ are sufficiently small so that high effort is induced (which is the case for $\psi \leq \psi^{PPP}(\pi, \alpha, \gamma)$ in case of a public-private partnership and for $\psi \leq \psi^{TP}(\pi, \alpha)$ in case of traditional procurement). Note that the cut-off value $\bar{\pi}(\alpha, \gamma)$ is decreasing in α, which again shows that the region in which the principal prefers traditional procurement becomes larger when her behavior approaches that of a welfare maximizer. Moreover, the cut-off value is decreasing in γ. In case of a public-private partnership, if information gathering becomes more costly, then the agent is worse off and the principal must pay a larger direct reward in the first stage to induce high effort. As a consequence, traditional procurement then becomes relatively more attractive for the principal.

The comparative statics findings are summarized in the following result.

Corollary 1 *Let Assumption 1 be satisfied. At date 0, the principal's choice between the two modes of provision depends on the precision π of the effort signal, the information gathering costs γ, and on the weight α that the principal puts on the agent's utility as follows. An increase of π, γ, or α makes traditional procurement relatively more attractive, whereas a public-private partnership becomes more attractive when π, γ, or α decrease.*

6 Unobservable information gathering

So far, we have assumed that the agent's decision to gather information at date 2.5 is observable by the principal. We now analyze a variant of the model in which

information gathering is a hidden action. Note that the analysis does not change in the case of traditional procurement.

Now consider the case of a public-private partnership. The analysis of the second stage remains unchanged if there was no innovation, because then there is no scope for information gathering. Thus, suppose that there was an innovation ($x = 1$) and the agent has gathered information with probability $\mu \in [0,1]$. It is straightforward to see that at date 3 it is then optimal for the principal to offer contract $\mathcal{A}_l$, $\mathcal{A}_{E[c]}$, or $\mathcal{A}_m$.[19] If the adaptations are sufficiently important and information gathering is not prohibitively costly, the agent will now gather information with a probability strictly between zero and one.

Lemma 5 *Consider a public-private partnership. Suppose that there was an innovation and the agent's information gathering decision is unobservable. If $b \leq c_m$ or if $\gamma \geq (1-p)p(c_m - c_l)$, then the agent never gathers information. Otherwise, the agent gathers information with probability $\mu \in (0,1)$.*

Proof. See the appendix. ∎

If $b \leq c_m$, then the principal offers contract $\mathcal{A}_l$, such that the agent never gathers information. Now suppose that $b > c_m$. Intuitively, if the agent always gathered information, the principal would offer either contract $\mathcal{A}_l$ (leaving no rent to the agent) or contract $\mathcal{A}_m$ (which the agent would accept regardless of the state of nature), so that the agent would have no incentive to gather costly information. Hence, the agent gathers information with a probability strictly smaller than one. If the agent never gathered information, the principal would offer contract $\mathcal{A}_{E[c]}$, so that the agent would prefer to gather information (and then accept the offer in the good state of nature only), provided that the information gathering costs are sufficiently small.

If there is no information gathering at date 2.5, then the principal is indifferent between a public-private partnership and traditional procurement. Hence, in the remainder of this section we assume that $b > c_m$ and $\gamma < (1-p)p(c_m - c_l)$, so that the agent gathers information with probability $\mu \in (0,1)$.

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[19]Suppose the principal wants the adaptations to be implemented only if the agent knows (or learns at date 3.5) that $c = c_l$. Then contract $\mathcal{A}_l$ makes the smallest possible transfer payment to the agent. If in addition the principal wants uninformed agents who at date 3.5 will learn $c = c_m$ to implement the adaptations, contract $\mathcal{A}_{E[c]}$ makes the smallest possible transfer payment. Finally, contract $\mathcal{A}_m$ makes the smallest possible transfer payment if the principal wants the adaptations always to be implemented.

Lemma 6 *Consider a public-private partnership. Suppose that there was an innovation, the agent's information gathering decision is unobservable, and $\gamma < (1 - p)p(c_m - c_l)$.*

(i) If $c_m < b < \hat{b}(\alpha)$, then at date 2.5 the agent gathers information with probability $\mu = \frac{b - c_m}{b - E[c] - \alpha(c_m - E[c])}$. At date 3, the principal offers contract $\mathcal{A}_{E[c]}$ with probability $\lambda = \frac{\gamma}{p(E[c] - c_l)}$ and contract $\mathcal{A}_l$ with probability $1 - \lambda$. At date 3, the principal's expected continuation payoff is $B - C_2 + p(b - c_l)$, and at date 2.5 the agent's expected rent is zero.

(ii) If $b \geq \hat{b}(\alpha)$, then at date 2.5 the agent gathers information with probability $\mu = \frac{(1 - \alpha)(c_m - E[c])}{(1 - p)(b - E[c]) - p\alpha(E[c] - c_l)}$. The principal offers contract $\mathcal{A}_{E[c]}$ with probability $\lambda = \frac{\gamma}{p(E[c] - c_l)}$ and contract $\mathcal{A}_m$ with probability $1 - \lambda$. At date 3, the principal's expected continuation payoff is $B - C_2 + b - c_m + \alpha p(c_m - c_l)$, and at date 2.5 the agent's expected rent is $p(c_m - c_l) - \frac{\gamma}{1 - p}$.

Proof. See the appendix. ∎

Recall that in the setting in which information gathering was observable, in equilibrium the adaptation decisions were always ex post efficient. This is no longer the case when information gathering is unobservable, so that the equilibrium is in mixed strategies.

First, consider case (i), where b is relatively small. When an innovation was made, at date 3 the principal mixes between the contracts $\mathcal{A}_l$ and $\mathcal{A}_{E[c]}$. Thus, there is an ex post inefficiency if the agent has already learnt at date 2.5 that $c = c_m$ or if the principal offers contract $\mathcal{A}_l$ to an uninformed agent who learns at date 4 that $c = c_m$. Even though the agent gathers information with positive probability (which in the case $b < \hat{b}(\alpha)$ he would not do if information gathering was observable), at date 2.5 his expected rent is zero (just as in the observable information setting). To see this, recall that the agent must be indifferent between gathering and not gathering information. If the agent does not gather information, his expected rent is zero, regardless of whether he is offered contract $\mathcal{A}_l$ or $\mathcal{A}_{E[c]}$. Moreover, the principal's expected second-stage payoff in case of an innovation now is $B - C_2 + p(b - c_l)$, which is less than the expected second-stage payoff $B - C_2 + b - E[c]$ that the principal would get in the setting with observable information gathering (where the agent is always uninformed when $b < \hat{b}(\alpha)$). As a consequence, whereas for $b < \hat{b}(\alpha)$ the principal was always indifferent between traditional procurement and a public-private partnership in the setting with observable information gathering, she now strictly prefers traditional procurement, provided that (at least under traditional procurement) she wants to

implement high effort.

Next, consider case (ii), where b is relatively large. After an innovation was made, the principal mixes between the contracts $\mathcal{A}_m$ and $\mathcal{A}_{E[c]}$. Hence, an ex post inefficiency occurs when contract $\mathcal{A}_{E[c]}$ is offered and the agent has already learnt at date 2.5 that $c = c_m$. Observe also that the principal must be indifferent between the contracts $\mathcal{A}_m$ and $\mathcal{A}_{E[c]}$, and an offer $\mathcal{A}_m$ is always accepted such that the principal's expected second-stage payoff is $B - C_2 + b - c_m + \alpha p(c_m - c_l)$, which is the same as in the setting with observable information gathering when $b \geq \hat{b}(\alpha)$. Yet, at date 2.5 the expected rent of the agent is now only $p(c_m - c_l) - \frac{\gamma}{1-p}$, whereas it was $p(c_m - c_l) - \gamma$ when information gathering was observable. Therefore, given information gathering costs γ, the principal now prefers a public-private partnership whenever in the setting with observable information gathering she preferred a public-private partnership given information gathering costs $\frac{\gamma}{1-p}$. In other words, regarding the choice between the two modes of provision, making information gathering unobservable has the same effect as an increase of γ in the setting with observable information gathering; i.e., the set of parameters for which a public-private partnership is preferred becomes smaller.

Specifically, we obtain the following result.

Proposition 4 *Suppose that the agent's information gathering decision is unobservable and $\gamma < (1-p)p(c_m - c_l)$.*

(i) Suppose that $c_m < b < \hat{b}(\alpha)$. If $\psi < \psi^{TP}(\pi, \alpha)$, then the principal prefers traditional procurement. Otherwise, she is indifferent between traditional procurement and a public-private partnership.

(ii) Suppose that $b \geq \hat{b}(\alpha)$. In the case $\psi \leq \phi[p(c_m - c_l) - \frac{\gamma}{1-p}]$, the principal prefers a public-private partnership if $\psi > \bar{\psi}(\pi, \alpha, \frac{\gamma}{1-p})$, whereas she prefers traditional procurement if $\psi < \bar{\psi}(\pi, \alpha, \frac{\gamma}{1-p})$. In the case $\psi > \phi[p(c_m - c_l) - \frac{\gamma}{1-p}]$, the principal prefers a public private partnership if $\psi < \psi^{PPP}(\pi, \alpha, \frac{\gamma}{1-p})$ and $\pi < \bar{\pi}(\alpha, \frac{\gamma}{1-p})$, she prefers traditional procurement if $\psi < \psi^{TP}(\pi, \alpha)$ and $\pi > \bar{\pi}(\alpha, \frac{\gamma}{1-p})$, and she is indifferent between the two modes of provision otherwise.

Proof. See the appendix. ∎

Overall, the unobservability of information gathering makes traditional procurement relatively more attractive for the principal. Specifically, if $b < \hat{b}(\alpha)$, then there are parameter constellations for which the principal strictly prefers traditional procurement when information gathering is unobservable, whereas she would be indifferent between the modes of provision if it was observable. If $b \geq \hat{b}(\alpha)$, then the analysis

of Section 5 does not change qualitatively (see Figure 3). In particular, Corollary 1 is robust when the agent's decision to gather information is unobservable.
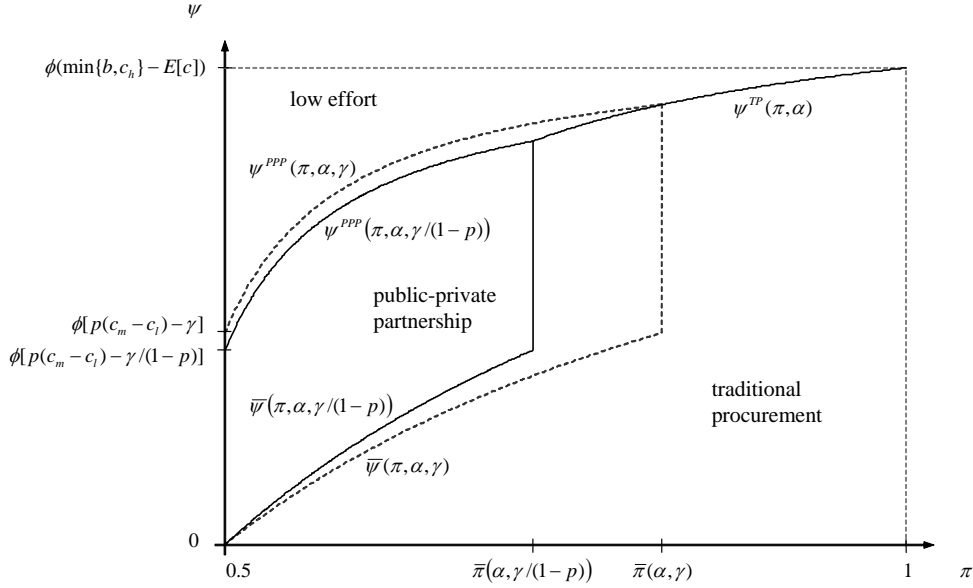

Figure 3. The principal's choice between traditional procurement and a public-private partnership when information gathering is unobservable and $b \geq \hat{b}(\alpha)$ (solid curves). For comparison, the dashed curves refer to the case of observable information gathering (cf. Figure 2).

7   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. In an incomplete contracting framework, 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. Indeed, in the case of 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 article 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. Whether a public-private partnership or traditional procurement is more attractive for the government agency then depends on the information gathering costs, the effort costs, and on the degree to which effort is contractible.

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, although beyond the scope of the present article, 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.

Appendix

Proof of Proposition 1.

(i) Suppose that $b \geq c_m$. Using Lemma 1, it is straightforward to see that the maximum expected payoff that the principal can attain in case of traditional procurement is $U_i^{TP}(\pi, \alpha) = B - C_1 - C_2 + \phi(b - E[c]) + (1 - \phi) \max\{b - c_h, 0\} - (1 - \alpha)\psi\pi/(2\pi - 1) - \alpha\psi$ if she implements high effort ($e = 1$), and it is $u_i^{TP} = B - C_1 - C_2 + \max\{b - c_h, 0\}$ otherwise. A comparison of these expected payoffs immediately shows that the principal prefers to implement high effort whenever $\psi \leq \psi^{TP}(\pi, \alpha)$.

(ii) Suppose that $b < c_m$. Then the maximum expected payoff that the principal can attain given traditional procurement is $U_{ii}^{TP}(\pi, \alpha) = B - C_1 - C_2 + \phi p(b - c_l) - (1 - \alpha)\psi\pi/(2\pi - 1) - \alpha\psi$ if she implements high effort ($e = 1$), and it is $u_{ii}^{TP} = B - C_1 - C_2$ otherwise. Comparing the expected payoffs shows that the principal implements high effort whenever $\psi \leq \tilde{\psi}^{TP}(\pi, \alpha)$. ■

Proof of Proposition 2.

(i) Suppose that $\psi \leq \phi[p(c_m - c_l) - \gamma]$. The discussion preceding Proposition 2 shows that then the agent will choose $e = 1$. Note that in this case the maximum expected payoff that the principal can attain given a public-private partnership is $U_i^{PPP}(\alpha, \gamma) = B - C_1 - C_2 + \phi[b - c_m + \alpha(p(c_m - c_l) - \gamma)] + (1 - \phi) \max\{b - c_h, 0\} - \alpha\psi$.

(ii) Suppose that $\psi > \phi[p(c_m - c_l) - \gamma]$. Then the maximum expected payoff that the principal can attain in case of a public-private partnership is $U_{ii}^{PPP}(\pi, \alpha, \gamma) = B - C_1 - C_2 + \phi[b - c_m + \alpha(p(c_m - c_l) - \gamma)] + (1 - \phi) \max\{b - c_h, 0\} - (1 - \alpha)\pi(\psi - \phi[p(c_m - c_l) - \gamma])/(2\pi - 1) - \alpha\psi$ if she implements $e = 1$, and it is $u_{ii}^{PPP} = B - C_1 - C_2 + \max\{b - c_h, 0\}$ otherwise. A comparison of the expected payoffs shows that the principal prefers to implement $e = 1$ whenever $\psi \leq \psi^{PPP}(\pi, \alpha, \gamma)$. ■

Proof or Proposition 3.

(i) Suppose that $\psi \leq \phi[p(c_m - c_l) - \gamma]$. Then according to Proposition 2 the agent always exerts high effort ($e = 1$) in case of a public-private partnership. We know from Proposition 1 that under traditional procurement, the principal implements $e = 1$ whenever the condition $\psi \leq \psi^{TP}(\pi, \alpha)$ is satisfied. The principal's expected payoff $U_i^{PPP}(\alpha, \gamma)$ in case of a public-private partnership is always larger than her expected payoff u_i^{TP} under traditional procurement with low effort. Moreover, the principal's expected payoff $U_i^{PPP}(\alpha, \gamma)$ in case of a public-private partnership is larger than her expected payoff $U_i^{TP}(\pi, \alpha)$ under traditional procurement with high effort whenever $\psi \geq \bar{\psi}(\pi, \alpha, \gamma)$. Note hat $\bar{\psi}(\pi, \alpha, \gamma) \leq \psi^{TP}(\pi, \alpha)$ must hold, because other-

wise there would exist effort costs larger than $\psi^{TP}(\pi, \alpha)$ (implying $u_i^{TP} > U_i^{TP}(\pi, \alpha)$) and smaller than $\bar{\psi}(\pi, \alpha, \gamma)$ (implying $U_i^{TP}(\pi, \alpha) > U_i^{PPP}(\alpha, \gamma)$), which would contradict $u_i^{TP} \leq U_i^{PPP}(\alpha, \gamma)$. Hence, the principal prefers a public-private partnership if $\psi > \bar{\psi}(\pi, \alpha, \gamma)$, whereas she prefers traditional procurement if $\psi < \bar{\psi}(\pi, \alpha, \gamma)$.

(ii) Suppose that $\psi > \phi[p(c_m - c_l) - \gamma]$. Under traditional procurement, the principal implements high effort whenever $\psi \leq \psi^{TP}(\pi, \alpha)$. In case of a public-private partnership, according to Proposition 2 the principal implements high effort whenever $\psi \leq \psi^{PPP}(\pi, \alpha, \gamma)$. Note that if low effort is implemented, the principal's expected payoff is $u_i^{TP} = u_{ii}^{PPP} = B - C_1 - C_2 + \max\{b - c_h, 0\}$, regardless of the mode of provision. If high effort is implemented under both modes, then the principal's expected payoff is $U_{ii}^{PPP}(\pi, \alpha, \gamma)$ in case of a public-private partnership, whereas it is $U_i^{TP}(\pi, \alpha)$ under traditional procurement, so that the principal's expected payoff is larger in case of a public-private partnership when $\pi < \bar{\pi}(\alpha, \gamma)$.

Note that $\psi^{TP}(\pi, \alpha)$ and $\psi^{PPP}(\pi, \alpha, \gamma)$ are increasing in π and $\psi^{TP}(1/2, \alpha) = 0 < \psi^{PPP}(1/2, \alpha, \gamma)$. Moreover, the unique level of π where $\psi^{TP}(\pi, \alpha) = \psi^{PPP}(\pi, \alpha, \gamma)$ holds is given by $\pi = \bar{\pi}(\alpha, \gamma)$. Hence, $\psi^{PPP}(\pi, \alpha, \gamma) \geq \psi^{TP}(\pi, \alpha)$ if $\pi \leq \bar{\pi}(\alpha, \gamma)$, and $\psi^{PPP}(\pi, \alpha, \gamma) < \psi^{TP}(\pi, \alpha)$ otherwise. Thus, the principal prefers a public-private partnership if $\pi < \bar{\pi}(\alpha, \gamma)$ and $\psi < \psi^{PPP}(\pi, \alpha, \gamma)$, she prefers traditional procurement if $\pi > \bar{\pi}(\alpha, \gamma)$ and $\psi < \psi^{TP}(\pi, \alpha)$, and she is indifferent between the modes of provision otherwise. ∎

Proof of Lemma 5.

If $b \leq c_m$, it is easy to see that it is always optimal for the principal to offer contract $\mathcal{A}_l$, so that the agent never gets an information rent and hence he has no incentive to gather costly information.

Now consider the case $b > c_m$. Suppose that the agent always gathers information ($\mu = 1$). If $b < \hat{b}(\alpha)$, then according to Lemma 3 the principal would offer contract $\mathcal{A}_l$ which leaves no rent to the agent. But this means that the agent would have no incentive to gather costly information, which contradicts $\mu = 1$. If $b \geq \hat{b}(\alpha)$, then the principal would offer contract $\mathcal{A}_m$, which the agent would always accept regardless of the state of nature. Hence, the agent would have no incentive to gather costly information, again contradicting $\mu = 1$. Now suppose that the agent never gathers information ($\mu = 0$). Then the principal would offer the contract $\mathcal{A}_{E[c]}$, so that the agent would not get a rent without information gathering. Yet, given the offer $\mathcal{A}_{E[c]}$, if the agent gathers information (and subsequently accepts the offer in the good state of nature only), his expected information rent is $p(E[c] - c_l) = (1 - p)p(c_m - c_l)$.

Hence, μ must be strictly positive whenever $\gamma < (1-p)p(c_m - c_l)$. ■

Proof of Lemma 6.

Suppose the agent has gathered information with probability μ. At date 3, the principal's expected payoff is $B - C_2 + p(b - c_l)$ when she offers contract $\mathcal{A}_l$, it is $B - C_2 + b - c_m + \alpha p(c_m - c_l)$ when she offers $\mathcal{A}_m$, and it is $B - C_2 + \mu p(b - E[c]) + (1-\mu)(b - E[c]) + \alpha\mu p(E[c] - c_l)$ when she offers $\mathcal{A}_{E[c]}$.

(i) If $c_m < b < \hat{b}(\alpha)$, then the principal prefers contract $\mathcal{A}_l$ over contract $\mathcal{A}_m$. Yet, in equilibrium the principal cannot always offer contract $\mathcal{A}_l$, because then the agent would never gather information which contradicts Lemma 5. Moreover, in equilibrium the principal cannot always offer contract $\mathcal{A}_{E[c]}$, because then the agent would always gather information, which would also contradict Lemma 5. Hence, the principal must be indifferent between the contracts $\mathcal{A}_l$ and $\mathcal{A}_{E[c]}$, which is the case if the agent gathers information with probability $\mu = \frac{b - c_m}{b - E[c] - \alpha(c_m - E[c])}$. Now suppose the principal offers contract $\mathcal{A}_{E[c]}$ with probability λ and contract $\mathcal{A}_l$ with probability $1 - \lambda$. Then at date 2.5, the agent's expected payoff if he gathers information is $\lambda p(E[c] - c_l) - \gamma$, and it is zero otherwise. Thus, the agent is indifferent between gathering and not gathering information if $\lambda = \frac{\gamma}{p(E[c] - c_l)}$.

(ii) If $b \geq \hat{b}(\alpha)$, then the principal prefers contract $\mathcal{A}_m$ over contract $\mathcal{A}_l$. In analogy to part (i), in equilibrium the principal must be indifferent between the contracts $\mathcal{A}_m$ and $\mathcal{A}_{E[c]}$, which is the case if $\mu = \frac{(1-\alpha)(c_m - E[c])}{(1-p)(b - E[c]) - p\alpha(E[c] - c_l)}$. Suppose the principal offers contract $\mathcal{A}_{E[c]}$ with probability λ and contract $\mathcal{A}_m$ with probability $1 - \lambda$. Then at date 2.5, the agent's expected payoff if he gathers information is $\lambda p(E[c] - c_l) + (1-\lambda)p(c_m - c_l) - \gamma$, and it is $(1-\lambda)p(c_m - c_l)$ otherwise. The agent is indifferent between gathering and not gathering information if $\lambda = \frac{\gamma}{p(E[c] - c_l)}$. ■

Proof of Proposition 4.

(i) Consider a public-private partnership. As the agent gets no information rent in the second stage, he exerts high effort in the first stage whenever $\pi w - \psi \geq (1-\pi)w$, so that the principal sets $w = \psi/(2\pi - 1)$ when she wants to implement high effort. The maximum expected payoff that the principal can attain is $B - C_1 - C_2 + \phi p(b - c_l) + (1-\phi)\max\{b - c_h, 0\} - (1-\alpha)\psi\pi/(2\pi - 1) - \alpha\psi$ if she implements high effort ($e = 1$), and it is $B - C_1 - C_2 + \max\{b - c_h, 0\}$ otherwise. A comparison of these expected payoffs immediately shows that the principal prefers to implement high effort whenever $\psi \leq \phi(p(b - c_l) - \max\{b - c_h, 0\})(2\pi - 1)/(\pi - \alpha(1-\pi))$. Note that this threshold level is smaller than $\psi^{TP}(\pi, \alpha)$. Hence, if ψ is larger than $\psi^{TP}(\pi, \alpha)$, then the principal always implements low effort, so that she is indifferent between

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the two modes of provision. If ψ is smaller than $\psi^{TP}(\pi, \alpha)$, then the principal prefers traditional procurement, because in case of an innovation her continuation payoff is larger under traditional procurement $(b - E[c])$ than given a public-private partnership $(p(b - c_l))$.

(ii) Consider a public-private partnership. The agent's expected information rent in case of an innovation is $p(c_m - c_l) - \frac{\gamma}{1-p}$, so that he exerts high effort in the first stage whenever

$$\pi w + \phi[p(c_m - c_l) - \frac{\gamma}{1 - p}] - \psi \geq (1 - \pi)w$$

is satisfied. Thus, the agent exerts high effort in the absence of a direct reward whenever $\psi \leq \phi[p(c_m - c_l) - \gamma/(1 - p)]$. It straightforward to see that then the maximum expected payoff that the principal can attain is $U_i^{PPP}(\alpha, \gamma/(1 - p))$. If $\psi > \phi[p(c_m - c_l) - \gamma/(1 - p)]$, the principal has to pay a direct reward if she wants to implement high effort. Then the maximum expected payoff that the principal can attain is $U_{ii}^{PPP}(\pi, \alpha, \gamma/(1 - p))$ if she implements $e = 1$, and it is u_{ii}^{PPP} otherwise. Hence, the remainder of the proof of Proposition 4(ii) is analogous to the proof of Proposition 3. ∎

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