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Bundling versus unbundling: asymmetric information on information externalities

Marco Buso[1]

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Abstract
This paper addresses the benefits of bundling two sequential activities in the context of public–private partnerships (PPPs). The paper introduces a source of asymmetric information in the form of an externality parameter that links the building stage with subsequent operational activity. Within this framework, bundling allows the government to extract private information about the magnitude of the externality parameter. The framework also implies a higher degree of asymmetric information related to the operational stage than unbundling does when the contract is written. Our results indicate that the use of bundled contracts allows PPPs to be commitment devices that force governments to define ex-ante more coherent and informed plans, thereby improving investments and reducing unexpected cost overruns. However, because of the presence of asymmetric information, bundling makes any cost-reducing effort suboptimal during the operational phase.

Keywords Bundling/unbundling · Agency theory · Information externality · Public–private partnership

JEL Classification D86 · H11 · H57

1 Introduction

In most countries, but especially in developing and emerging economies, immediate governmental responses to crises had the intention of providing a direct stimulus to economic activities, while less attention was paid to the choice of the optimal tools to

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✉ Marco Buso
marco.buso@unipd.it

[1] Interuniversity Centre for Public Economics (CRIEP) and Interdepartmental Centre G. Levi Cases for Energy, Economics and Tehcnology, University of Padova, Padova, Italy

pursue efficient public expenditure strategies (Brumby and Verhoeven 2010). As this situation is not expected to change for some time, governments are asked "to do better with less by spending smarter" (OECD 2014, p. 6).

With the objective of dealing with some of these challenges, this paper addresses the optimal delegation from the public to the private sector of sequential tasks for the realization of strategic public investment that can enhance long-term growth rates, accumulate public capital, and generate long-term outputs (ECB 2016). One critical aspect of the delegation process in long-term projects is the allocation of connected activities among multiple agents. On one hand, the presence of positive externalities among tasks may motivate the adoption of ex-ante "bundled" contracts with a single private contractor to allow governments to exploit economies of scope and increase the efficiency of projects (Iossa and Martimort 2015; Martimort and Pouyet 2008). On the other hand, in the presence of future uncertainty and low competition for bundled contracts, governments may prefer "unbundled" schemes, where tasks are sequentially allocated to agents through independent awarding procedures (Li et al. 2015; Hoppe and Schmitz 2013; Bentz et al. 2002).

Public authorities have traditionally selected unbundled contracts to procure investments. The idea of bundling tasks for the realization of a public project has become common thanks to developed and developing countries' growing use of public–private partnerships (PPPs). PPPs have been implemented in a wide array of sectors, from standard projects for which the main source of revenue is user fees (e.g., motorways, parking facilities, and public transport), to highly complex projects in which private profits come from government subsidies (e.g., hospitals, schools, and prisons).[1] In PPPs, the private consortium that is in charge of designing, realizing, and managing the infrastructure can assume the role of financier, and the risks are optimally shared between public and private partners (OECD 2013). The focus in this paper is on a particular aspect of PPPs—that is, the bundling of tasks—while setting aside the analysis of such aspects of PPPs as the transfer of risks, control, and cashflow rights from the public to the private sector.

In particular, the paper compares "bundling" with "unbundling" given the presence of an externality between sequential activities whose magnitude is ex-ante uncertain and unobserved by the government, while the private operator is able to infer this information during the first stage of the project. Moreover, as in Auriol and Picard (2009a, b, 2013) the study assumes that the principal has a budget constraint and, hence, faces a shadow cost of public funds. Using the contract theory methodology (Laffont and Tirole 1993), the theoretical analysis relaxes the usual assumption of perfectly observable externalities by using a more realistic environment in which a budget-constrained public authority that seeks to maximize the project's net social welfare decides whether to select bundled or unbundled contracts without having all of the relevant information ex-ante. The results of the study reveal a trade-off: The advantage of the government's choosing bundling is related to the first stage of investment, and it increases with the level of ex-ante uncertainty about the real

[1] In most cases, their implementation led to the achievement of satisfactory and efficient outcomes in terms of cost overruns, execution time, and quality of goods/services provided (Saussier and Phuong Tra 2012; Koontz and Thomas 2012; Raisbeck et al. 2010; Hodge and Greve 2007).

impact of the building investment in its operational activity. On the other hand, if the government chooses unbundling, it can save informational rents, as the contract with the operator is written after the building stage once it has observed the real value of the externality.

These results may explain the rationale behind the increased adoption of bundled contracts like the BOT (Build, Operate and Transfer), the BOOT (Build, Operate, Own and Transfer), and the FDBO (Finance, Design, Build, Operate and Transfer) in sectors like public transport, health, sanitation, and energy. In these sectors the link between building investment and operational costs can be significant but also highly uncertain at the ex-ante stage. In such frameworks, public administrations generally understand the need for investment in technologies that can control operational costs (e.g., intelligent transportation systems, medical technologies, energy-efficient instruments, waste water treatments), but these administrations usually cannot perfectly assess up front the long-term impacts and risks of such innovations (OECD 2014). The involvement of private contractors in the design, realization and future management of the project may allow public administrations to exploit their stronger market/sector knowledge and expertise for the provision of efficient investment levels in adequate innovative solutions (Iossa and Russo 2008).

The paper is organized as follows. Section 2 presents a review of the related literature. Section 3 lays out the model, and Sects. 4 and 5 discuss the unbundling and bundling scenarios, respectively. Section 6 uses a welfare analysis to identify the net surplus the scenarios produce, and Sect. 7 concludes.

2 Literature review

The model developed in the paper considers aspects of public procurement that come from two strands of literature, one that focuses on identifying how problems like incomplete contracts and asymmetric information influence the organizational management of a multi-period public investment, and one that focuses on the impact of government budget constraints in the choice between traditional regulation mechanisms and outsourcing strategies or PPPs.

Hart (2003) is the first to address the pros and cons of bundling, focusing on the investment decisions of a public infrastructure's builder in the current period, given its commitment to running the infrastructure in a future period. Hart concludes that, in a context of incomplete contracts, bundling can create indirect incentives to make investments during the building stage that can reduce operational costs.

Following Hart (2003), the papers of Martimort and Pouyet (2008) and Iossa and Martimort (2015) develop a two-stage model that introduces an externality parameter as a connection between the stages of a project. This parameter, known from the beginning of the project, is negative when the first-stage investment increases the second-stage costs and positive otherwise. The authors' conclusions are driven by the externality variable inasmuch as the bundling mechanism that internalizes the costs and benefits that are related to the second-period activity is socially preferable only when the externality is positive.[2]

Compared to previous papers, the current analysis relaxes the assumption of ex-ante perfect knowledge about the externality parameter that is considered as a source of asymmetric information between the public principal and the private agent.

Few papers address the role of asymmetric information. Hoppe and Schmitz (2013) develop a two-stage model in which the agent may invest during the building stage in innovations that can reduce the cost of undertaking changes to the project during the operational stage. Specifically, during the second stage the principal may contract with the private agent for an improvement to the service provision at a cost that is lower if the agent has invested in innovations, but is initially not observable by both contracting parties. At the end of the first stage, the agent in charge can spend money to gather information about the cost of this improvement. Because of the anticipated second-stage information rent, bundling creates indirect incentives to innovate, but these incentives also push the private partner to gather costly information that would be freely available later on.

Unlike the model in Hoppe and Schmitz (2013), the model proposed in this paper allows the externality between the two tasks to be either positive or negative. In addition, the analysis in this paper assumes a single initial contract in the case of bundling and that private information can be learnt at no additional cost by the private agent. Starting from different approaches, both analyses show that bundling may improve the optimality of first-stage outcomes, although it may increase the level of asymmetric information when the government contracts the operational activity. This trade-off is found also in Bentz et al. (2002), where it is the government that knows some of the cost characteristics of the service provision and must decide whether to share them with the private agent before the agent signs the contract (when an efficient investment is needed) or not to share its information (to limit the private agent's information rent). This analysis assumes an information structure that differs from that of Bentz et al. (2002) and, as a result, allows bundling to be chosen in the presence of a negative externality, not only a positive externality.

A second strand of literature is developed based on standard regulation models of a natural monopoly (Laffont and Tirole 1993; Baron and Myerson 1982), and includes in its scope the comparison between traditional regulation mechanisms and other forms of PPPs, such as outsourcing and BOT contracts (Auriol and Picard 2009a, b, 2013; Engel et al. 2013). Those analyses consider the presence of government budget constraints [the shadow cost of public funds as per Laffont and Tirole (1993)], and allow for asymmetric information between the principal and the agent.

A first paper related to this analysis is that of Auriol and Picard (2009a), which addresses how budget constraints can impact the government's choice between regulation and outsourcing for monitoring a natural monopoly in the presence of asymmetric information about the cost realization. As a result, the paper shows that outsourcing

[2] Martimort and Pouyet (2008) expand their basic model to allow for general schemes in which the builder's payment depends on the operator's cost, more complete contracts, and the introduction of an adverse-selection issue concerning operating costs. The authors conclude that, with a benevolent decision-maker and a privately informed operator, bundling is still the optimal organizational form when the externality is positive.

may outperform regulation because it can lead the firm to increase its level of production, and it allows the government to extract franchise fees ex-ante and avoid subsidizing money-losing firms ex-post. Therefore, governments are more likely to choose outsourcing either when the shadow cost of public funds is small enough (in sectors characterized by large uncertainties) or when the shadow cost of public funds is very large. In the first case, the optimal choice is outsourcing with ex-post contractual arrangements, while in the second case the optimal choice is outsourcing, leaving the firm free to operate under a *laissez-faire* regime.[3]

A second analysis by Auriol and Picard (2013) is even more closely related to the present paper, as it discusses the effect of budget constraints (shadow cost of public funds) in explaining the government's choice between public management (regulation) and a BOT contract for the realization and management of a facility/infrastructure project. As a result, they conclude that governments have more incentives to choose BOT contracts in the presence of larger shadow cost of public funds, larger business risk, larger information asymmetries, and when project characteristics are transferred from the concession holder to the government at the end of the concession period. These conclusions contrast with the "irrelevance result" in Engel et al. (2013), which says that PPPs cannot be justified by their ability to free public funds. Unlike Engel et al. (2013), Auriol and Picard (2013) consider the marginal cost to be a source of private information for the agent and assume that, under the BOT contract, control and cashflow rights are transferred to the concession holder for a well-define concession period.

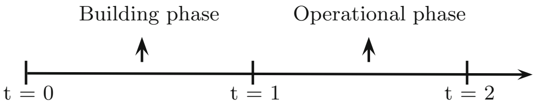
The current analysis shows how the shadow cost of public funds may affect the government's choice between bundling and unbundling. Final results relate to Auriol and Picard (2009a, 2013) and as in these previous analyses, the introduction of asymmetric information plays a critical role. However, the focus in this paper is on comparing alternative public–private contracts in a context with sequential and connected tasks and where project risk management and control lie with the public sector.

This paper links the two strands of literature. On one hand, as in Iossa and Martimort (2015), Hoppe and Schmitz (2013), Martimort and Pouyet (2008) and Bentz et al. (2002), it develops a two-stage model of infrastructure that is characterized by the presence of an externality between stages. On the other hand, as in Auriol and Picard (2009a, b, 2013) it studies the impact of the shadow cost of public funds on the government's choice between bundling and unbundling in a context that is characterized by both moral hazard and adverse selection. The hidden-information problem is related to the externality parameter that connects the two investment stages, whereas the hidden-action problem concerns the unverifiable effort of the agent as it relates to the operational stage. The joint use of elements from both strands of literature facilitates the achievement of innovative results for the study of PPPs.

[3] Since the shadow cost of public funds is higher in developing countries than it is in developed countries, optimal choices between regulation, on one hand, and outsourcing or privatization strategies, on the other, are expected to differ between those countries (Auriol and Picard 2009b).

3 The model

The government seeks to build public infrastructure that can provide services for its citizens. This project is made up of two stages: the construction of the public asset and the provision of services.



The realized facility generates a social surplus shown by $CS = S_0 + sI$, that can be divided into two components:

1. S_0, which is related to the realization of the basic infrastructure;
2. An incremental innovation I that can be carried out during the building stage and that increases the value of the infrastructure to end-users (sI, with $s > 0$).

In the analysis the government is assumed to be benevolent and able to commit to a long-term project. It acts as a principal and writes the contracts to maximize the social welfare function such that:

$$W = S_0 + sI + U - (1 + \lambda)T, \tag{1}$$

where $S_0 + sI$ is the social surplus, U is the utility of the firm or firms involved in the project, T is the government's expenses related to the building and operational stages, and λ is the shadow cost of public funds, which captures the distortion imposed on taxpayers to collect the money needed for the investment (Laffont and Tirole 1986).

During the first stage of the project, the contractor is in charge of constructing the infrastructure, which entails a cost that is verifiable by the government and that rises with the level of innovation ($C_b(I)$). The cost function is assumed to satisfy the properties: $\frac{dC_b}{dI} > 0$, $\frac{d^2C_b}{dI^2} > 0$.

Operational activities carried out during the second stage of the project entail a monetary cost ($C_o(\theta, e)$), and a non-monetary disutility of effort ($\phi(e)$). The monetary cost, which is verifiable and observable, is as follows:

$$C_o(\theta, e) = F - (a\theta + e)I$$

The cost is given by the fixed part F and a second component that reflects the impact of the first-stage investment (I) on the second phase. The last effect is driven by θ, which reflects the operator's private information, and by e, which represents the cost reducing effort. The parameter θ defines the magnitude of the externality effect whose impact may be positive ($a = 1$) or negative ($a = -1$).[4] The effort e reflects activities carried out by the operator to improve the efficiency of service provision in accordance with the first-stage innovation (Hoppe and Schmitz 2013). It magnifies

[4] For instance, an automated metro system may reduce the need for drivers (positive externality). However, while innovative designs and materials for the construction of sustainable public buildings can increase the social surplus, they can also increase maintenance costs (negative externality).

the effect of a positive externality on operational costs and mitigates the effect of a negative externality.[5]

The operator can acquire the information about θ during the building stage, when the main features of the infrastructure become observable. For example, it can capture the impact of introducing an automated metro system or an energy-efficient technology in public buildings/transports: The government can forecast the effect of these innovations on management costs, but only the operator can compare perfectly the cost savings in the form of lower drivers' salaries or energy costs, considering the potential increase in expenses from organizational adaptations, transaction costs, or new professional workers' salaries. The government can detect this private information only after the asset is realized; before realization, it knows the sign of the externality (the parameter $a \in \{-1, 1\}$ that corresponds to 1 in the case of a positive externality, and -1 in the case of a negative externality), and can observe the distribution of the variable over a range of values: $f(\theta) \sim [\theta^l, \theta^h]$, where $\int_{\theta^l}^{\theta^h} \theta f(\theta) d\theta = \overline{\theta}$. For the purpose of this analysis, $F(\theta)$ is assumed to be a continuous distribution function with density $f(\theta)$ that represents the prior of the regulator and is positive for all θ between θ^l and θ^h (with $\theta^h > \theta^l > 0$). In addition to monetary expenses, the operator experiences a non-monetary cost for the adaptation effort that is captured by the function $\phi(e)$, which is assumed to satisfy the following properties: $\frac{d\phi}{de} > 0$, $\frac{d^2\phi}{de^2} > 0$, and $\phi(0) = 0$.

The government can choose between two ways to realize the project: unbundling and bundling. In unbundling, the two stages are managed by multiple firms, whereas in bundling, a single private consortium takes care of both stages. It is supposed that the firms' managers cannot commit not to quit the relationship once they know the private information parameter, so in both bundling and unbundling, the contract the regulator offers must ensure that the firm or the consortium receives a nonnegative utility for all possible realizations of θ. This assumption allows for the presence of risk aversion in the case of negative payoffs (Laffont and Tirole 1993) and is empirically supported by the difficulties governments experience in enforcing penalties on private firms for failure to comply with contractual clauses (Coviello et al. 2017; Girth 2014; Spagnolo 2012). The remainder of this section provides results related to the optimal levels of investment and effort under the benchmark (first best) scenario. The following two sections provide optimal outcomes related to the unbundling and bundling scenarios. The welfare analysis that leads to Proposition 1 has been developed using some quadratic cost functions, which are in line with the model's initial assumptions.

3.1 Benchmark (first best scenario)

In the first best scenario, investment and effort are observable, and θ is common knowledge from the beginning of the project. The government, having all the bargaining power, can choose a transfer that makes the agent(s) indifferent between participating

[5] This cost function follows the structure proposed by Laffont and Tirole (1986). In the context of PPPs, the setting of our model is related to Hoppe and Schmitz (2013), where the agent in charge of the building task can come up with an innovation, while the agent in charge of the operation task can implement adaptations to improve the service provision whose cost depends on the first stage innovation.

or not participating in the program (Reservation utilities are normalized to 0). In the first best scenario, there are no differences between bundling and unbundling, investment and effort derive directly from the maximization of the government surplus, and contracts lead to total rent extraction:

$$max_{I,e}\{S_0 + sI - (1+\lambda)\,[C_b(I) + C_o(\theta, e) + \phi(e)]\}$$

Ignoring constant terms, I and e are chosen to maximize:

$$sI - (1+\lambda)[C_b(I) + \phi(e) - (a\theta + e)I]$$

so first-order conditions are:

$$(1+\lambda)C_b'(I^{FB}) = s + (1+\lambda)(a\theta + e^{FB}) \tag{2}$$

and

$$\phi'(e^{FB}) = I^{FB}. \tag{3}$$

The builder's first best investment comes from Eq. (2). The left side of the equation is the marginal cost, weighted with the shadow cost of public funds (λ). The right side of the equation gives the marginal positive impact of the first-stage investment in terms of social surplus (s) and, in the case of positive externality, future cost savings ($a = 1$). Otherwise, in the case of negative externality, marginal benefits decrease and, as a consequence, the optimal level of investment drops ($a = -1$). The operator's first best effort is given in Eq. (3). Contracts are written in a situation of symmetry of information, so the management's effort is set at the most efficient level, where marginal cost equals marginal benefit.

4 Unbundling

In the unbundling scenario, the government chooses to undertake the two stages of the project through two agents, a builder and an operator, who act independently of each other. The government has all the bargaining power and offers these agents two separate transfers T_b and T_o, respectively. As a consequence, the builder's and the operator's utilities may be written as follows:

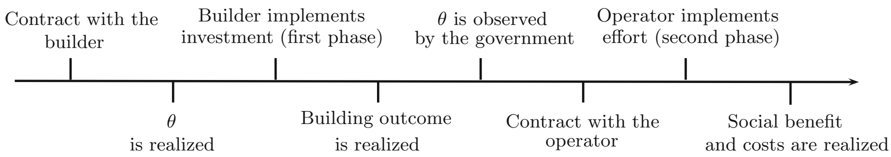
$$U_b = T_b - C_b(I) \tag{4}$$

$$U_o = T_o - C_o(\theta, e) - \phi(e) \tag{5}$$

In the first stage, the building stage, the government wants to maximize the builder's investment by offering a contract based on the level of observable and verifiable outcomes, that is, a transfer $\{T_b = C_b(I)\}$ that makes the builder indifferent between participating and not participating in the program. After the first stage, the parameter θ is observable by both the government and the operator, so the contract is signed in a context of symmetric information. After observing the final operational cost, the government can infer the agent's effort perfectly and can completely extract the operator's private rents ($T_o = C_o(\theta, e) + \phi(e)$).

The externality's value is the operator's private information, so the regulator cannot allow the builder's payment scheme to be contingent on θ.[6] However, ex-post, the government can observe the externality's value and completely extract the operator's rents. This situation is plausible in real-world situations because information related to a public asset's management and maintenance costs becomes observable to the government only when the infrastructure is realized. In such cases, with ex-post contracting, the government can erase the operator's information advantage.

In this scenario, the contractual agreements are signed according to a timeline, as follows:



The government seeks to characterize the optimal equilibria of the overall project; the solution to this problem is standard and is found using backward induction.

Second stage of the project

In the second stage, the government maximizes the net social welfare related to the second operating period, taking into account the operating agent's participation constraint. The contract is offered at the ex-post stage once θ is known. As a consequence, the participation constraint is binding for the realized value of the externality parameter. To accept the contract, the operator must receive at least its reservation utility:

$$
\begin{aligned}
&max_e\{T_o - C_o(\theta, e) - \phi(e) - (1+\lambda)T_o\} \\
&\text{subject to} \\
&T_o - C_o(\theta, e) - \phi(e) = 0
\end{aligned}
$$

The problem's solution includes the optimal level of effort,

$$\phi'(e^U) = I^U. \tag{6}$$

The result is standard in the literature, as the government can achieve the first best result in the absence of asymmetric information.

6 This hypothesis is believable in real world cases where is the operator that is informed about the magnitude of his own maintenance and management costs for a given quality of the infrastructure. The information setting of the model is particularly suitable for some sectors, such as the transport sector, where the operator
Footnote 6 continued
is entitled of most of the relevant information and, in practice, has to manage all relevant risks (Roumboutsos 2015).

First stage of the project

At the beginning of the first stage, the government's objective function is comprised of the social surplus derived from the realization of the infrastructure, the expected second-stage value function (V_o), and the builder's payoff net of the government's costs and weighted by the shadow cost of public funds. The expected second-stage value function is found by first substituting the optimal operator effort level in the second-stage objective function of the government and then calculating the expected value:

$$V_o = -(1+\lambda)F + (1+\lambda)(a\overline{\theta} + e^U)I - (1+\lambda)\phi(e^U)$$

The parameters of the transfer are decided according to the agent's participation constraint:

$$\begin{aligned}&max_I\{S_0 + sI + T_b - C_b(I) - (1+\lambda)T_b + V_o\}\\&s.t.\\&T_b - C_b(I) = 0\end{aligned}$$

Thus, substituting the private constraint in the principal optimization function and ignoring constant terms, I is chosen to maximize:

$$\{sI + V_o - (1+\lambda)C_b(I)\}$$

The problem's solution includes the following result:

$$C_b'(I^U)(1+\lambda) = s + (1+\lambda)(a\overline{\theta} + e^U) \tag{7}$$

The first-order condition equalizes the expected marginal benefit [right side of Eq. (7)] with the marginal cost (left side). Increasing the level of investment creates a current benefit for the society and possible future savings in operating costs when the expected externality between the two stages is positive ($a = 1$). If the expected externality is negative ($a = -1$), the total level of expected marginal benefit decreases. The main parameters introduced in Eq. (7) are the expected externality value ($\overline{\theta}$) and the shadow cost of public funds (λ). $\overline{\theta}$ affects the marginal benefit negatively or positively, depending on whether, in expected terms, the investment realized during the first phase increases or decreases the costs of managing the infrastructure. λ captures the distortion imposed on taxpayers when public money is transferred to the private builder ($\lambda C'(I^U)$) and reinforces the positive or negative impact of the externality parameter. Unlike the first best solution, in Eq. (7) the link with the operational phase is taken into account only in terms of expected externality.

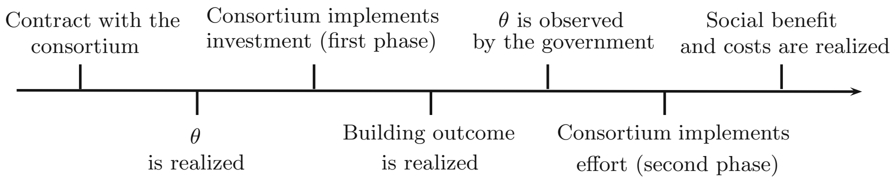
5 Bundling

The approach and the initial assumptions in a bundling scenario are similar to those of the unbundling scenario. There is a single private agent (consortium) that sustains a cost over the two periods, dependent on the same parameters as before and based on an ex-ante information structure that does not change with the new environment. The consortium receives compensation for its activities, which compensation is defined as follows:

$$U_c = T_c - C_b(I) - C_o(\theta, e) - \phi(e) \tag{8}$$

In this case, the government can offer various incentives based on verifiable outcomes that require truthful revelation of the operator's cost parameter and that enhance the first-period investment, that is, a triplet, $\{t_c(\hat{\theta}), C_b(\hat{\theta}), C_o(\hat{\theta})\}_{\theta\epsilon[\theta^l,\theta^h]}$, which respects the constraints of the incentives and defines costs and transfers when the private-information parameter $\hat{\theta}$ is made known. In this setting, we take the accounting convention that the regulator reimburses the agents' monetary costs[7] and that the consortium receives a net monetary transfer t_c as compensation for the non-monetary cost sustained during the operation stage.

In this scenario, the project's time-line takes the following form:



Through this screening strategy, the government seeks to maximize the social welfare and extract the agent's rent. At the same time, it must take into consideration the agent's incentives and interests, which are embodied in two constraints: a truthful revelation of the private-information parameter and the participation constraint. In this case, to facilitate understanding, the resolution is structured in two subsections: one that is dedicated to the case of a positive externality, and one that is dedicated to the case of a negative externality.

5.1 Positive externality ($a = 1$)

In the first subsection we consider the case of a positive externality, meaning that the cost to operate the infrastructure can be defined as follows:

$$C_o(e) = F - (\theta + e)I,$$

[7] Starting from this case, there is always the possibility of decentralizing through a menu of linear contracts $T = a - bC$ (Laffont and Tirole 1993).

The government seeks to maximize the social welfare and extract the agent's rent taking into account the private agent's participation and incentive compatibility constraints:

$$max_{I(\theta),e(\theta)} \int_{\theta^l}^{\theta^h} \{[S_0 + sI(\theta)] + U_c(\theta) - (1+\lambda)[t_c(\theta) + C_b(I(\theta)) + C_o(\theta, e(\theta))]\} f(\theta) d\theta$$

$$s.t.$$

The mechanism for the truthful revelation of the private information is:[8]

$$\frac{dU_c}{d\theta} = \phi'(e(\theta)),$$

while the participation constraint is:

$$U_c = t_o - \phi(e(\theta)) \geq 0 \quad \text{which is binding for } \theta = \theta^l$$

Substituting private constraints in the principal optimization function and ignoring constant terms, I and e are chosen to maximize:[9]

$$\mathbf{E}_\theta \left[sI(\theta) - (1+\lambda)[\phi(e(\theta)) + C_b(I(\theta)) - (\theta + e(\theta))I(\theta)] - \lambda \frac{(1-F(\theta))}{f(\theta)} \phi'(e(\theta)) \right]$$

The maximization solution leads to the following outcomes:

$$C_b'(I^B)(1+\lambda) = s + (1+\lambda)(\theta + e^B) \tag{9}$$

$$\phi'(e^B) = I^B - \frac{\lambda}{1+\lambda} \frac{(1-F(\theta))}{f(\theta)} \phi''(e^B) \tag{10}$$

In this setting the second-stage effort is decreased by adverse selection [Eq. (10)]. The government grants positive rents to obtain a truthful revelation of the private information parameter θ. Equation 9 reports the first-order condition that is related to the first-stage innovation. Unlike the unbundling scenario, the contract with the consortium is made before the start of the investment, so, because of the revelation mechanism, the information becomes contractible since the first-stage level of investment and the optimal level of investment can be set on the basis of the real value of θ disclosed by the consortium.

8 This IC condition gives the agent no incentive to deviate and ensures truth-telling. This necessary condition is also sufficient if the marginal cost decreases as the positive externality increases. For a detailed proof, see the online appendix (Lemma 1).

9 For a detailed proof, see the online appendix (Lemma 2).

5.2 Negative externality ($a = -1$)

In the second subsection we consider the case of a negative externality, where the cost to operate the infrastructure can be defined as follows:

$$C_o(e) = F + (\theta - e)I,$$

The government seeks to maximize the social welfare taking into account the private agent's participation and incentive compatibility constraints:

$$max_{I(\theta),e(\theta)} \int_{\theta^l}^{\theta^h} \{[S_0 + sI(\theta)] + U_c(\theta) - (1+\lambda)[t_c(\theta) + C_b(I(\theta)) + C_o(\theta, e(\theta))]\} f(\theta) d\theta$$

$$s.t.$$

The mechanism for the truthful revelation of the private information is:[10]

$$\frac{dU_c}{d\theta} = -\phi'(e(\theta)),$$

while the participation constraint is:

$$U_c = t_o - \phi(e(\theta)) \geq 0 \text{ which is binding for } \theta = \theta^h$$

Substituting private constraints in the principal optimization function and ignoring constant terms, I and e are chosen to maximize:[11]

$$\mathbf{E}_\theta \left[sI(\theta) - (1+\lambda)[\phi(e(\theta)) + C_b(I(\theta)) + (\theta - e(\theta))I(\theta)] - \lambda \frac{F(\theta)}{f(\theta)} \phi'(e(\theta)) \right]$$

The maximization solution leads to the following outcomes:

$$C_b'(I^B)(1+\lambda) = s - (1+\lambda)(\theta - e^B) \tag{11}$$

$$\phi'(e^B) = I^B - \frac{\lambda}{1+\lambda} \frac{F(\theta)}{f(\theta)} \phi''(e^B) \tag{12}$$

The results are similar to the case of bundling with a positive externality. As in the previous subsection, the level of second-stage effort is decreased by adverse selection [Eq. (12)]. Equation 11 reports the first-order condition that is related to the first-stage innovation. Also in this case, the contract with the consortium is made before the start of the investment, so the information becomes contractible since the first-stage level of investment and the optimal level of investment can be set on the basis of the real

[10] This IC condition gives the agent no incentive to deviate and ensures truth-telling. This necessary condition is also sufficient if the marginal cost increases as the negative externality increases. For a detailed proof, see the online appendix (Lemma 3).

[11] For a detailed proof, see the online appendix (Lemma 4).

value of θ disclosed by the consortium. However, unlike in Eqs. (9), (11) the impact of the initial investment on the second stage costs is negative.

In a scenario with either a positive or a negative externality, the main parameters in the outcomes' equations under bundling are the shadow cost of public funds λ and the externality parameter θ. λ increases the marginal cost of effort and magnifies the effect of the externality, while θ captures the positive or negative impact of the initial investment on the second-stage costs. In the case of bundling the first-stage innovation is chosen based on the real value of θ, while at the same time the asymmetric information on θ distorts the investment and effort downward.

The analysis in this section assumes that the agent cannot commit not to exit the contract when he or she discovers θ and before the operational activity starts. Alternatively, if the analysis is generalized to relax this assumption, the potential benefits of bundling increase. In fact, if the agent can commit not to exit the contract, the government's optimal strategy consists of offering a second-term fixed-price contract $t_o(C_o) = a - C_o$, where $a = \int_{\theta^l}^{\theta^h} \{\psi(e(\theta)) + C_o(\theta)\} d\theta$. In this situation, the bundling mechanism could increase the agent's effort, as the distortion induced by adverse selection will disappear.

6 Welfare analysis

This section compares the bundling and unbundling scenarios in terms of ex-ante social welfare to identify the factors that drive the choices for governments that face informational settings similar to that modeled in this paper.

The welfare analysis is performed using the expected value of the government's objective function over the two periods: $\mathbf{E}_\theta[S_0 + sI + U - (1+\lambda)T]$. We assume that $C_b(I) = \frac{I^2}{2p}$ and $\phi(e) = \frac{e^2}{2h}$, which respect the initial assumptions of the model and allow us to compute the optimum value of the agents' investments and efforts.[12] The result is summarized by Eq. (13), which describes the difference in value functions between the levels of social welfare produced under bundling and unbundling:

$$V^B - V^U = W_n = IE - AS, \tag{13}$$

where

- $IE = \frac{p(1+\lambda)}{2(1-hp)} \sigma_\theta^2$,
- $AS = \frac{\lambda}{2h} \int_{\theta^l}^{\theta^h} \left\{ \frac{1-F(\theta)}{f(\theta)} \left(e^B + \frac{hp}{1-hp} \frac{s+(1+\lambda)\theta}{1+\lambda} \right) \right\} f(\theta) d\theta$ in the case of a positive externality, and
  $AS = \frac{\lambda}{2h} \int_{\theta^l}^{\theta^h} \left\{ \frac{F(\theta)}{f(\theta)} \left(e^B + \frac{hp}{1-hp} \frac{s-(1+\lambda)\theta}{1+\lambda} \right) \right\} f(\theta) d\theta$ in the case of a negative externality,

where IE is the information externality effect and AS is the adverse selection effect. The result can be decomposed into two effects:

[12] The introduction of the parameters p and h allows for more general results. For the purpose of this analysis, it is assumed that $p > 0$, $h > 0$ and $hp < 1$.

Information externality effect (IE) This effect is always either positive or zero. Bundling commits the government to defining an informed investment plan that takes into account every short-term and long-term relationship between the builder's investment and the future stages of the project. Bundling the two tasks allows the government to internalize the operator's private information in the builder's innovative investment. This effect increases with the uncertainty of the private-information parameter, so if the variance decreases, the private information is less valuable to the operator and there is less benefit in choosing bundling. The relevance of the effect increases as the shadow cost of public funds increases, but it is positive even when $\lambda = 0$.

Adverse selection effect (AS) This effect, which reflects the cost that the government sustains under bundling to detect the operator's private information (adverse selection distortion), negatively affects the difference in value functions between bundling and unbundling. In the case of unbundling, the contract is signed when the information regarding θ is already available to the government. The effect is increasing with the value of λ and is relevant whenever the shadow cost of public funds is different from zero.

These effects lead to Proposition 1, which summarizes the result of Eq. (13).

Proposition 1 *: In a context characterized by non-verifiable effort and temporarily hidden information on θ (i.e., the externality is uncertain for the government), there is a unique value of σ_θ^w such that bundling dominates unbundling if $\sigma_\theta > \sigma_\theta^w$, where in the case of a positive externality:*

$$\sigma_\theta^w = \sqrt{\frac{\lambda(1-hp)}{hp(1+\lambda)} \int_{\theta^l}^{\theta^h} \left\{ \frac{1-F(\theta)}{f(\theta)} \left(e^B + \frac{hp}{1-hp} \frac{s+(1+\lambda)\theta}{1+\lambda} \right) \right\} f(\theta) d\theta}, \tag{14}$$

where $e^B = \frac{hp}{1-hp}\frac{s+(1+\lambda)\theta}{1+\lambda} - \frac{hp}{1-hp}\frac{\lambda}{1+\lambda}\frac{1-F(\theta)}{f(\theta)} - \frac{\lambda}{1+\lambda}\frac{1-F(\theta)}{f(\theta)}$, but, in the case of a negative externality:

$$\sigma_\theta^w = \sqrt{\frac{\lambda(1-hp)}{hp(1+\lambda)} \int_{\theta^l}^{\theta^h} \left\{ \frac{F(\theta)}{f(\theta)} \left(e^B + \frac{hp}{1-hp} \frac{s-(1+\lambda)\theta}{1+\lambda} \right) \right\} f(\theta) d\theta}, \tag{15}$$

where $e^B = \frac{hp}{1-hp}\frac{s-(1+\lambda)\theta}{1+\lambda} - \frac{hp}{1-hp}\frac{\lambda}{1+\lambda}\frac{F(\theta)}{f(\theta)} - \frac{\lambda}{1+\lambda}\frac{F(\theta)}{f(\theta)}$. In such a situation, benefits from the early acquisition of information outweigh the costs (rent transfers).

Proof See the "Appendix" □

The value of σ_θ^w represents the government's cost of bundling that is due to asymmetric information when it writes the contract with the private agent. In fact, while bundling allows the government to provide more informed ex-ante planning in the presence of uncertainty (σ_θ), under the unbundling scenario the management contract is written in a context of symmetric information, and rents are completely extracted from the operator.

The next paragraphs explain what Proposition 1 brings to the literature regarding how either the externality parameter or the shadow cost of public funds may affect the government's choice between the bundling option and the unbundling option.

The model helps to clarify the externality parameter that Iossa and Martimort (2015) and Martimort and Pouyet (2008) introduce. These earlier analyses consider non-contractible building investment to show that bundling may solve problems of total or partial contract incompleteness. The current analysis introduces asymmetric information on the externality parameter to show that bundling may allow governments to contract ex-ante with more informed private agents. These two approaches are complementary in their final message that, in models with two stages connected through an externality, the benefit of bundling over unbundling depends on the link between the phases, whose marginal impact may be unknown ex-ante by the government (adverse selection problem) and whose total impact is strictly related to the first-stage building investment that may or not be observable ex-post by the government (moral hazard problem). The comparison between bundling and unbundling will be driven largely by the sign (variance) of the externality parameter as the moral hazard (adverse selection) becomes more relevant to the adverse selection (moral hazard) problem.

As it is usually easier to estimate building costs ex-ante than it is to estimate operational costs ex-ante, the variance of the externality plays a prominent role in the decision concerning whether bundling or unbundling is optimal from a welfare point of view. Indeed, a higher value of σ_θ may drive the government's preference toward bundling, even in the presence of a negative externality: In such situations, bundling allows governments to avoid excessive investment in building innovations that have excessive costs during the operation stage. Some prominent examples of projects in which the adverse selection issue is predominant are found in public transportation and energy efficiency projects, where operational costs strictly depend on the building innovation introduced (e.g., self-driving vehicles/metro, light rail, connected mobility networks, hybrid-electric buses, cogeneration plants, solar water heaters) and where governments may be able to approximate construction costs but not the exact impact of the innovation on operational costs and/or service effectiveness. In these projects, as in many other types of public projects, the government can design, ex-ante, a more informed and less costly investment plan by making use of the expertise of private operators with more specific market and sector knowledge.

Another finding concerns the shadow cost of public funds. Starting from Eqs. (14) and (15), Corollary 2 summarizes the role of λ in explaining the government's preference between bundling and unbundling:

Corollary 2 *The value of* σ_θ^w *varies with the level of* λ*. Then the government preference for bundling over unbundling is affected by the value of the shadow cost of public funds.*

In contrast to Engel et al. (2013), the present paper shows that, in a context of sequential activities with asymmetric information, the comparison between bundling and unbundling is affected by the shadow cost of public finance. λ positively affects both the IE and the AS effects, so an increase in λ may affect the government's preference in favor of either bundling or unbundling. The study of the function $\sigma_\theta^w(\lambda)$ suggests that, at least in the presence of a negative externality, there is a value of λ between 0

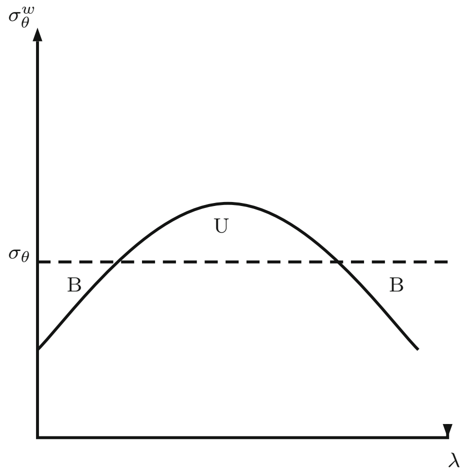


Fig. 1 Comparative statics of $\sigma_\theta^w(\lambda)$ with respect to λ

and 1 that maximizes the value of $\sigma_\theta^w(\lambda)$ (*Proof:* See the "Appendix").[13] Therefore, for a given level of uncertainty (σ_θ), the government's preference for bundling over unbundling may vary according to the graph depicted in Fig. 1.

According to the graph, Bundling (B) is preferred over Unbundling (U) for high or low values of λ. Intuitively, when λ is close to 0, the AS effect tends to 0, while the IE is positive. However, when λ is very high, the levels of investment and effort at the equilibrium are low. As a consequence, the amount of rents (AS effect) decreases, while the IE effect always increases with λ.

Auriol and Picard (2009a) also consider the social cost of additional rents to private firms as a part of what they call the "fiscal effect". Auriol and Picard (2009a) explain that the rents are larger for low-cost firms in the case of outsourcing compared to regulation because of differences in the participation constraints. This explanation holds because, under regulation, the reservation utility is assumed to be equal to zero, while under outsourcing, it is considered to be equal to the operating profit the firm would get under *laissez faire*, which itself depends on the type of firm and is higher than zero. In contrast, the present analysis compares bundling with unbundling in a scenario in which private firms must receive a nonnegative utility for all possible realizations of the private information parameter, while differences between the two scenarios are related to the timing and type of contract. Auriol and Picard (2013) also address the role of the shadow cost of public funds in public procurement contracts by comparing the public management scenario with the case of a BOT contract, where the private information may be either transferred or not transferred to public authorities at the end of the concession period. The current analysis compares two types of public–private contracts (unbundling vs. bundling) with the assumption that the private information is always transferred to (observed by) the government at the end of the building stage. In Auriol and Picard (2013), the BOT contract is preferred over public management for high values of λ. However, unlike the current analysis, their study explains this finding

[13] In the presence of a positive externality, the function σ_θ^w is concave and reaches a maximum for a value of λ between 0 and 1 unless the value of θ is very high.

in terms of the possibility of limiting government spending through the transfer under BOT contracts of investment costs and responsibilities for potential looses from the public sector to the private sector, not in terms of the intrinsic differences between bundled and unbundled arrangements.

7 Conclusion

This paper addresses the choice between bundling and unbundling for the realization and management of long-term projects in contexts in which the consequences of short-term investment are uncertain and governments are not privy to all of the information known to private agents.

The study focuses on the role of the externality between the building and operational stages, treating it as the main source of asymmetric information. Unlike results in the extant literature, the comparison between bundling and unbundling in the current analysis depends in part on the government's prior knowledge, rather than only on how and to what extent the project's activities are related. More precisely, relative to the unbundled scenario, bundling has the advantage that the government can gain from using a screening contract structure. Because the operations cost depends on θ, the government can offer a menu of remuneration schemes that makes the joint entity vary its first-stage investment based on the realized value of θ. This approach is not possible with unbundled contracting, as θ is an operator's private information that does not enter in the builder's stand-alone utility. The ability of the government to use its direct observation of θ to achieve the first best level of operational effort in the unbundled scenario is an information cost of bundling. Hence, the government faces a trade-off in deciding which contracting form to use.

This effect can help to clarify why, in real-world cases, PPPs are particularly used to yield energy savings in the public sector (EPEC 2012), and in general why cost overruns are lower when PPPs with bundled contracts are chosen (EPEC 2011; Dewatripont and Legros 2005). In infrastructure projects, estimated costs often differ from their ex-post realizations, perhaps because of the substantial uncertainty that characterizes ex-ante evaluations, expecially when the project is innovative. Bundling allows the government to collect more information at the beginning of the project so ex-ante evaluations are more precise and large cost overruns are less likely.

Another result of the analysis is that the shadow cost of public funds (λ) is related to social welfare when asymmetric information is introduced in projects with connected sequential stages. This result is explained by differences in the times of contracting: In the unbundling scenario, the contract between the government and the operator/consortium is written after the building stage in a context of symmetric information, while in the bundling scenario the contract is written ex-ante in a context of asymmetric information.

The implication of these findings is that PPPs with bundled contracts are particularly advantageous when governments cannot easily assess ex-ante the long-term risks associated with public investments, but it can verify performance ex-post. Neither standardized projects nor R&D investments meet this requirement.[14] What matters is private agents' ability to use their expertise to evaluate innovative projects, and governments' ability to execute contracts based on final outcomes.[15] The advantage of bundling increases when the initial investment is particularly important to the second-period activity. In such cases, bundling provides substantial gains in the form of higher levels of investment and fewer cost overruns.

The present study was developed as applied to PPPs, but the model detects a general theoretical result that can be applied to other frameworks. The electricity, gas, and water markets are feasible contexts, given the complexity of the sequential supply system and the presence of high levels of asymmetric information. These extensions of the present analysis could expand the analysis's contribution in terms of real-world applications.

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Appendix

This Appendix contains the proofs and the the comparative statistical analysis.

Proof of Proposition 1

The expected function that is used to perform the welfare analysis is the following:

$$\int_{\theta^l}^{\theta^h} \{S_0 + sI - (1+\lambda)[T_b + T_o] + (T_b - C_b(I)) + (T_o - C_o(\theta, e) - \phi(e))\} f(\theta) d\theta$$

Positive externality ($a = 1$)

Using the new investment and effort functions, the first-order conditions in the bundling case become:

- $I^B = \frac{p}{1-hp}\frac{s+(1+\lambda)\theta}{1+\lambda} - \frac{p}{1-hp}\frac{\lambda}{1+\lambda}\frac{1-F(\theta)}{f(\theta)}$,
- $e^B = hI^B - \frac{\lambda}{1+\lambda}\frac{1-F(\theta)}{f(\theta)}$.

[14] In standard projects, information on management costs is generally common knowledge for both parties, while in R&D investments, future information on costs or project outcomes is uncertain for both the public and the private sectors.

[15] All projects that involve new applications of existing innovations are suitable examples.

Substituting in the government's objective formula, we obtain the value function under bundling:

$$
\begin{aligned}
V^B &= \int_{\theta^l}^{\theta^h} \left\{ S_0 + sI^B - (1+\lambda)\left[\frac{(I^B)^2}{2p} + \frac{(e^B)^2}{2h} + F - (\theta + e^B)I^B\right] \right. \\
&\quad \left. - \lambda \frac{1-F(\theta)}{f(\theta)} \frac{e^B}{h} \right\} f(\theta) d\theta \\
&= \int_{\theta^l}^{\theta^h} \left\{ S_0 + I^B(s + (1+\lambda)(\theta + e^B)) \right. \\
&\quad - (1+\lambda)\left[\frac{(I^B)^2}{2p} + \frac{(I^B)^2 h}{2} + \frac{1}{2h}\left(\frac{\lambda}{1+\lambda}\frac{1-F(\theta)}{f(\theta)}\right)^2 \right. \\
&\quad \left. \left. - \frac{\lambda}{1+\lambda}\frac{1-F(\theta)}{f(\theta)} I^B + F\right] - \lambda \frac{1-F(\theta)}{f(\theta)} \left(I^B - \frac{1}{h}\frac{\lambda}{1+\lambda}\frac{1-F(\theta)}{f(\theta)}\right) \right\} f(\theta) d\theta \\
&= \int_{\theta^l}^{\theta^h} \left\{ S_0 - (1+\lambda)F + \frac{(1+\lambda)(1-hp)}{2p}(I^B)^2 \right. \\
&\quad \left. + (1+\lambda)\frac{1}{2h}\left(\frac{\lambda}{1+\lambda}\frac{1-F(\theta)}{f(\theta)}\right)^2 \right\} f(\theta) d\theta \\
&= \int_{\theta^l}^{\theta^h} \left\{ S_0 - (1+\lambda)F + \frac{p(1+\lambda)}{2(1-hp)}\left(\frac{s + (1+\lambda)\theta}{1+\lambda}\right)^2 + \frac{p(1+\lambda)}{2(1-hp)}\left(\frac{\lambda}{1+\lambda}\frac{1-F(\theta)}{f(\theta)}\right)^2 \right. \\
&\quad \left. - \frac{(1+\lambda)p}{1-hp}\frac{s+(1+\lambda)\theta}{1+\lambda}\frac{\lambda}{1+\lambda}\frac{1-F(\theta)}{f(\theta)} + (1+\lambda)\frac{1}{2h}\left(\frac{\lambda}{1+\lambda}\frac{1-F(\theta)}{f(\theta)}\right)^2 \right\} f(\theta) d\theta \\
&= S_0 - (1+\lambda)F + \frac{p(1+\lambda)}{2(1-hp)}\left(\frac{s^2 + (1+\lambda)^2(\overline{\theta} + \sigma_\theta^2) + 2s(1+\lambda)\overline{\theta}}{(1+\lambda)^2}\right) \\
&\quad - \frac{\lambda}{h}\int_{\theta^l}^{\theta^h} \left\{ \frac{1-F(\theta)}{f(\theta)} \left[\frac{hp}{(1-hp)} \frac{s+(1+\lambda)\theta}{1+\lambda} - \right. \right. \\
&\quad \left. \left. - \frac{hp}{2(1-hp)}\left(\frac{\lambda}{1+\lambda}\frac{1-F(\theta)}{f(\theta)}\right) - \frac{1}{2}\left(\frac{\lambda}{1+\lambda}\frac{1-F(\theta)}{f(\theta)}\right)\right]\right\} f(\theta) d\theta \\
&= S_0 - (1+\lambda)F + \frac{p(1+\lambda)}{2(1-hp)}\left(\frac{s+(1+\lambda)\overline{\theta}}{1+\lambda}\right)^2 + \frac{p(1+\lambda)}{2(1-hp)}\sigma_\theta^2 \\
&\quad - \frac{\lambda}{2h}\int_{\theta^l}^{\theta^h} \left\{ \frac{1-F(\theta)}{f(\theta)} \left(e^B + \frac{hp}{1-hp}\frac{s+(1+\lambda)\theta}{1+\lambda}\right)\right\} f(\theta) d\theta
\end{aligned}
$$

The new efforts functions applied to the unbundling case yield, respectively:

- $I^U = p\frac{s+(1+\lambda)\overline{\theta}}{(1+\lambda)(1-hp)}$,
- $e^U = hI^U$.

Substituting in the government's objective formula, we obtain the value function under unbundling:

$$
V^U = \int_{\theta^l}^{\theta^h} \left\{ S_0 + sI^U - (1+\lambda)\left[\frac{(I^U)^2}{2p} + \frac{(e^U)^2}{2h} + F - I^U(\theta + e^U)\right]\right\} f(\theta) d\theta
$$

$$
\begin{aligned}
&= \int_{\theta^l}^{\theta^h} \left\{ S_0 + sI^U - (1+\lambda)\left[\frac{(I^U)^2}{2p} + \frac{(I^U)^2 h}{2} + F - I^U(\theta + I^U h)\right]\right\} f(\theta)d\theta \\
&= \int_{\theta^l}^{\theta^h} \left\{ S_0 - (1+\lambda)F + I^U(s + (1+\lambda)\theta) - (1+\lambda)\frac{(I^U)^2}{2p}(1-hp)\right\} f(\theta)d\theta \\
&= S_0 - (1+\lambda)F + I^U(s + (1+\lambda)\overline{\theta}) - (1+\lambda)\frac{(I^U)^2}{2p}(1-hp) \\
&= S_0 - (1+\lambda)F + I^U\frac{I^U}{p}(1+\lambda)(1-hp) - (1+\lambda)\frac{(I^U)^2}{2p}(1-hp) \\
&= S_0 - (1+\lambda)F + (1+\lambda)\frac{(I^U)^2}{2p}(1-hp) \\
&= S_0 - (1+\lambda)F + \frac{p(1+\lambda)}{2(1-hp)}\left(\frac{s+(1+\lambda)\overline{\theta}}{1+\lambda}\right)^2
\end{aligned}
$$

The net welfare gain/loss of governments when using bundling is equal to:

$$
V^B - V^U = \frac{p(1+\lambda)}{2(1-hp)}\sigma_\theta^2 - \frac{\lambda}{2h}\int_{\theta^l}^{\theta^h}\left\{\frac{1-F(\theta)}{f(\theta)}\left(e^B + \frac{hp}{1-hp}\frac{s+(1+\lambda)\theta}{1+\lambda}\right)\right\} f(\theta)d\theta
$$

where $e^B = \frac{hp}{1-hp}\frac{s+(1+\lambda)\theta}{1+\lambda} - \frac{hp}{1-hp}\frac{\lambda}{1+\lambda}\frac{1-F(\theta)}{f(\theta)} - \frac{\lambda}{1+\lambda}\frac{1-F(\theta)}{f(\theta)}$.

As a result, bundling dominates unbundling if and only if:

$$
\sigma_\theta^2 \geq \frac{\lambda(1-hp)}{hp(1+\lambda)}\int_{\theta^l}^{\theta^h}\left\{\frac{1-F(\theta)}{f(\theta)}\left(e^B + \frac{hp}{1-hp}\frac{s+(1+\lambda)\theta}{1+\lambda}\right)\right\} f(\theta)d\theta
$$

$$
\begin{aligned}
\sigma_\theta^2 \geq \int_{\theta^l}^{\theta^h} &\left\{\frac{\lambda(1-hp)}{hp(1+\lambda)}\frac{1-F(\theta)}{f(\theta)}\left(\frac{hp}{1-hp}\frac{s+(1+\lambda)\theta}{1+\lambda} - \frac{hp}{1-hp}\frac{\lambda}{1+\lambda}\frac{1-F(\theta)}{f(\theta)}\right.\right. \\
&\left.\left. - \frac{\lambda}{1+\lambda}\frac{1-F(\theta)}{f(\theta)} + \frac{hp}{1-hp}\frac{s+(1+\lambda)\theta}{1+\lambda}\right)\right\} f(\theta)d\theta
\end{aligned}
$$

Proof of Corollary 2—positive externality

To study the sign of the derivative of σ_θ^w varies with λ, it is sufficient to study the derivative of the integrand in the previous inequality with respect to λ that is equal to:

$$
\begin{aligned}
&= \frac{1-hp}{hp}\frac{1}{(1+\lambda)^2}\frac{1-F(\theta)}{f(\theta)}\left(e^B + \frac{hp}{1-hp}\frac{s+(1+\lambda)\theta}{1+\lambda}\right) \\
&\quad + \frac{1-hp}{hp}\frac{\lambda}{1+\lambda}\frac{1-F(\theta)}{f(\theta)}\left(-\frac{hp}{1-hp}\frac{2s}{(1+\lambda)^2} - \frac{hp}{1-hp}\frac{1}{(1+\lambda)^2}\frac{1-F(\theta)}{f(\theta)}\right. \\
&\quad \left. - \frac{1}{(1+\lambda)^2}\frac{1-F(\theta)}{f(\theta)}\right) \\
&= 2\frac{1-hp}{hp}\frac{1}{(1+\lambda)^2}\frac{1-F(\theta)}{f(\theta)}\left(\frac{hp}{1-hp}\frac{s(1-\lambda)+(1+\lambda)\theta}{1+\lambda} - \frac{hp}{1-hp}\frac{\lambda}{1+\lambda}\frac{1-F(\theta)}{f(\theta)}\right. \\
&\quad \left. - \frac{\lambda}{1+\lambda}\frac{1-F(\theta)}{f(\theta)}\right)
\end{aligned}
$$

$$= 2\frac{1-hp}{hp}\frac{1}{(1+\lambda)^2}\frac{1-F(\theta)}{f(\theta)}\left(e^B - \frac{hp}{1-hp}\frac{\lambda s}{1+\lambda}\right)$$

As a conclusion, the value of σ_θ^2 can increase or decrease with λ. Precisely, the derivative is positive if $\lambda = 0$, while it may become negative as λ increases. The second derivative is equal to:

$$\begin{aligned}
&= 4\frac{1-hp}{hp}\frac{1}{(1+\lambda)^3}\frac{1-F(\theta)}{f(\theta)}\left(-e^B + \frac{hp}{1-hp}\frac{\lambda s}{1+\lambda}\right) + \\
&\quad + 2\frac{1-hp}{hp}\frac{1}{(1+\lambda)^2}\frac{1-F(\theta)}{f(\theta)}\left(-\frac{hp}{1-hp}\frac{2s}{(1+\lambda)^2}\right. \\
&\quad \left. - \frac{hp}{1-hp}\frac{1}{(1+\lambda)^2}\frac{1-F(\theta)}{f(\theta)} - \frac{1}{(1+\lambda)^2}\frac{1-F(\theta)}{f(\theta)}\right) \\
&= -2\frac{1-hp}{hp}\frac{1}{(1+\lambda)^3}\frac{1-F(\theta)}{f(\theta)}\left(2e^B + 2\frac{hp}{1-hp}\frac{s(1-\lambda)}{1+\lambda}\right. \\
&\quad \left. + \frac{hp}{1-hp}\frac{1}{1+\lambda}\frac{1-F(\theta)}{f(\theta)} + \frac{1}{1+\lambda}\frac{1-F(\theta)}{f(\theta)}\right) \leq 0
\end{aligned}$$

Negative externality ($a = -1$)

Using the new investment and effort functions, the first-order conditions in the bundling case become:

- $I^B = \frac{p}{1-hp}\frac{s-(1+\lambda)\theta}{1+\lambda} - \frac{p}{1-hp}\frac{\lambda}{1+\lambda}\frac{F(\theta)}{f(\theta)}$,
- $e^B = hI^B - \frac{\lambda}{1+\lambda}\frac{F(\theta)}{f(\theta)}$.

Substituting in the government's objective formula, we obtain the value function under bundling:

$$\begin{aligned}
V^B &= \int_{\theta^l}^{\theta^h} \left\{ S_0 + sI^B - (1+\lambda)\left[\frac{(I^B)^2}{2p} + \frac{(e^B)^2}{2h} + F + (\theta - e^B)I^B\right] - \lambda\frac{F(\theta)}{f(\theta)}\frac{e^B}{h}\right\} f(\theta)d\theta \\
&= \int_{\theta^l}^{\theta^h} \left\{ S_0 + I^B(s - (1+\lambda)(\theta - e^B)) \right. \\
&\quad - (1+\lambda)\left[\frac{(I^B)^2}{2p} + \frac{(I^B)^2 h}{2} + \frac{1}{2h}\left(\frac{\lambda}{1+\lambda}\frac{F(\theta)}{f(\theta)}\right)^2 \right. \\
&\quad \left. \left. - \frac{\lambda}{1+\lambda}\frac{F(\theta)}{f(\theta)}I^B + F\right] - \lambda\frac{F(\theta)}{f(\theta)}\left(I^B - \frac{1}{h}\frac{\lambda}{1+\lambda}\frac{F(\theta)}{f(\theta)}\right)\right\} f(\theta)d\theta \\
&= \int_{\theta^l}^{\theta^h} \left\{ S_0 - (1+\lambda)F + \frac{(1+\lambda)(1-hp)}{2p}(I^B)^2 + (1+\lambda)\frac{1}{2h}\left(\frac{\lambda}{1+\lambda}\frac{F(\theta)}{f(\theta)}\right)^2\right\} f(\theta)d\theta \\
&= \int_{\theta^l}^{\theta^h} \left\{ S_0 - (1+\lambda)F + \frac{p(1+\lambda)}{2(1-hp)}\left(\frac{s-(1+\lambda)\theta}{1+\lambda}\right)^2 + \frac{p(1+\lambda)}{2(1-hp)}\left(\frac{\lambda}{1+\lambda}\frac{F(\theta)}{f(\theta)}\right)^2 \right. \\
&\quad \left. - \frac{(1+\lambda)p}{1-hp}\frac{s-(1+\lambda)\theta}{1+\lambda}\frac{\lambda}{1+\lambda}\frac{F(\theta)}{f(\theta)} + (1+\lambda)\frac{1}{2h}\left(\frac{\lambda}{1+\lambda}\frac{F(\theta)}{f(\theta)}\right)^2\right\} f(\theta)d\theta
\end{aligned}$$

$$
\begin{aligned}
&= S_0 - (1+\lambda)F + \frac{p(1+\lambda)}{2(1-hp)}\left(\frac{s^2 + (1+\lambda)^2(\overline{\theta} + \sigma_\theta^2) - 2s(1+\lambda)\overline{\theta}}{(1+\lambda)^2}\right) \\
&\quad - \frac{\lambda}{h}\int_{\theta^l}^{\theta^h}\left\{\frac{F(\theta)}{f(\theta)}\left[\frac{hp}{(1-hp)}\frac{s-(1+\lambda)\theta}{1+\lambda} - \right.\right. \\
&\quad \left.\left. - \frac{hp}{2(1-hp)}\left(\frac{\lambda}{1+\lambda}\frac{F(\theta)}{f(\theta)}\right) - \frac{1}{2}\left(\frac{\lambda}{1+\lambda}\frac{F(\theta)}{f(\theta)}\right)\right]\right\} f(\theta)d\theta \\
&= S_0 - (1+\lambda)F + \frac{p(1+\lambda)}{2(1-hp)}\left(\frac{s-(1+\lambda)\overline{\theta}}{1+\lambda}\right)^2 + \frac{p(1+\lambda)}{2(1-hp)}\sigma_\theta^2 \\
&\quad - \frac{\lambda}{2h}\int_{\theta^l}^{\theta^h}\left\{\frac{F(\theta)}{f(\theta)}\left(e^B + \frac{hp}{1-hp}\frac{s-(1+\lambda)\theta}{1+\lambda}\right)\right\} f(\theta)d\theta
\end{aligned}
$$

The new efforts functions applied to the unbundling case yield, respectively:

- $I^U = p\frac{s-(1+\lambda)\overline{\theta}}{(1+\lambda)(1-hp)}$,
- $e^U = hI^U$.

Substituting in the government's objective formula, we obtain the value function under unbundling:

$$
\begin{aligned}
V^U &= \int_{\theta^l}^{\theta^h}\left\{S_0 + sI^U - (1+\lambda)\left[\frac{(I^U)^2}{2p} + \frac{(e^U)^2}{2h} + F + I^U(\theta - e^U)\right]\right\} f(\theta)d\theta \\
&= \int_{\theta^l}^{\theta^h}\left\{S_0 + sI^U - (1+\lambda)\left[\frac{(I^U)^2}{2p} + \frac{(I^U)^2 h}{2} + F + I^U(\theta - I^U h)\right]\right\} f(\theta)d\theta \\
&= \int_{\theta^l}^{\theta^h}\left\{S_0 - (1+\lambda)F + I^U(s-(1+\lambda)\theta) - (1+\lambda)\frac{(I^U)^2}{2p}(1-hp)\right\} f(\theta)d\theta \\
&= S_0 - (1+\lambda)F + I^U(s-(1+\lambda)\overline{\theta}) - (1+\lambda)\frac{(I^U)^2}{2p}(1-hp) \\
&= S_0 - (1+\lambda)F + I^U\frac{I^U}{p}(1+\lambda)(1-hp) - (1+\lambda)\frac{(I^U)^2}{2p}(1-hp) \\
&= S_0 - (1+\lambda)F + (1+\lambda)\frac{(I^U)^2}{2p}(1-hp) \\
&= S_0 - (1+\lambda)F + \frac{p(1+\lambda)}{2(1-hp)}\left(\frac{s-(1+\lambda)\overline{\theta}}{1+\lambda}\right)^2
\end{aligned}
$$

The net welfare gain/loss of governments when using bundling is equal to:

$$
V^B - V^U = \frac{p(1+\lambda)}{2(1-hp)}\sigma_\theta^2 - \frac{\lambda}{2h}\int_{\theta^l}^{\theta^h}\left\{\frac{F(\theta)}{f(\theta)}\left(e^B + \frac{hp}{1-hp}\frac{s-(1+\lambda)\theta}{1+\lambda}\right)\right\} f(\theta)d\theta
$$

where $e^B = \frac{hp}{1-hp}\frac{s-(1+\lambda)\theta}{1+\lambda} - \frac{hp}{1-hp}\frac{\lambda}{1+\lambda}\frac{F(\theta)}{f(\theta)} - \frac{\lambda}{1+\lambda}\frac{F(\theta)}{f(\theta)}$.

As a result, bundling dominates unbundling if and only if:

$$
\sigma_\theta^2 \geq \frac{\lambda(1-hp)}{hp(1+\lambda)}\int_{\theta^l}^{\theta^h}\left\{\frac{F(\theta)}{f(\theta)}\left(e^B + \frac{hp}{1-hp}\frac{s-(1+\lambda)\theta}{1+\lambda}\right)\right\} f(\theta)d\theta
$$

$$\sigma_\theta^2 \geq \frac{\lambda(1-hp)}{hp(1+\lambda)} \int_{\theta^l}^{\theta^h} \left\{ \frac{F(\theta)}{f(\theta)} \left(\frac{hp}{1-hp} \frac{s-(1+\lambda)\theta}{1+\lambda} - \frac{hp}{1-hp} \frac{\lambda}{1+\lambda} \frac{F(\theta)}{f(\theta)} \right.\right.$$
$$\left.\left. - \frac{\lambda}{1+\lambda} \frac{F(\theta)}{f(\theta)} + \frac{hp}{1-hp} \frac{s-(1+\lambda)\theta}{1+\lambda} \right) \right\} f(\theta) d\theta$$

Proof of Corollary 2—negative externality

To study the sign of the derivative of σ_θ^w varies with λ, it is sufficient to study the derivative of the integrand in the previous inequality with respect to λ that is equal to:

$$\begin{aligned}
&= \frac{1-hp}{hp} \frac{1}{(1+\lambda)^2} \frac{F(\theta)}{f(\theta)} \left(e^B + \frac{hp}{1-hp} \frac{s-(1+\lambda)\theta}{1+\lambda} \right) \\
&\quad + \frac{1-hp}{hp} \frac{\lambda}{1+\lambda} \frac{F(\theta)}{f(\theta)} \left(- \frac{hp}{1-hp} \frac{2s}{(1+\lambda)^2} \right. \\
&\quad \left. - \frac{hp}{1-hp} \frac{1}{(1+\lambda)^2} \frac{F(\theta)}{f(\theta)} - \frac{1}{(1+\lambda)^2} \frac{F(\theta)}{f(\theta)} \right) \\
&= 2 \frac{1-hp}{hp} \frac{1}{(1+\lambda)^2} \frac{F(\theta)}{f(\theta)} \left(\frac{hp}{1-hp} \frac{s(1-\lambda)-(1+\lambda)\theta}{1+\lambda} \right. \\
&\quad \left. - \frac{hp}{1-hp} \frac{\lambda}{1+\lambda} \frac{F(\theta)}{f(\theta)} - \frac{\lambda}{1+\lambda} \frac{F(\theta)}{f(\theta)} \right) \\
&= 2 \frac{1-hp}{hp} \frac{1}{(1+\lambda)^2} \frac{F(\theta)}{f(\theta)} \left(e^B - \frac{hp}{1-hp} \frac{\lambda s}{1+\lambda} \right)
\end{aligned}$$

As a conclusion, the value of σ_θ^2 can increase or decrease with λ. Precisely, the derivative is positive if $\lambda = 0$, while it is negative if $\lambda = 1$. The second derivative is equal to:

$$\begin{aligned}
&= 4 \frac{1-hp}{hp} \frac{1}{(1+\lambda)^3} \frac{F(\theta)}{f(\theta)} \left(-e^B + \frac{hp}{1-hp} \frac{\lambda s}{1+\lambda} \right) + \\
&\quad + 2 \frac{1-hp}{hp} \frac{1}{(1+\lambda)^2} \frac{F(\theta)}{f(\theta)} \left(- \frac{hp}{1-hp} \frac{2s}{(1+\lambda)^2} \right. \\
&\quad \left. - \frac{hp}{1-hp} \frac{1}{(1+\lambda)^2} \frac{F(\theta)}{f(\theta)} - \frac{1}{(1+\lambda)^2} \frac{F(\theta)}{f(\theta)} \right) \\
&= -2 \frac{1-hp}{hp} \frac{1}{(1+\lambda)^3} \frac{F(\theta)}{f(\theta)} \left(2e^B + 2 \frac{hp}{1-hp} \frac{s(1-\lambda)}{1+\lambda} \right. \\
&\quad \left. + \frac{hp}{1-hp} \frac{1}{1+\lambda} \frac{F(\theta)}{f(\theta)} + \frac{1}{1+\lambda} \frac{F(\theta)}{f(\theta)} \right) \leq 0
\end{aligned}$$

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