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Elisabetta Iossa and David Martimort

THE SIMPLE MICRO-ECONOMICS OF PUBLIC-PRIVATE PARTNERSHIPS.¹

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ELISABETTA IOSSA^a AND DAVID MARTIMORT^b

ABSTRACT: We build on the existing literature in Public Private Partnerships (*PPP*) to analyze the main incentive issues in *PPPs* and the shape of optimal contracts in those contexts. We present a basic model of procurement in a multi-task environment in which a risk averse firm chooses non-contractible efforts in cost reduction and quality improvement. We first consider the effect on incentives and risk transfer of bundling building and management stages into a single contract, allowing for different assumptions on feasible contracts and information available to the government. Then we extend the model in novel directions. We study the relationship between the operator and its financiers and the impact of private finance. We discuss the trade-off between incentive and flexibility in *PPP* agreements and the dynamics of *PPPs*, including cost overruns. We also consider how institutions, and specifically the risk of regulatory opportunism, affects contract design and incentives. The conclusion summarizes policy implications on the desirability of *PPPs*

KEYWORDS: Public-private partnerships, public-service provision..

1. INTRODUCTION

Under a public-private partnership (hereafter abbreviated as *PPP*), a local authority or a central-government agency enters a long-term contract with a private supplier for the delivery of some services. The supplier takes responsibility for building infrastructure, financing the investment and then managing and maintaining this facility.

PPPs are being used across Europe, Canada, the US and a number of developing countries as part of a general trend seeing an increasing involvement of the private sector in the provision of public services, under the form of privatization, deregulation, outsourcing and downsizing of government.¹ *PPPs* have traditionally been employed in transportation, energy and water but their use has recently been extended to IT services, accommodation, leisure facilities, prisons, military training, waste management, schools and hospitals.

In Europe, the *PPP* approach was pioneered by the Private Finance Initiative (*PFI*) launched in 1992 in the UK.² By 2009, approximately 800 *PFI* projects had been signed for a capital value of £ 64 billion (HL, 2010). *PPPs* have also been in operation for more than 10 years in Portugal where investment through *PPPs* reached up about 20% of total public investment during 1999-2003.³ Other European countries have also invested in *PPPs*, especially Spain, France, and Italy. Overall, more than 1300 *PPP* contracts have

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^aUniversity of Rome Tor Vergata, CMPO, CEPR and EIEF, elisabetta.iossa@uniroma2.it

^bParis School of Economics-EHESS, david.martimort@parisschoolofeconomics.eu

¹Armstrong and Sappington (2006), Levin and Tadelis (2010), Estache and Imi (2011).

²Grout (1997).

³Välilä, Kozluk and Mehrotra (2005).

been signed in the EU from 1990 to 2009, representing a capital value of more than EUR 250 billion (EIB, 2010). In the US, *PPPs* are most common for projects involving highway and road transportation, rail, water supply and waste water treatment (CBO, 2007).⁴ Whilst *PPPs* have not accounted for a significant share of public infrastructure spending in the U.S. so far, they are being actively encouraged by Federal Departments (DOT 2007). *PPPs* are also being encouraged in Canada: In November 2007 the Canadian Federal government announced a plan to promote use of *PPPs* and created a national fund for *PPP* investments of 1.26b CD. In developing countries, *PPP* agreements have grown steadily since the 1990s. According to the World Bank's Private Participation in Infrastructure (PPI) database, between 2000 and 2010, 29 countries in Latin America and the Caribbean implemented 688 infrastructure projects with private participation for capital value of US\$191 billion. Between 2000 and 2010, 17 countries out of the 23 in East Asia and Pacific implemented 908 infrastructure projects with private participation for capital value of U.S. \$154 billion. India is the largest market for private participation in infrastructure in the developing world.

Despite this worldwide growth, evidence on *PPP* performance remains mixed.⁵ On the one hand, *PFI* projects in the UK seem to be delivering cost saving compared to traditional procurement.⁶ Improvements in completion time and cost of delivery have also been achieved,⁷ and public bodies using private finance have shown satisfaction with the services provided by contractors.⁸

On the other hand, *PPPs* have resulted in higher water prices than traditional procurement in France.⁹ *PPPs* seem also unsuitable for fast-moving sectors; performance failures have been widespread in *PPPs* for specialized IT in the UK. Existing evidence also suggests that renegotiation has played a pervasive role in *PPPs* worldwide. In LAC countries, governments have sometimes failed to enforce contracts and projects have been abandoned.¹⁰ Adverse institutional conditions have also mattered. High transaction costs and unrealistic demand expectations have made *PPPs* in Central and Eastern Europe less successful than in other countries.¹¹

These pieces of evidence not only question the values of *PPPs* but also call for a better understanding of the incentive issues in *PPPs*. This paper aims to build on previous works so as to identify circumstances in which the main characteristics of *PPPs* are suitable to provide adequate incentives for private contractors in infrastructure and public service provision. We also extensively describe the empirical evidence on *PPPs* and use our insights to derive clear policy implications.

For our purpose, we characterize *PPPs* by three main features: (i) tasks bundling, (ii) risk transfer, (iii) long-term contract.

⁴In the U.S., the cumulative project costs of *PPPs* funded or completed by October 2006 totaled about \$48 billion out of nominal capital spending on infrastructure by the federal government and states and localities of \$1.6 trillion between 1985 and 2004 (averaging \$80 billion annually). A number of *PPPs* were also developed in the 70's for inner-city infrastructure (see Rosenau, 2000).

⁵For a general and comprehensive discussion of *PPP* successes and failures, see Engel, Fisher and Galetovic (2011) and the countries studies therein.

⁶Arthur Andersen and LSE (2000).

⁷The HM Treasury (2003) reports that 76% of *PPP* projects have been completed on time, compared to 30% of traditionally procured projects. However, we do not know what the time line was, so we are unable to assess whether *PPP* delivered faster projects than traditional procurement.

⁸NAO (2009).

⁹See Chong, Huet and Saussier (2006).

¹⁰Guash (2004).

¹¹Brench, Beckers, Torsten and von Hirschhausen (2005).

(i) *Bundling*. A *PPP* typically involves bundling design, building, finance, and operation of the project, which are all contracted out to a consortium of private firms. The consortium includes a construction company and a facility-management company and it is responsible for all aspects of services. The *DBFO* model (‘Design’, ‘Build’ ‘Finance’ and ‘Operate’), the *BOT* model (‘Build’, ‘Operate’ and ‘Transfer’) or the *BOO* (‘Build’, ‘Own’ and ‘Operate’) all account for bundling of building and operations but differ with regard to the ownership of the infrastructure at the end of the contract, which may either be retained by the private sector (e.g. as under *BOO*) or be transferred to the public sector (e.g. as under *BOT*).

(ii) *Risk transfer*. Compared to traditional procurement, a *PPP* involves a greater transfer of risk and responsibility to the contractor. A system of output specifications is used: The government specifies the service and the basic standards, but leaves the consortium with control rights and responsibility over how to deliver the service and meet the pre-specified standards. So design, construction and operational risk are generally substantially transferred to the private-sector party.

(iii) *Long-term contracts*. A *PPP* is a long-term contract lasting typically 20 to 35 years. The payments to the private-sector party for the use of the facility is made either by the government (as in the case of *PFI* projects) or by users of the facility (as in more standard concession contracts).

To capture those features, we present in Section 2 a simple model of procurement. Consistently with real-world evidence, our model features both aspects of the optimal contracting (the contractibility of some profit dimension and the need to share operating risk) and the property rights literatures. Moral hazard is key to investigate two issues that are pervasive in the economics of *PPPs*. The first one is the existing agency costs borne by governments when delegating to the private sector the task of providing a public service. The second one concerns risk sharing between those parties. A key point of our analysis is to discuss the nature of agency costs and risk sharing in a multi-task environment where the agent not only manages assets necessary to provide the service but also may design, build and finance these assets.¹²

Section 3 isolates conditions under which bundling of project phases (in particular building and operation) is optimal. An important distinction that we draw is between *positive* and *negative externalities* across different stages of production. Positive externality (resp. negative externality) refers to the case where a building innovation reduces (resp. increases) costs at the management stage. We show that when the externality across stages is positive, bundling then forces contractors to look at the long-term performances of the asset (the so called ‘whole life asset management’) and boosts the contractor’s incentives to invest in asset quality. Importantly, bundling goes hand in hand with higher power incentives. Bundling and risk transfer to the private sector are two complementary features of *PPPs*. This explains the greater risk premium that is typically observed in *PPPs* compared to traditional procurement. Furthermore, we show that private ownership during the contract dominates public ownership from a social welfare perspective. Finally, the gains from bundling with private ownership are greater for generic facilities, such as leisure centers, accommodations and public housing, than for

¹²In our view, this multi-task aspect of the delegation process is what makes the theoretical analysis of *PPPs* quite specific compared with the whole literature on privatization. This literature analyzes the agency cost of delegation to the private sector when a single task has to be performed by the private sector. See the seminal papers by Sappington and Stiglitz (1987) and Shapiro and Willig (1990) among others, and for some overviews Shleifer (1998) and Martimort (2006).

specific facilities, such as prisons, hospitals and schools which have limited use outside the public sector.

Once equipped with the rationale for bundling and risk transfer in *PPPs*, we develop our basic insights in more elaborated environments which have been viewed as particularly interesting both in the public debate and within recent academic research.

Section 4 studies another important characteristic of many *PPPs*, namely the use of private finance, focusing on the contracts between operators and financiers. This issue is of tantamount importance given the estimated size of investments in infrastructure for the next twenty years, and the role that infrastructure funds will play. Outside finance improves risk allocation if it helps alleviating moral hazard.

Long-term contracts also suffer from uncertainty over the future of users' needs. This might make them unsuitable when users needs evolve rapidly and the output specifications set up in the initial contract become quickly obsolete. We discuss this cost of *PPPs* in Section 5. We show that for fast-moving sectors, the benefit of bundling needs to be weighted against the cost of contract rigidity. This cost may be severe enough to make *PPPs* unsuitable when users needs evolve rapidly.

Section 6 analyzes incentives for investments over the length of a long-term contract. We start by considering the case of a public authority having a strong commitment power; the risk of unilateral changes of contract terms by governments being then minimal. We show that the optimal long-term contract entails increasing incentives over time to foster the renewal of investment. Cost-plus contracts arise in early periods whereas fixed-price agreements are expected close to the end of the contract.

Long-term contracts however suffer from being signed in contexts with pervasive uncertainty over future demands and costs. When estimates turn out to have been optimistic, renegotiation may occur, partially nullifying the incentive power of the initial contract. We then extend our analysis of the dynamics of *PPPs* by considering the distortions that are needed to prevent cost overruns. We show that incentives should be lower powered and less risk should be transferred at earlier stages of contracting. However, this non-stationarity of incentives does not necessarily undo the benefits of bundling.

Section 7 analyzes how the institutional environment, and most specifically the risk of regulatory opportunism, affects contract design and incentives. We consider thus settings where the risk of unilateral changes of contract terms by governments is significant. This typically might depict developing countries with low quality institutions but, beyond, the kind of political uncertainty that we have in mind certainly has some appeal also for developed countries subject to the political risk that electoral uncertainty generates. In weak institutional environments, less risk transfer should occur. This of course reduces the benefits of bundling without again coming to the conclusion that bundling should be given up.

Section 8 summarizes our conclusions and discusses the scope for future research.¹³

¹³Let us already stress that one omitted domain of investigation for this paper is the macro-economic/public finance side of *PPPs*. On this issue we refer to Vålilä (2005), Vålilä, Kozluc and Mehrotra (2005), Sadka (2007) and Engel, Fisher and Galetovic (2007). Note nevertheless that any efficiency gains that *PPPs* may bring end up relaxing the State budget constraint so in, a sense, the micro approach that we are taking here already also offers a clue on the benefits of this organizational choice for public finance.

2. THE GENERAL FRAMEWORK

A government (sometimes referred to as G) relies on a private contractor (a firm or consortium) to provide a public service for society. Examples of such delegation include of course transportation, water production and sanitation, waste disposal, etc. In such settings, providing the service requires that a good quality infrastructure has been first designed and built. This delegation must thus be modeled as a multi-task problem.¹⁴ The main feature of a *PPP* can then be viewed as the bundling of various phases of contracting.

Benefits and quality index. Benefits from the service are stochastic. Even when there is a reasonable level of confidence in forecasts, they can be dramatically affected by competition from substitutable services (in transport for instance, competition may come from un-tolled roads, ferries, buses; in the health sector competition may instead come from private health clinics etc), changing user needs, and macroeconomic conditions. Benefits are also influenced both by the innate quality of the infrastructure and the operating effort.¹⁵

The above features are captured by assuming that one unit of services yields a benefit to users worth

$$(2.1) \quad B = b_0 + ba + de + \eta,$$

where a denotes an effort to improve quality of the infrastructure, e denotes an operating effort and η is a random shock normally distributed with variance σ_η^2 and zero mean. The marginal benefit of efforts are positive ($b, d > 0$) and $b_0 \geq 0$ denotes some base level benefit that would have been obtained even without any specific effort.

We assume that, for services where users pay, the service provider extracts all their surplus.¹⁶ The firm then gets revenues worth B . We shall use B interchangeably to refer to social benefit or revenues, depending on the scenario.

Costs. The operating cost of providing one unit of service is also stochastic. Major maintenance and operational risks affect *PPP* projects. Operating costs depend also on the quality of the infrastructure, although the magnitude and sign of this externality varies across sectors and projects. In some cases, improving infrastructure reduces operational costs. For example, the design of a prison with better sight-lines for staff that improve security (i.e., social benefit) has the positive externality that the required number of security guards is reduced. In other cases, improving the quality of infrastructure increases operational costs. An innovative design of a hospital, using recently developed materials, may lead to improved lighting and air quality, and therefore better clinical outcomes, but may also increase maintenance costs.

The above features are captured by considering the following cost function:

$$(2.2) \quad C = \theta_0 - \gamma e - \delta a + \varepsilon.$$

¹⁴Holmström and Milgrom (1991).

¹⁵For example the benefits enjoyed by users of motorways depend on the route safety, the asphalt conditions, the efficiency of traffic alerts and toll stations and so on. In railways, the benefits for users depend on the quality and comfort of trains, on service reliability, on-the train services, the efficiency of the ticketing system and so on.

¹⁶This is a restriction that is introduced to simplify the analysis, by combining into a single framework both the case where users pay and the case where they do not. The implication is that we do not discuss optimal user prices.

The random variable ε captures operational risk. It is normally distributed with variance σ_ε^2 and zero mean. θ_0 is the base level cost of the service (linked to the underlying technology); γ is a positive parameter and e is the firm's cost-reducing effort. The case $\delta > 0$ corresponds to a *positive externality* where improving the quality of the infrastructure also reduces the costs. Instead, $\delta < 0$ arises for a *negative externality*. For simplicity, we normalize construction costs (other than a) to zero.

Efforts. For simplicity, quality-enhancing and operating efforts have quadratic monetary costs $\frac{a^2}{2}$ and $\frac{e^2}{2}$, respectively. Note that there are no (dis-)economies of scope between efforts so that bundling those tasks can only arise because agency costs have diseconomies of scope when both a and e are nonverifiable.

Objectives. The risk-neutral government G maximizes consumer surplus net of the transfer(s) made to the contractor.¹⁷ We denote by t such payments. The contractor is risk averse with a constant absolute degree of risk aversion $r > 0$. This assumption captures the fact that a *PPP* project might represent a large share of the firm's activities so that it can hardly be viewed as being fully diversified.

Relevant scenarios. In the rest of the paper, we develop our results by means of a main model but discuss their robustness to alternative contracting scenarios. To simplify exposition, these scenarios are assumed to be mutually exclusive although in practice they need not to be so.

Consider the case where a contractor is in charge of both building and operation. The contractor bears costs C and receives a transfer t from G . For services where users pay, the contractor also receives revenues B . The following three cases will be discussed:

1. **Contractible profits.** The contractor's gross profit $\Pi = B - C$ is observable and can be contracted upon. The firm receives $t(\Pi)$ from G , where $t(\Pi) = \alpha - (1 - \beta)\Pi$. Under this profit-sharing rule, the contractor obtains a net profit of: $\alpha + \beta\Pi - \frac{a^2}{2} - \frac{e^2}{2}$.¹⁸ In the case $\beta = 0$ the contractor actually acts as an employee of the public sector who has no particular incentives to raise profits. Instead, $\beta > 0$ holds when the contractor bears profit risk. In the extreme case where $\beta = 1$, all risks are transferred to the contractor. This scheme is typically used for complex transport projects where users pay for the service.
2. **Contractible revenues.** The revenues from the service B is observable and can be contracted upon whereas costs are not contractible. The payment mechanism takes the form $t(B) = \alpha - (1 - \beta)B$. Under this revenue-sharing rule, the contractor obtains $\alpha + \beta B - C - \frac{a^2}{2} - \frac{e^2}{2}$. Revenue sharing schemes are often used also in transport projects. A payment mechanism solely based on user charges corresponds to $\alpha = 0$

¹⁷The assumption of risk neutrality for the government gives a simple benchmark: Without moral hazard, optimal risk sharing requires that the public sector bears all risk. This assumption might be questionable in the case of a small local government whose *PPP* project under scrutiny represents a significant share of the overall budget. For a large country's government, the existing deadweight loss in the cost of taxation may as well introduce a behavior towards risk if *PPP* projects were to represent a large share of the budget. Lewis and Sappington (1995) and Martimort and Sand-Zantman (2007) analyze the consequences for optimal regulation of having risk averse local governments.

¹⁸Given our CARA-normal distribution environment, restriction attention to linear rules follows the justification given by Holmström and Milgrom (1991). The same restriction applies as well to the other cases below.

and $\beta = 1$ so that the contractor keeps all revenues and bears all demand risk. This is the case of *PPP* for leisure centres for example. A payment mechanism based on availability only, corresponds instead to $\alpha > 0$ and $\beta = 0$ so that the contractor's reward is fixed and G retains all demand risk. This scheme is typically used for *PPPs* in hospitals, schools and prisons (the so called *PFI* model) where users do not pay for the service. The revenues for the contractor then consist only of an 'availability payment' α that G pays for making the service available to users.

3. Contractible costs. The contractor receives no revenues from users, operating cost C is observable and contracted upon. The contractor is paid $t(C) = \alpha + (1 - \beta)C$ and obtains $\alpha - \beta C - \frac{a^2}{2} - \frac{e^2}{2}$. The case $\beta = 0$ corresponds to a cost-plus contract where the contractor is fully reimbursed for its own costs, whereas $\beta = 1$ holds for a fixed-price contract, where the contractor receives a fixed payment.

Benchmark. At the first best, efforts are observable and contractible. The risk averse firm is fully insured by the risk-neutral government: its reward being independent of the realized costs or revenues. Given that G runs an auction to attract potential service providers, it has all bargaining power ex ante and chooses a fee that makes the contractor just indifferent between producing the service or getting an outside option worth zero. That contract also forces the firm to choose the first-best efforts a^{FB} and e^{FB} that maximize the overall expected surplus:

$$(a^{FB}, e^{FB}) = \arg \max_{(a,e)} E_{\epsilon,\eta}(B - C) - \frac{a^2}{2} - \frac{e^2}{2} \equiv b_0 - \theta_0 + (b + \delta)a + (d + \gamma)e - \frac{a^2}{2} - \frac{e^2}{2}$$

or

$$(2.3) \quad (a^{FB}, e^{FB}) = (b + \delta, d + \gamma).$$

The first-best quality-enhancing effort a^{FB} trades off the marginal social value of that effort, including its impact on operating costs (δ) and on the social value of the service (b), with its marginal cost (a). We assume $b + \delta > 0$, so that a^{FB} is always positive. The operating cost-reducing effort e^{FB} trades off the marginal benefit of raising social benefit (d) and lowering those operating costs (γ) with its marginal monetary disutility (e).

3. BUNDLING OR UNBUNDLING?

We now provide a rationale for relying on *PPPs* rather than adopting more traditional procurement contracts. With such contracts, G first buys the infrastructure from a given builder and then selects an operator. We thus investigate whether the two tasks of designing/building and then operating assets should be *bundled* and performed by the same contractor (a consortium) or instead be *unbundled* and undertaken by two separate firms (a builder and a separate operator).¹⁹

To make our point in a simple setting, we focus on the scenario where users do not pay and costs are contractible but we shall also discuss implications of our insights for other scenarios. Furthermore, we normalize effort so that $\gamma = 1$, let $d = 0$ in the benefit function and focus on the case where B is deterministic, so that social benefits reduce to:

$$B = b_0 + ba.$$

¹⁹We thus focus here on the provision of public infrastructures and services by private firms. The analysis could however be extended to cover the case where under traditional procurement the private sector builds the infrastructure but then a government agency provides the services.

For simplicity, we assume that b_0 and θ_0 are common knowledge.²⁰

3.1. Pure Agency Considerations: Bundling Dominates

Unbundling. Under traditional procurement, G first approaches a builder (B) and then a separate operator (O). The operator receives a cost-reimbursement rule $t(C) = \alpha + (1 - \beta)C$, whilst the builder gets only a fixed payment t_B .²¹ With such payment unrelated to his own effort, the builder does not exert any effort:

$$(3.1) \quad a = \arg \max_{\tilde{a}} t_B - \tilde{a}^2/2 = 0.$$

The operator maximizes the certainty equivalent of its expected payoff, taking as given the zero effort exerted by the builder. The corresponding incentive constraint writes as:

$$(3.2) \quad e = \arg \max_{\tilde{e}} \alpha - \beta E_{\tilde{e}}(C) - \frac{e^2}{2} - \frac{r\sigma_{\tilde{e}}^2\beta^2}{2} \equiv \alpha - \beta(\theta_0 - \tilde{e}) - \frac{\tilde{e}^2}{2} - \frac{r\sigma_{\tilde{e}}^2\beta^2}{2} = \beta.$$

An increase in the incentive power β , the share of the profit risk borne by the operator, boosts its cost-reducing effort. However, as more operational risk is transferred to the operator, the risk premium $\frac{r\sigma_{\tilde{e}}^2\beta^2}{2}$ also increases which is at the core of a standard moral hazard trade-off between incentives and insurance.

Since G has all the bargaining power, it sets the fixed payments to the builder t_B and the operator α so as to extract all their surplus. The principal's payoff then coincides with the expected value of the project net of the risk premium, that is:

$$W(e, a, \beta) = b_0 - \theta_0 + (b + \delta)a + e - \frac{a^2}{2} - \frac{e^2}{2} - \frac{r\sigma_{\tilde{e}}^2\beta^2}{2}.$$

Maximizing the above expression with respect to (e, a, β) while taking into account the incentive constraints (3.1) and (3.2) that hold under unbundling yields the following expressions of the second-best operating effort and the share of the risk borne by the operator:

$$(3.3) \quad e_u^{SB} = \frac{1}{1 + r\sigma_{\tilde{e}}^2} = \beta_u^{SB} < 1.$$

Because providing incentives requires the agent to bear more risk which is socially costly, the second-best effort is lower than its first-best level so as to reduce the corresponding risk premium. More risk ($\sigma_{\tilde{e}}^2$ larger) also tilts the trade-off between insurance and incentives towards low powered incentives.²² G 's expected payoff is then:

$$(3.4) \quad W_u^{SB} = b_0 - \theta_0 + \frac{1}{2(1 + r\sigma_{\tilde{e}}^2)}.$$

²⁰This assumption allows us to disregard any adverse selection problem. This fits well with the observation made by Bajari and Tadelis (2001) that, in many procurement contexts, buyers and sellers face the same uncertainty on costs and demand.

²¹We rule out the possibility that the builder obtains any incentive payment conditional on C . This may be justified when G cannot delay payment for the delivery of the infrastructure. The possibility of a collusion between G and the operator to exaggerate the latter's contribution to cost-reducing activities and underestimate that of the builder might also preclude such cost-dependent payments. We discuss how the results can be extended when this assumption is relaxed in Section 3.2.

²²Suppose that there is a positive cost of public funds $\lambda > 0$. The objective function would be as above provided the social benefit of the project is deflated as $\frac{b_0 + ba}{1 + \lambda}$. Since e_u^{SB} given by (3.3) does not depend on the social benefit of the project, the power of incentives under unbundling is unchanged. Whether bundling is optimal or not does not depend of the cost of public funds.

Bundling. The building and the operational phases are now both in the same hands. The consortium (BO) chooses the effort levels so as to maximize the sum of its profit at both the building and operational stages and thus internalizes the impact of the design stage on the operational costs. The corresponding effort levels thus solve:

$$(e, a) = \arg \max_{(\tilde{e}, \tilde{a})} \alpha - \beta (\theta_0 - \tilde{e} - \delta \tilde{a}) - \frac{\tilde{a}^2}{2} - \frac{\tilde{e}^2}{2} - \frac{r\sigma_\varepsilon^2 \beta^2}{2}.$$

Taking into account the additional non-negativity constraint $a \geq 0$, we obtain the following incentive constraints:

$$(3.5) \quad e = \beta \text{ and } a = \begin{cases} \beta\delta & \text{if } \delta > 0 \\ 0 & \text{if } \delta \leq 0. \end{cases}$$

Observe that, in the case of a negative externality ($\delta \leq 0$), those effort levels just replicate those found under unbundling. Instead, with a positive externality ($\delta > 0$), the first-stage effort is positive because now the firm at least partially takes into account the impact of this first stage on costs.

As before, the fixed fee α is adjusted by G so that to extract all surplus from the consortium. Now, G 's maximization problem consists in maximizing $W(e, a, \beta)$ subject to the incentive constraints in (3.5).

Of course, efforts remain unchanged with respect to the unbundling scenario in the case of a negative externality:

$$e_b^{SB} = e_u^{SB} = \beta_u^{SB} \text{ and } a_b^{SB} = 0 \text{ if } \delta \leq 0.$$

Instead, effort levels are higher under bundling in the case of a positive externality:

$$e_b^{SB} = \frac{1 + \delta(b + \delta)}{1 + \delta^2 + r\sigma_\varepsilon^2} \equiv \beta_b^{SB} \text{ and } a_b^{SB} = \delta e_b^{SB} \text{ if } \delta > 0. \text{²³}$$

Using these values of efforts, the expression for the expected welfare can be written as:

$$W_b^{SB} = b_0 - \theta_0 + \frac{(1 + (b + \delta)\delta)^2}{2(1 + \delta^2 + r\sigma_\varepsilon^2)} \text{ if } \delta > 0 \text{ and } W_b^{SB} = W_u^{SB} \text{ if } \delta \leq 0.$$

We can thus immediately conclude:

PROPOSITION 1 *Bundling is strictly desirable in the presence of positive externality and there is an indifference between organizational forms otherwise.*

When $\delta \leq 0$, the consortium never performs any quality-enhancing effort because it is not rewarded for doing so. This replicates the case of unbundling. With a negative externality, investment a is already at a minimum under unbundling (the builder having no incentives to invest), and the internalization of the negative externality under bundling cannot depress these incentives further. Investment a remains at a minimum under both organizational forms which yield the same expected benefits to the principal.

When $\delta > 0$, a consortium anticipates how a high quality infrastructure also reduces costs. Bundling then induces the consortium to internalize the positive externality generated by its quality-enhancing effort a on the fraction of costs that it bears at the

²³In particular, $\delta b \leq r\sigma_\varepsilon^2$ ensures that $\beta_b^{SB} \leq 1$. Note also that $e_b^{SB} = e_u^{SB} + \delta \frac{b(1+r\sigma_\varepsilon^2) + \delta r\sigma_\varepsilon^2}{(1+r\sigma_\varepsilon^2 + \delta^2)(1+r\sigma_\varepsilon^2)} > e_u^{SB}$.

operational stage. This unambiguously raises welfare as it reduces the underinvestment problem during the building stage, raising quality-enhancing effort.²⁴ Quality-enhancing effort however remains suboptimal: the consortium only internalizes the effect of a on the fraction of costs that it bears (this effect is measured by $\beta\delta a$), and thus not the total effect on costs (measured by δ), and also it does not internalize the effect on social benefits (measured by ba).

Moving from traditional procurement to *PPP* changes cost-reimbursement rules. Bundling shifts more risk to the operator ($\beta_b^{SB} > \beta_u^{SB}$) and increases incentives to invest in asset quality. This is intuitive: Transferring more operational risk (through higher values of β) induces the operator to exert higher cost-reducing effort but it brings the cost of a higher risk premium. Under bundling, the transfer of operational risk brings the additional benefit of also inducing quality-enhancing effort. This justifies transferring more operational risk. Thus, bundling and fixed-price contracts go hand in hand under *PPP* whereas unbundling and cost-plus contracts are more likely under traditional procurement. This is in lines with existing evidence that *PPPs* are characterized by more risk transfer and thus greater risk premiums than traditional procurement.

Other scenarios. The benefits of bundling in the presence of a positive externality carry over to the other contractual scenarios mentioned in Section 2. When users pay for the service and the contractor is residual claimant for the revenues (as in the case of *Contractible Profits* or of *Contractible Revenues*), the consortium's incentives to enhance quality are still stronger than those of the builder under unbundling. For example, in the case where there is no moral hazard on costs and B in expression (2.1) denotes the revenues from the service, the expected revenues from the service are:

$$E_\eta(B) = E_\eta(\max\{b_0 + ba + de + \eta, 0\}) \approx (b_0 + ba).$$

where the approximation holds for σ_η^2 small enough. In this case, it is immediate that the builder obtains no benefit from raising operational revenues under unbundling and thus $a_u = 0$. At the same time, the operator chooses:

$$(3.6) \quad e_u = \arg \max_e \alpha + \beta(b_0 + ba + d\tilde{e}) - \frac{\tilde{e}^2}{2} - \frac{r\sigma_\eta^2\beta^2}{2} = \beta d.$$

In that scenario, G 's problem is to maximize with respect (e, β) its expected payoff

$$(3.7) \quad b_0 + de - \frac{e^2}{2} - \frac{r\sigma_\eta^2\beta^2}{2}$$

subject to the incentive constraint (3.6). This gives the following expressions of the incentive power and the second-best effort under unbundling:

$$\beta_u^{SB} = \frac{d^2}{d^2 + r\sigma_\eta^2} \text{ and } e_u^{SB} = \beta_u^{SB}d.$$

Under bundling instead the consortium maximizes:

$$(3.8) \quad (e, a) = \arg \max_{(\tilde{e}, \tilde{a})} \alpha + \beta(b_0 + b\tilde{a} + d\tilde{e}) - \frac{\tilde{a}^2}{2} - \frac{\tilde{e}^2}{2} - \frac{r\sigma_\eta^2\beta^2}{2} = (\beta d, \beta b).$$

²⁴To give some intuition, take the incentive scheme offered to the operator under unbundling, and suppose it is now given to the consortium. The incremental welfare gain from doing so is $(b + \delta)a_u^{SB} - \frac{(a_u^{SB})^2}{2} > 0$ since now the consortium exerts a quality-enhancing effort $a_u^{SB} = \delta e_u^{SB}$. The stronger the positive externality, the greater the benefit of bundling.

G 's problem is thus to maximize

$$(3.9) \quad b_0 + ba + de - \frac{e_b^2}{2} - \frac{a_b^2}{2} - \frac{r\sigma_\eta^2\beta^2}{2}$$

subject to the incentive constraints (3.8). This yields the following expressions of the incentive power and the second-best effort under bundling:

$$\beta_b^{SB} = \frac{b^2 + d^2}{b^2 + d^2 + r\sigma_\eta^2}; \quad e_b^{SB} = d\beta_b^{SB} \text{ and } a_b^{SB} = b\beta_b^{SB}.$$

It is immediate to show that welfare is higher under bundling since $e_u^{SB} < e_b^{SB} < e_b^{FB}$ and $a_u^{SB} < a_b^{SB} < a_b^{FB}$.²⁵

Intuitively, the consortium anticipates that increasing a raises revenues B . The greater the share β of revenues kept by the consortium, the greater the incentives to increase a . Since the builder under unbundling gets no revenues, incentives are there absent. As with verifiable costs, bundling boosts effort at the building stage. This unambiguously raises welfare and the stronger the effect of infrastructure quality on revenues (higher b) the greater the benefits of bundling. Furthermore, since higher risk transfer (higher β) raises both e and a , bundling again comes with more risk transfer: $\beta_b^{SB} > \beta_u^{SB}$. Finally, comparative statics on β_b^{SB} characterizes the optimal allocation of demand risk under a *PPP*. The optimal payment mechanism trades off incentives and insurance: transferring demand risk to the contractor gives it incentives to boost demand (a increases) and raises consumer surplus (B increases) but it costs the government a higher risk-premium ($\frac{r\sigma_\eta^2\beta^2}{2}$). Thus, the more demand levels are affected by the contractor's action (higher b), the lower the demand risk (lower σ_η^2) or the risk aversion of the contractor (r), the more demand risk should be borne by the contractor.

In *PPP* projects such as prisons, users do not pay, and government policies determine most of demand changes. Since the contractor's effort has little impact on demand levels (b small), not transferring demand risk to the contractor ($\beta = 0$) is indeed optimal. With financially free-standing projects, such as leisure centres, the contractor recoups its initial investment through charges to final users. Here, revenue risk lies entirely with the contractor ($\beta = 1$) since the contractor's effort has large impact on demand levels (b high). Transport projects instead typically fall in the intermediate case, where there is some revenue sharing between the contractor and the public authority.²⁶

3.2. More Complete Contracting

As a robustness check of our previous findings, we now envision the consequences of allowing more complete contracts. This may be by making the builder's payment depend on costs under unbundling or on a quality index for the infrastructure. We focus on the case of positive externality under the contractible-cost scenario.

3.2.1. Costs Incentives

Suppose that the builder's payment is now linked to the realized level of operating costs with a contract of the form $t_B(C) = \alpha_B - \beta_B C$. If the builder is risk averse (assuming

²⁵For a more detailed discussion see Iossa and Martimort (2011a).

²⁶For a more in depth discussion on demand risk allocation, see Iossa, Spagnolo and Vellez (2007). An interesting issue that we do not address concerns political accountability under various contractual forms. In this respect, Athias (2008) compares the performance of concession contracts and availability contracts in terms of their impacts on the incentives of public authorities to respond to customers needs.

the same degree of risk aversion as the operator) such payment comes with an extra risk premium worth $\frac{r\sigma_\varepsilon^2\beta_B^2}{2} = \frac{r\sigma_\varepsilon^2 a^2}{2\delta^2}$ to induce the builder's participation. This premium quickly increases when the positive externality is small enough, i.e., when the noisy observable does not track so easily the builder's effort. The builder then maximizes:

$$\alpha_B - \beta_B (\theta_0 - e - \delta a) - \frac{a^2}{2} - \frac{r\sigma_\varepsilon^2\beta_B^2}{2}.$$

Whilst nothing changes under bundling, under unbundling such a scheme now gives to the builder some incentives to exert effort a . His incentive constraint is indeed given by:

$$a = \beta_B \delta.$$

The quality-enhancing effort is then easily obtained by trading off the efficiency gain of more effort against the risk premium and one finds:

$$(3.10) \quad a_u^{SBC} = \frac{(b + \delta)\delta^2}{\delta^2 + r\sigma_\varepsilon^2}.$$

This effort level is second order in δ for small externalities. Contracting on costs is thus of little help if the builder's effort does not significantly affect those costs.

The advantage of bundling stems from the possibility to use the incentive scheme at the operating stage (the cost reimbursement rule) to incentivize both the effort at building stage and the effort at operating stage. Transferring operational risk to the contractor (through the cost-reimbursement rule) is thus more effective for incentive purposes.

Other scenarios. The insights from this robustness check carry over when profit sharing or revenue sharing rules can be used. When profits or revenues are verifiable, G can reward the builder when higher profits or revenues are observed. With $b > 0$, this induces higher quality-enhancing effort under unbundling. However, with a positive externality bundling still strictly dominates unbundling, since the incentive scheme at the operating stage (the profit sharing or revenue sharing rule) helps to incentivize both efforts at the and the operating building stages.

3.2.2. Quality Incentives

Let us now suppose that a noisy index q for the quality of the infrastructure (which is also an imperfectly aligned proxy for the social benefit) is available:

$$q = a + \varepsilon'$$

where ε' is a random variable which is assumed to be normally distributed with (for simplicity) variance σ_ε^2 and zero mean. For simplicity, we keep the same variance of noise on this quality index and on the operating costs. This assumption is particularly relevant when q stems for an earlier realization of operating costs in a context where the investment consists of complementary and renewed assets. The builder's incentive scheme is now of the form $t_B(q) = \alpha_B + \beta_B q$.

Unbundling. The builder's incentive constraint is now

$$(3.11) \quad a = \arg \max_a \alpha_B + \beta_B a - \frac{a^2}{2} - \frac{r\sigma_\varepsilon^2\beta_B^2}{2} = \beta_B$$

while that of the operator remains unchanged as (3.2). Although the ability to contract on a quality index improves the builder's incentives and raises the quality of the infrastructure, it does not change the operator's incentives.

Bundling. The consortium's incentive constraint can be written as:

$$(3.12) \quad (a, e) = \arg \max_{(\tilde{a}, \tilde{e})} \alpha + \beta_B \tilde{a} - \beta(\theta_0 - \tilde{e}) - \frac{\tilde{a}^2}{2} - \frac{\tilde{e}^2}{2} - \frac{r\sigma_\varepsilon^2}{2}(\beta_B^2 + \beta^2) + \beta\delta a = (\beta_B + \beta\delta, \beta).$$

By making the firm's payment depend on the quality index, incentives to invest in asset quality are boosted. As BO is risk averse, such payment raises the risk premium by an amount $\frac{r\sigma_\varepsilon^2\beta_B^2}{2}$. However, part of the risk necessary to induce incentives in quality-enhancing also comes from making the cost reimbursement rule more powerful, which improves welfare.

PROPOSITION 2 *Bundling strictly dominates unbundling when complete contracts on both operating costs and a quality index are feasible and the externality is positive.*

Even if using a quality index eases agency problems under unbundling, bundling remains preferable whenever this index remains imperfect. Providing incentives to the builder under unbundling still entails a costly risk premium but bundling dominates since it reduces this risk premium.

Robustness check. It can be shown that when the quality index is on the service quality rather than infrastructure quality, the main insights of this section continue to hold. Since a service quality index is positively affected by a , via the effect that a has on social benefits B , a payment system that rewards the builder for higher service quality eases the agency problem under unbundling. Bundling however remains preferable whenever the firm is risk averse.

3.3. Residual Value and Ownership

Proposition 1 told us that bundling always weakly dominates unbundling. We now show that when instead the builder has some incentives to invest under unbundling and the externality is negative, unbundling may become the preferred mode of provision.²⁷

To tackle the issue of ownership, we now identify PPP as an organizational form where there is bundling of the design and operation phases but also private ownership of the assets over the whole length of the contract. Traditional contracting corresponds instead to the case where G buys an asset built by the private sector and delegates operations to a second firm.

When contracts allocate rights and duties and there are no unforeseen contingencies, ownership matters only to the extent that assets have some residual value at the end of the contract. Ownership entitles the owner with the market value of these assets. This residual value provides incentives to invest in asset quality. Of course, that residual value will depend on assets specificity. In the case of generic facilities (such as leisure centers, office accommodation, general IT systems and land use), there is demand from users

²⁷We prove this by extending the analysis so as to consider the value of ownership of the infrastructure, but it can be shown that in the context of Section 3.2.2 unbundling also strictly dominates for a negative externality.

other than the government, so that the public and private residual value do not differ significantly. This is of course different for specific facilities, such as hospitals, prisons and schools.

Let thus sa ($s > 0$) denote the value of the assets at the end of the contract when these assets are used by the government for public service provision. Let also πsa , with $\pi < 1$, denote their value for private use. Consistently with the incomplete contracts literature, the residual value of these assets cannot be specified ex ante in a contract although it is ex post observable and can be bargained upon at that date. The parameter π captures the degree of asset specificity, with π being higher the less specific is the facility.²⁸ Since $\pi < 1$ public ownership is always optimal at the end of the contract.²⁹

As a benchmark, note that the first-best level of a now solves

$$a^{FB} = s + b + \delta.$$

Public Ownership. Suppose that assets are publicly owned throughout the contract. Since a is not contractible and there is no sale of the facility once the contract expires, the builder cannot be incentivized. Whether bundling or unbundling is chosen, efforts and welfare with public ownership remain the same as before. Public ownership has no impact on incentives. Whether bundling strictly dominates depends only on the sign of the externality as in Section 3.1.

Private Ownership. Suppose assets are privately owned. At the end of the contract, efficiency requires to transfer ownership to G . Ex post, the price p^* at which ownership is transferred results from Nash bargaining (assuming equal bargaining powers):

$$p^* = \arg \max_p (sa - p)(p - \pi sa) = \frac{(1 + \pi)}{2} sa.$$

The private owner's net benefit $\frac{(1-\pi)}{2} sa$ boosts his incentives to enhance assets quality if he is a builder.³⁰ The owner's incentives to invest are also greater with less specific assets. Indeed, asset specificity reduces the status quo payoff if ownership is not transferred to the public sector. This exacerbates the hold-up problem that occurs through ex post bargaining and dampens the private owner's incentives.

Private ownership and unbundling: The builder's incentive constraint when he is also the owner can be written as:

$$(3.13) \quad a_u^{pr} = \frac{(1 - \pi)}{2} s.$$

On the other hand, the operator's effort and optimal incentive scheme remain the same as in Section 3.1:

$$(3.14) \quad e_u^{pr} = e_u^{SB}.$$

²⁸Hart (1995).

²⁹That the asset returns to G at the end of the contract is one of the main features that distinguishes PPPs from privatization. The analysis can however easily be extended to the case of $\pi > 1$, where private ownership at the end of the contract becomes optimal, as the facility has high market value (think for example of Car Parks or Leisure Centers). This is the case in BOO models (Build, Own, Operate) as opposed to BOT models (Build Operate Transfer).

³⁰Under unbundling, builder ownership is preferred to operator ownership since the operator has no control on the quality-enhancing effort.

Private ownership and bundling. Ownership has still some value with bundling. The consortium's expected payoff is maximized for effort levels that solve:³¹

$$(3.15) \quad (a, e) = \arg \max_{(\tilde{e}, \tilde{a})} \frac{(1 - \pi)}{2} s \tilde{a} + \alpha - \beta (\theta_0 - \tilde{e} - \delta \tilde{a}) - \frac{\tilde{a}^2}{2} - \frac{\tilde{e}^2}{2} = \left(\beta \delta + \frac{(1 - \pi)}{2} s, \beta \right)$$

Comparing public and private ownerships, we immediately obtain:

PROPOSITION 3 *Private ownership always dominates public ownership. The gain from private ownership is non-increasing in the level of asset specificity.*

Comparing now *PPPs* and traditional procurement, we get:

PROPOSITION 4 *PPPs, i.e., private ownership and bundling, strictly dominates traditional contracting, i.e., private ownership and unbundling, with a positive externality:*

$$W_b^{pr} > W_u^{pr} \text{ if and only if } \delta > 0.$$

Efforts are greater under bundling with a positive externality:

$$a_b^{pr} > a_u^{pr} = \frac{(1 - \pi)}{2} s \text{ and } e_b^{pr} > e_u^{pr} \text{ if and only if } \delta > 0.$$

Compared to public ownership, under private ownership bundling implements strictly lower efforts than unbundling if the externality is negative. Ownership gives to the builder some incentives to invest in asset quality. These incentives are depressed if the builder internalizes the negative externality that quality exerts on costs.

3.4. Related Literature

Our baseline model has merged two strands of the literature on *PPPs* which have both emphasized the multi-task nature of the procurement problem when building and managing assets matter. Using the property rights approach, Hart (2003) provided a model where the sole source of incentives is ownership. A builder can perform two kinds of investment (productive and unproductive) which may both reduce costs, although only the productive investment raises also benefits. Under traditional procurement, the builder cannot internalize the impact of his effort neither on benefits nor on costs. He implements too little of the productive investment but the right amount of the unproductive one. Under *PPP*, the builder somewhat internalizes the impact of his productive investment whereas he also exerts too much of the unproductive one. Francesconi and Muthoo (2011) and King and Pitchford (2001) considered the case of impure public goods and showed that shared authority can be optimal when the parties' investments are comparable.

Bennett and Iossa (2006) studied the desirability of bundling project phases and of giving ownership to the investor. Innovations are non-contractible ex ante but verifiable ex post. Ownership gives control right to the owner to decide whether to implement quality enhancing or cost-reducing innovations proposed by the investor. The hold-up problem is less severe under *PPP*, compared with traditional procurement, when there is a positive externality between the building and managing stages, and vice versa when

³¹Let s be large enough to insure a positive quality-enhancing effort even with a negative externality.

the externality is negative. Public ownership acts as a commitment for the government to renegotiate and share with the investor the surplus from implementing the innovation. Private ownership is nevertheless optimal for generic facilities with high residual value. Chen and Chiu (2010) extend Bennett and Iossa (2006) to the case of interdependent tasks and show that complementarity between tasks favors unbundling.

In a complete contracting framework, Martimort and Pouyet (2008) built a model where both the quality of the infrastructure and operating costs are contractible. Incentives and welfare are higher under a *PPP* when there is a positive externality between building and managing assets compared to traditional procurement.³² Ownership aligns incentives but, to a large extent, the important issue is not who owns the asset but instead whether tasks are bundled or not. That insight is developed in various extensions of their basic model allowing for risk sharing as a motive for forming consortia, or for political economy. In the same spirit, Iossa and Martimort (2011) built an agency model where operating costs are non-contractible but both the quality of the infrastructure and the demand for the service are contractible. They focus on how bundling affects incentives to raise demand, and the optimal allocation of demand risk. Our baseline model borrows a lot from these principal-agent models: a common theme is that *PPP* comes with higher powered incentives.

Taking also a complete-contract approach, Bentz, Grout and Halonen (2001) showed that the government buys services (as in *PFI*) rather than facilities (as in traditional procurement) if the building and service delivery costs are low.³³ Hoppe and Schmitz (2012) focused instead on the incentives to gather information about future costs to adapt the service provision to changing circumstances. They showed that whether bundling or unbundling is better for information gathering depends on the costs of efforts in innovation and in information gathering, and on the degree to which effort is contractible. Finally Iossa and Martimort (2012a) considered a dynamic multi-task moral hazard environment where the mapping between effort and performance is *ex ante* uncertain but information may come along during operations. In that context, compounding of asymmetric information *ex post* plus moral hazard and renegotiation may generate diseconomies of scope in agency costs which, for high operational risk, can make unbundling optimal also with positive externalities.

3.5. Implications

Our results suggest that *PPPs* deliver efficiency gains when a whole-life cost approach to the project yields significant cost savings and when risk is effectively transferred to the private operator. Transferring design, construction and operating risks to the contractor provides incentives for keeping project costs down and efficiently provide the service. A report commissioned by the Treasury Taskforce estimated saving on a sample of *PFI* projects equal to 17%, compared to traditional procurement.³⁴ Significant cost savings were realized in the prison sector. The National Audit Office (2003a) reported that innovative designs helped to reduce the level of staffing needed to ensure security and this

³²See the review of the literature in Martimort and Pouyet (2008) for other arguments found in the agency literature to justify that "*one agent is better than two*".

³³In a setting not specific to procurement, Schmitz (2005) studied how the control of sequential tasks should be allocated when the agent has limited liability. Under bundling, the prospect of getting liability rent in the second-stage acts as a powerful engine for first-stage incentives.

³⁴See Arthur Andersen and LSE (2000). Pollock and Vickers (2000) questioned the Arthur Andersen report and argue that, once outliers are excluded from the calculations, the average saving is only 6%.

resulted in an overall cost reduction by approximately 30%. Conclusive evidence is however still to be found. Blanc-Brude, Goldsmith and Vällilä (2009) studied a sample of road projects financed by the EIB between 1990 and 2005 in all EU-15 countries plus Norway. They found that *ex ante* construction costs (i.e., costs before construction actually starts) are some 20% higher for *PPP* roads than for traditionally procured roads.³⁵

Our results also suggest that, when a higher asset quality increases social benefit but has a negative impact on whole-life cost, the scope for *PPP* might be limited. Evidence of negative externalities is more difficult to find. However, a report by the Audit Commission (see *PPP Focus, Education 2*, 2004) noted that the quality of many early *PFI* school buildings was disappointing. School quality has a direct positive impact on pupil behavior and educational achievement. Local Education Authorities now anticipate this problem and include more detailed output specifications in the contract. As a result the quality of school buildings has improved.

Our results also shed some lights on the current approach to facility ownership. Under *PPP*, ownership during the contract length goes to the consortium, but ownership once the contract expires varies depending on the circumstances. Assets tend to revert to the public sector either when they have no obvious alternative use or when they are required to continue the service after contract ends (for example, schools, prisons and hospitals). For generic facilities with an alternative use outside the public sector and no clear long-term public sector needs, ownership is retained by the private sector.

We have focused on the benefits of bundling that may come from inducing the contractor to take a long-term approach to the project. However, bundling also brings other benefits. First, *PPPs* are characterized by a longer procurement process and by higher costs of bidding than traditional procurement. Albeit with differences between sectors, it has been estimated that *PPP* tendering periods last an average of 34 months (NAO, 2007) and that procurement costs can reach 5-10% of the capital cost of a project (Yescombe, 2007). These transaction costs are also to a large extent independent of the size of a project, which suffices to make *PPP* unsuitable for low capital value projects.³⁶

Second, bundling of different phases of the project increases project complexity and limits participation of small construction companies that do not have the necessary financial resources to sustain the costs and risks of bidding for *PPP* contracts. Albeit with differences across sectors, in the UK, there is an average of 4 bidders per *PPP* contract. This is problematic as collusion among bidders is certainly more likely if the number of participants is small.³⁷

In our basic model we have only focused on “build” and ‘operate’. In practice, the realization of a project comprises a wider variety of tasks. Services in the operational stage for example include ‘soft’ facility-management services (e.g. cleaning, catering, security) and ‘hard’ facility-management services (e.g. routine and/or life-cycle maintenance of buildings and equipment). The arguments set up in Section 3 apply to hard services where asset quality matters and externalities are significant but less so to soft services where asset quality plays a limited role and externalities are relatively small. Whether to include soft services in *PPPs* should then follow other considerations. On the one hand, their inclusion creates a single point of responsibility within the private sector in

³⁵The data does not reveal the actual (*ex post*) cost of the projects and thus whether risk transfer under *PPPs* was effective in containing cost overruns.

³⁶HM Treasury (2006) currently considers *PFI* projects for less than £20m as poor value for money.

³⁷Li and Yu (2011) studied the impact on bundling project stages in a context of sequential auctions where bidders may learn over their costs.

charge of service provision and allows to internalize the externalities. On the other hand, unbundling helps to employ short-term contracts for soft services and thus to benefit from more competitive pressure. Separate tendering for soft services also favors the participation of small firms. There are no uniform experiences across countries regarding service unbundling and the HM Treasury (2006) currently advises against their inclusion.

4. BUNDLING FINANCING AND OPERATING TASKS

4.1. *The Benefits of Outside Finance*

So far we have focused on the effects of bundling building and operation in a single contract with a single agent. *PPPs* however are often also characterized by the private sector financing a substantial part, or all of, the project (the “F” in the *DBFO* model). The firm then recoups its initial investment through charges to final users or from government availability payments, that is, government contributions for making the service (e.g. prison services) available. In this section we briefly study the rationale for private finance in *PPPs*.

The relationship between investment and their financing is particularly critical for privately financed infrastructure. On the one hand, an often heard benefit of *PPPs* is that they might bring in the expertise of outside financiers in evaluating risks. In this respect, bundling the task of looking for outside finance (be it through outside equity or debt) and operating assets could improve on the more traditional mode of procurement where the cost of investment is paid through taxation and investment is not backed up by such level of expertise within the public sphere. On the other hand, private finance adds an additional layer of contracting, the one between the consortium and the financier, and this could have perverse effects on incentives.

To analyze the effect of private finance, we consider the case of contractible profits and focus on the benefit of bundling operation and financing, assuming away any incentive problem on a . We let $b = \delta = 0$ so that, there are no benefit of building a better infrastructure. All the benefits of having private finance, if any, are thus due to the reduced agency costs that it might bring. For simplicity we also let $d = 1$, $\gamma = 0$, so that the profit function is given by:

$$(4.1) \quad \Pi = b_0 - \theta_0 + e + \varepsilon.$$

To model the transaction costs that might still arise when the operator looks for outside finance, we assume now that financiers have expertise to get access to some informative signal y on the contractor’s effort:

$$(4.2) \quad y = e + \varsigma$$

where ς is a random variable normally distributed with variance σ_ς^2 and zero mean. Such informative signal may be quite useful to provide cheaper incentives.

We investigate in turn the case of public finance where the investment is financed by taxation and the case of outside private finance. We assume throughout that financiers operate in a perfectly competitive financial market.

Public finance. The government itself provides funds to cover an investment I . It does not observe the informative signal y and implements only the second-best effort e_u^{SB} .

Outside finance. The operator has now full control over his access to the financial market on top of control over operations. To fix ideas, suppose that only profits are verifiable, so that the firm operates under a linear scheme $t(\Pi) = \alpha - (1 - \beta)\Pi$, and thus therefore keeps a gross payoff of $\alpha + \beta\Pi$. The operator and its financiers agree on how to share the remaining risk induced by such a contract.

Let ω denote the fraction of the gross payoff $\alpha + \beta\Pi$ that is kept by the operator. Because outside financiers can condition the firm's repayment on the extra signal y , a linear repayment scheme that share risk between the operator and its financiers is given by:

$$z(\Pi, y) = E + (1 - \omega)(\alpha + \beta\Pi) - \xi y.$$

The term ξy ($\xi > 0$) is a bonus in case the signal on the firm's effort is positive and a punishment otherwise. Since financiers are competitive, the fixed payment E is the price of equity they hold in the project net of the investment cost I .

The operator's incentive constraint is now written as:

$$(4.3) \quad e = \arg \max_{\tilde{e}} -E + \omega(\alpha + \beta(b_0 - \theta_0 + \tilde{e})) + \xi\tilde{e} - \frac{\tilde{e}^2}{2} - \frac{r\sigma_\varepsilon^2\omega^2\beta^2}{2} - \frac{r\sigma_\xi^2\xi^2}{2} = \beta\omega + \xi.$$

This incentive constraint highlights two important features. First, only a fraction of the incentive power of the government's scheme ends up being useful to foster operational effort because of subsequent risk sharing between the firm and financiers. Second, financiers can improve incentives by conditioning the firm's repayment on the informative signal they get on its effort.

Going backwards, let us turn now to the design of the overall repayment scheme given the transfer scheme with the government. Because financiers are competitive, this repayment maximizes the certainty equivalent of the operator's payoff taking into account the moral hazard incentive constraint (4.3):

$$(4.4) \quad (\xi, \omega) = \arg \max_{(\tilde{e}, \tilde{\omega})} \alpha + \beta(b_0 - \theta_0 + \tilde{e}) - \frac{\tilde{e}^2}{2} - \frac{r\sigma_\varepsilon^2\tilde{\omega}^2\beta^2}{2} - \frac{r\sigma_\xi^2\tilde{\xi}^2}{2} - I$$

$$\text{subject to } \tilde{e} = \beta\tilde{\omega} + \tilde{\xi}.$$

The optimal repayment scheme designed by financiers is straightforward. The share of risk left to the operator is independent of the government's scheme. The firm gets positive bonus in case y is good news on the firm's effort:

$$\omega = \frac{1}{1 + \frac{\sigma_\varepsilon^2}{\sigma_\xi^2}(1 + r\sigma_\xi^2)} \quad \text{and} \quad \xi = \omega\beta\frac{\sigma_\varepsilon^2}{\sigma_\xi^2}.$$

This corresponds to a risk premium borne by the operator which is worth

$$\frac{r\sigma_\varepsilon^2\beta^2\left(1 + \frac{\sigma_\varepsilon^2}{\sigma_\xi^2}\right)}{2\left(1 + \frac{\sigma_\varepsilon^2}{\sigma_\xi^2}(1 + r\sigma_\xi^2)\right)^2}.$$

Finally, the effort level implemented by the operator when one compounds the impact of government's and the financiers' contracts can be written as:

$$(4.5) \quad e = \frac{(\sigma_\xi^2 + \sigma_\varepsilon^2)}{\sigma_\xi^2(1 + r\sigma_\xi^2) + \sigma_\varepsilon^2}\beta.$$

This is the incentive constraint of the coalition made of the operator and its financiers.

Notice that this effort level converges towards β when σ_ζ^2 goes to zero. When financiers have a very informative signal on the firm's effort, there is no further dilution of incentives within their coalitional agreement: Effort is efficiently set within the firm/financiers coalition. Instead, when σ_ζ^2 converges towards infinity, the effort level converges towards $\frac{\beta}{1+r\sigma_\zeta^2}$ which captures the fact that part of the incentives given by G are dissipated through further risk sharing with financiers.

Comparing with public finance, private finance unambiguously raises incentives and comes closer to the first-best.

PROPOSITION 5 *Bundling private finance and operation is optimal when outside financiers have access to some informative signal on the operator's effort level. The power of incentives unambiguously raises and aggregate welfare improves with respect to public finance.*

Relying on outside finance makes the operator less risk averse, even though outside finance may exacerbate moral hazard by introducing further risk sharing. The point is that, as the financial contract is made under a better information structure, the extra round of contracting with financiers has more benefits in terms of improved incentives than costs in terms of modified risk sharing. Everything happens as if the government itself was enjoying the financiers' expertise to provide funds at a cheaper cost.

REMARK 1 *When financiers are specialized in infrastructure risk, they might have some market power. It is unlikely that, in such environment, the government can recoup all benefits from the financiers' expertise. A double-marginalization problem might occur with both the government and financiers willing to reduce the firm's effort. There would be a trade-off between the benefits of the financiers' expertise and the extra distortions that financial contracts might bring.*

4.2. Related Literature

Engel, Fischer and Galetovic (2006) were the first to study the rationale for private finance in *PPPs*. They showed that private finance cannot save on distortionary taxation. Any additional \$1 invested by the contractor saves society some distortionary taxes but the concessionaire must be compensated for the additional investment through a longer contract term. This costs society future distortionary taxes equal to the initial tax saving. De Bettignies and Ross (2009) also discussed the benefit of private finance in *PPPs*. In their model, information is symmetric but private finance may lead to the efficient termination of bad projects, while public developers may sustain such projects for political reasons. On a related line, Auriol and Picard (2009, 2011) showed that the cost of public funds may actually justify outsourcing activities through *PPPs* in more incomplete contracting environments. The model of this section bears some similarities with Iossa and Martimort (2012a). In that paper, like here, the financier has better information than the Government, though the information refers to operational risk rather than operational effort.

4.3. Implications

Our analysis has shown that outside finance improves risk allocation if it helps alleviating moral hazard. In practice, the use of private finance has been made also because

it has allowed the public sector to finance the construction of infrastructure “off the balance sheet” and to accelerate delivery of projects.³⁸ The accounting treatment of *PPPs* stream of payments can vary and it can often make the government budget look healthier than what it is, thereby undervaluing the cost of *PPP* financed infrastructure. This not only biases decisions in favor of *PPPs* as opposed to more traditional procurement arrangements but it can make *PPPs* a means to unduly transfer costs from current to future generations.³⁹ There is no economic justification for *PPPs* being promoted for allowing investment off the balance sheet. To ensure homogeneity across member states and limit accounting tricks made to comply with the rules of the Stability and Growth Pact, Eurostat made a decision (news release 18/2004) on the accounting of *PPPs*, which clarified and made the process of accounting true *PPPs* more transparent. However, the temptation to adopt *PPPs* as a tool to window dress budget deficits has not been fully removed.⁴⁰

5. UNCERTAINTY, FLEXIBILITY AND THE COSTS OF *PPPS*

5.1. *Unbundling and Flexibility*

PPP agreements are output-based in the sense that the public-sector party specifies basic capacity and quality standards but the private sector assumes responsibility over how to meet the output specified. *PPPs* also develop along a long-time horizon, typically 20-35 years. Both these features imply that the provisions set in the initial contract might become obsolete over the life of the contract. The need for flexibility and adaptation of the contractual relationship is then far greater than in for more traditional procurement where provisions are input-based and contracts are short-term.⁴¹

Factors that affect the suitability of the initial contractual clauses and are anticipated can be specified in the initial contract (e.g. changes in capacity). Other possible changes, however, may be unexpected and hard to specify in advance. Contract flexibility is then key for agreements in fast-moving sectors such as the health sector and the IT sector where preferences and/or technology change quickly.

When the original output specifications become obsolete, the contractual agreement can be modified by the mutual consent of the parties. Flexibility may then be achievable through well-designed “*change the mechanism-clauses*” that regulate the possibility of renegotiation of contract terms. However, contract renegotiation typically occurs in a bilateral “lock-in” situation rather than in the multilateral competitive one as under original contract drafting and awarding. The risk is twofold: The contractor can exploit its now strong bargaining position or the government can expropriate the contractor of its past investment. Thus both when renegotiation occurs and new contract terms are drafted and when the contract is rigid and no change occurs, *PPP* might deal inefficiently with uncertainty. This induces a cost of *PPPs* that we now study. For simplicity we focus on the case where the contract fails to adapt to uncertainty on future demand and

³⁸IPPR (2001).

³⁹Maskin and Tirole (2008) studied optimal public accounting rules when the official’s choice among projects is biased by ideology or social ties or because of pandering to special interests.

⁴⁰According to the 2004 Eurostat’s decision assets involved in a *PPP* should be classified as non-government assets, and therefore recorded off balance sheet for government, if the private partner bears the construction risk and at least one of either the availability risk or the demand risk. Otherwise, the assets should be classified as government assets.

⁴¹Arve (2007) analyzed the incentives to build-up investment over time as more of the initial uncertainty on demand gets realized both under full and limited commitment.

renegotiation does not occur.

Consider the case of contractible costs but assume now that in the cost function in (2.2) γ is a (positive) random variable with $E_\gamma(\gamma) = 1$ and $\delta > 0$ (positive externality). Had γ been common knowledge at the time of contracting, our previous result would go through. Bundling would dominate unbundling.

Suppose that the bundling contract (viewed as a *PPP*) is offered before γ realizes and cannot depend on that shock that just cannot even be foreseen at the time of contracting. In other words, G ties his hands with a contract which is not flexible.

Under unbundling, there is no quality-enhancing investment when, as in Section 3.1 the builder receives a flat payment. However, and this is the benefit of splitting tasks, contracting with the operator might be delayed up to the point where γ becomes verifiable. This captures the positive value of information in uncertain environments that only comes with unbundling and not with *PPPs*.

PROPOSITION 6 *Unbundling dominates bundling for small positive externality in the case of uncertainty.*

This result also suggests that long-term contracts are unsuitable in uncertain environments. Consider a twice-repeated and slightly modified version of our basic procurement model and let period-2 cost be given by

$$C_2 = \theta_0 - \gamma e_2 - \delta a + \varepsilon_2.$$

Assume that γ is realized during period 1 and that a two-period contract covering both periods 1 and 2 cannot be made contingent on the realized γ . It is easy to show that with a low externality (δ small) a one-period contract becomes preferable to a contract covering both periods. When the externality is small, the loss from not internalizing period 2 cost at the time of choosing asset quality a is small and the one-period contract allows to enjoy the value of information on γ whilst the two-period contract cannot.

5.2. Related Literature

Bajari and Tadelis (2001) discussed the cost of renegotiating design. When the firm has private information on the cost of a new design, cost-plus contracts are cheaper to renegotiate than fixed-price ones. Sectors where changes in demand are highly expected may be better procured through cost-plus contracts even though fixed-price contracts have better incentive virtues. Ross and Yan (2011) analyzed the cost of renegotiation in *PPP* contracts when changes to service production and delivery become necessary. This cost is shown to depend on the likelihood that changes will be necessary, the productivity of non-contractible effort exerted by private sector partners, the costs of renegotiation and the bargaining power of governments vis-a-vis private parties. The trade-off between incentives and flexibility was also examined by Ellman (2006) who showed that a long-term contract better protects the contractor's investment from being expropriated by the government but it also reduces the government's incentives to discover new service innovations.

5.3. Implications

Our results point to the unsuitability of *PPP* for fast-moving sectors, much in line with empirical evidence. Several recent reports on *PPPs* highlight the cost of changes

in user needs that – in the presence of rigid contracts - have sometimes triggered costly renegotiation.⁴² In the UK it was reported that changes occurred during negotiations with contractors for 33% of Central Government Departments *PFI* projects signed between 2004 and 2006. The changes amounted to a value of over £4m per project per year equivalent to about 17% of the project value.⁴³ Illustrative is also the case of specialized IT provision where the appropriate use of the facility involves continuous adaptation. Following performance failures and costly contract renegotiation, the HM Treasury in the UK now recommends against using *PPPs* for IT projects.⁴⁴

6. CONTRACTUAL DYNAMICS

PPPs are typically long term projects which might cover 20 to 35 years. Over such a long period the quality of durable assets and infrastructure may significantly depreciate. An important issue concerns the extent to which contractors are willing to invest to improve the stock of existing infrastructure or whether they prefer to choose management strategies that maintain costs low in the short-run.

6.1. *The Trade-Off Between Investment and Maintenance*

To analyze the trade-off between investment and maintenance, we consider a twice-repeated and slightly modified version of our basic model with contractible costs. To focus on the operator's incentives to invest, we assume that the firm gets a basic stock of infrastructure to run off public service at date $t = 1$. Improving this stock requires some extra investment which costs $\frac{a^2}{2}$ today but it lowers operating costs at date $t = 2$ by an amount a . Another strategy would be to avoid incurring any initial investment and then cutting operating costs with more maintenance.

There is no discounting. Operating costs in each period are respectively given by:

$$C_1 = \theta_0 - e_1 + \frac{a^2}{2} + \varepsilon_1 \quad \text{and} \quad C_2 = \theta_0 - e_2 - a + \varepsilon_2$$

where the shocks ε_i ($i = 1, 2$) are normally distributed with zero mean and variance σ^2 , and e_i is the maintenance effort undertaken at date i .⁴⁵

Investing increases accounting costs in the short-run but, because of a positive externality between design and operation, reduces the long-run cost of the service.⁴⁶ Implicit in our formulation is the fact that the cost of investment is non-contractible, e.g. because it is (at least partly) aggregated with other costs, noticeably the first-period operating costs, in the firm's book.⁴⁷

⁴²HM Treasury (2006).

⁴³NAO (2007).

⁴⁴See HM Treasury (2006). Examples of *PPP* failures in IT include the £400m Libra project to provide IT systems for magistrates' courts.

⁴⁵In full generality, we could allow uncertainty on operating costs to be time-dependent. In particular, we might give particular attention to the case where uncertainty on operating costs may decrease over time (due for instance to learning by doing and better assessments of performances). Similarly, in the case of a growing demand, having growing operating costs in the second-period may also call for greater returns on maintenance as time goes on.

⁴⁶With respect to Section 3.3, the investment a has no impact on the social value of the assets which remains fixed and equal to b_0 .

⁴⁷Our formulation slightly differs from that in Section 2 where the cost of the quality-enhancing effort was off the book.

Consistently with Section 3, we assume that the stock of new investment has a social value $b_0 + ba$ with $b > 0$. In practice, this simply means that there is a difference between the social and the private returns on investment. Assuming that investment is verifiable, its first-best level is $a^{FB} = 1 + b$ whereas $a = 1$ would be privately optimal.

Non-contractible investment. Suppose that the investment a is non-contractible and must be induced by designing adequate incentives. Denote by $t_i(C_i) = \alpha_i + (1 - \beta_i)C_i$ the cost-reimbursement rule used at date i .⁴⁸ Let us first consider the case where G can commit himself to such a two-period contract $\{t_1(C_1), t_2(C_2)\}$.

Still assuming a quadratic disutility of maintenance effort in each period, the firm chooses its whole array of actions (a^*, e_1^*, e_2^*) to maximize the certainty equivalent of its intertemporal payoff:

$$(a, e_1, e_2) = \arg \max_{(\tilde{a}, \tilde{e}_1, \tilde{e}_2)} \left(\sum_{i=1}^2 \alpha_i - \beta_i(\theta_0 - \tilde{e}_i) - \frac{\tilde{e}_i^2}{2} - \frac{\sigma_\varepsilon^2 \beta_i^2}{2} \right) - \beta_1 \frac{\tilde{a}^2}{2} + \beta_2 \tilde{a}.$$

This leads to the following incentive constraints:

$$(6.1) \quad e_1 = \beta_1, \quad e_2 = \beta_2 \text{ and } \beta_2 = \beta_1 a.$$

An interesting benchmark is obtained when G offers the stationary contract with slope β_u^{SB} , i.e., the contract that would be optimal without of any concern on the renewal of the infrastructure. This contract induces a stationary effort $e_1 = e_2 = \beta_u^{SB}$ and an investment level, $a = 1$, which is privately optimal but not socially so when $b > 0$. There is too little investment in renewing infrastructure with such stationary contract. Raising investment requires modifying the intertemporal pattern of incentives.

PROPOSITION 7 *Assuming full commitment; the optimal long-term contract entails higher powered incentives towards the end of the contract than at the beginning and an inefficient level of investment:*

$$e_1^{SB} < e_u^{SB} < e_2^{SB}, \text{ and } a^{SB} < a^{FB}.$$

To boost incentives to undertake a non-verifiable investment, G must let BO bear less of the costs and enjoy most of the benefits associated to that investment. This is best achieved by offering cost-plus contracts in the earlier periods and fixed-price contracts towards the end of the relationship.⁴⁹ Still, this is not enough to align the private incentives to invest with the socially optimal ones and underinvestment follows.

⁴⁸Decomposing the agent's rewards into two different incentive schemes in each period makes presentation somewhat easier especially in view of the no-commitment case that will be analyzed later on. Of course, this class of incentive schemes entails a loss of generality since, contract $t_2(C_2)$ does not depend on the first period realization of costs. In other words, history-dependent contracts whose value in dynamic incentive problems is well-known are ruled out. See Remark 2 below. Alternatively, one could view the overall intertemporal incentive scheme $\sum_{i=1}^2 \alpha_i - \beta_i C_i$ as being offered upfront by the government with all payments being delayed when all realizations of first- and second-period costs are known in which case those contracts are without loss of generality.

⁴⁹Suppose that the effect of a new investment depreciates over time. The power of the incentive scheme must decrease over time after the first period to optimally trade off incentives and insurance. As investments have been made earlier in the past, the firm will rely more on maintenance to keep operational costs low.

REMARK 2 HISTORY-DEPENDENT CONTRACTS. *Let us suppose now that G can commit to two-period history dependent contract $\{t_1(C_1), t_2(C_1, C_2)\}$ where $t_1(C_1) = \alpha_1 + (1 - b_1)C_1$ and $t_2(C_1, C_2) = \alpha_2 + (1 - b_2)C_1 + (1 - \beta)C_2$. The benefit of considering this larger class of incentive schemes is well-known since Rogerson (1985), pushing part of the rewards (and punishments) for a good first-period cost towards the second period improves the first-period trade-off between insurance and incentives. To then check the robustness of our earlier results, observe first that, given the history-dependent contract above, the agent chooses his effort array (e_1, e_2, a) so that:*

$$(6.2) \quad e_1 = b_1 + b_2 = \beta_1, \quad e_2 = b_2, \quad \text{and } b_2 = \beta_1 a.$$

For a given β_1 the risk borne by the agent over the two periods is better spread when half of those incentives are pushed to the second period, i.e., when $b_1 = b_2 = \frac{\beta_1}{2}$. Everything happens as if the first-period variance on costs was lowered by one half. This implies high-powered incentives to reduce costs in the first period and an unambiguously increase in welfare. But, it has a detrimental impact on investment which becomes less attractive than improved maintenance.

Other scenarios. In the case of *Verifiable Profits* or of *Verifiable Revenues*, the optimal long-term contract also calls for low-powered incentives in the earlier periods of the contract and high-powered incentives towards the end of the relationship. By offering greater profit or revenue shares to the firm towards the end of the contract than at the beginning, G makes BO bear less of the costs and enjoy most of the benefits associated to its non-contractible investment.⁵⁰

6.2. Cost Overruns

As we already stressed, long-term contracting takes place under significant uncertainty on the realizations of future costs and demand. In infrastructure projects and maybe due to competitive pressures in awarding projects, contractors are often overly optimistic in estimating future costs.⁵¹ Following costs overruns, long-term contracting may be subject to renegotiation. Firms may obtain a tariff increase or an increase in the number of cost components passed through tariffs, a reduction in their payment to the public sector and delays and reduction in investments.

To model cost overruns in a nutshell, we will simplify the modeling of Section 6.1, neglect the investment issue or the building stage of contracting and instead focus only on the hazard coming from uncertainty on costs. To model this uncertainty, we assume that, although it may not be known *ex ante* at the time of contracting, the base cost level θ_0 is later on privately observed by the firm. Asymmetric information allows us to consider the firm's strategic incentives to exaggerate costs and pretend that costs overruns occur. More formally, we assume now that costs can be written as:

$$(6.3) \quad C = \theta_0 - e + \varepsilon$$

⁵⁰Iossa and Martimort (2011a).

⁵¹For some empirical evidence, see Flyvbjerg, Skamris Holm and Buhl, (2002) and Gannuza (2007). Based on a sample of 258 transportation infrastructure projects worth US\$90 billion and representing different project types, geographical regions, and historical periods, the authors found with overwhelming statistical significance that the cost estimates used to decide whether such projects should be built are highly and systematically misleading.

where the base cost level θ_0 is random and may be either high, $\theta_0 = \bar{\theta}$ with probability $1 - \nu$ or low, $\theta_0 = \underline{\theta}$ with probability ν (denote $\Delta\theta = \bar{\theta} - \underline{\theta} > 0$).

An incentive mechanism must now not only induce the firm to choose a high level of effort but also to reveal private information once it knows whether costs are high or low. From the Revelation Principle, there is no loss of generality in restricting the analysis to direct revelation mechanisms which consist of a pair of contracts $\{(\alpha(\hat{\theta}_0), \beta(\hat{\theta}_0))\}_{\hat{\theta}_0 \in \{\underline{\theta}, \bar{\theta}\}}$ stipulating a fixed fee $\alpha(\hat{\theta}_0)$ and a share $\beta(\hat{\theta}_0)$ of the cost borne by the firm as a function of its report $\hat{\theta}_0$ on its innate base cost level. Since, for any slope of the incentive scheme $\beta(\hat{\theta}_0)$, the firm always choose an effort level given by $e = \beta(\hat{\theta}_0)$, we define the certainty equivalent of the firm's expected utility when knowing θ_0 as:

$$(6.4) \quad U(\theta_0) = \max_{\hat{\theta}_0 \in \{\underline{\theta}, \bar{\theta}\}} \alpha(\hat{\theta}_0) - \beta(\hat{\theta}_0)\theta_0 + \frac{(1 - r\sigma_\varepsilon^2)\beta^2(\hat{\theta}_0)}{2}.$$

Taking the profile of rents and slopes of the incentive schemes $\{(U(\hat{\theta}_0), \beta(\hat{\theta}_0))\}_{\hat{\theta}_0 \in \{\underline{\theta}, \bar{\theta}\}}$ as the true primitives of our problem allows to write the truthtelling constraint for an efficient firm as:⁵²

$$(6.5) \quad U(\underline{\theta}) \geq U(\bar{\theta}) + \Delta\theta\beta(\bar{\theta}).$$

The contract consisting in offering a rent/effort profile given by $U^*(\theta_0) = 0$ and $e^*(\theta_0) = e_u^{SB}$ that would be offered had θ_0 been contractible can no longer be implemented under asymmetric information because an efficient firm would strategically inflate its costs. Cost overruns arise for such badly designed contract.

To avoid cost overruns, the truthtelling constraint (6.5) must be binding at the optimum. This imposes some extra risk on the firm and an extra risk premium that society bears to induce the firm's participation. Reducing this risk premium requires to distort downward $e(\bar{\theta})$ below its complete information value, which is obtained by giving to an inefficient firm a low-powered cost-plus contract.

PROPOSITION 8 *With ex post asymmetric information, strategic cost overruns are a concern. The optimal menu of incentive contracts that prevents cost overruns is such that the less efficient firm produces under low powered incentives whereas the firm receives incomplete insurance against the realizations of innate cost:*

$$U^{SB}(\underline{\theta}) > 0 > U^{SB}(\bar{\theta}) \text{ and } e^{SB}(\underline{\theta}) = e_u^{SB} > e^{SB}(\bar{\theta}).$$

REMARK 3 **COST OVERRUNS AND BUNDLING.** *With low-powered incentives needed to avoid strategic cost overruns, it becomes less valuable to bundle construction and management in an extended multi-task version of the model along the lines of Section 2. This does not implies that bundling is no longer optimal. Indeed, cost overruns also occur with the more traditional mode of contracting and would shift the power of incentives the same way. We conjecture that a priori, a positive externality between construction and management would still be conducive to bundling even with ex post asymmetric information.*

⁵²We only focus here on the relevant upward incentive constraints where the low cost firm wants to strategically inflate its costs. See Laffont and Martimort (2002, Chapter 2).

REMARK 4 COST OVERRUNS, RENEGOTIATION AND THE SOFT BUDGET CONSTRAINT. *The optimal contract found above is not renegotiation-proof once θ_0 is known. Indeed, to induce revelation information, this contract requires that an inefficient one runs a loss. This creates incentives for the least efficient firm to stop the ongoing project if its innate costs are high. Anticipating this outcome, G may not refrain from instilling more subsidy to ensure that even the worst firms breaks even; another instance of the soft budget constraint fallacy. Such renegotiation is akin to assuming that the firm is protected by a pair of interim participation constraints ensuring it indeed always breaks even:*

$$(6.6) \quad U(\theta_0) \geq 0 \quad \forall \theta_0.$$

Such constraints harden the trade-off between incentive and participation. It can be easily seen that only the firm with type $\theta_0 = \underline{\theta}$ obtains now a positive expected payoff and the corresponding distortion needed to induce truth-telling are exacerbated leading to a large effort distortion.

6.3. Related Literature

Laffont and Tirole (1993, Chapter 8) proposed an adverse selection model with repeated auctions of incentive contracts which shares many features of our model, most noticeably the shift towards higher powered incentives over time. An incumbent invests in period 1 but, because of contract renewal, may lose the benefits of its investment if it is not granted the new contract for date 2. They particularly focused on the necessary bias towards the incumbent as an incentive tool to secure investment. Our pure moral hazard model can be viewed as providing a simplified version of the same insight. Dewatripont and Legros (2005) argued that ex ante competition between potential consortia may limit the extent of cost overruns and that introducing a third-party (typically outside shareholders or creditors) in a *PPP* contract may improve monitoring which limits cost overruns as well.

6.4. Implications

Empirical evidence on effort allocation in long-term projects shows that effort rises over time. Projects within firms often run beyond deadlines and most resources are increased towards the final stages as in Marshall and Meckling (1962) and Mansfield et al. (1995). Actual costs often significantly exceed cost estimates used to decide whether public projects should be built. *PPPs* are not immune to cost overruns, though no clear evidence exists as to whether cost overruns under *PPPs* are more or less likely than under traditional procurement. In the UK, with traditionally procured contracts, in 73 % of central government's construction projects the price to the public sector had exceeded the contractors' tender price and the project ran over budget; actual costs were between 2 and 14 % above estimates. The equivalent figure with *PFI* was 22 % although that was due to the private companies bearing the cost increase rather than the cost increase not occurring (NAO, 2003b). Examples of cost overruns under *PPP* also include the disastrous case of Metronet, the private tube contractor for London Underground, whose cost overruns lead it to bankruptcy.

Whilst risk allocation in *PPPs* generally forces the contractor to bear a significant part of the construction and operational risks, the actual risk allocation may differ from what was originally planned. Governments are providers of last resort and contractors are aware that public authorities cannot afford prolonged service disruption. The re-tendering of a *PPP* contact is a long and costly process. Also, as the case of London Underground

points out, a market for secondary contracts may not always exist. In fact very few *PPP* contracts have been pre-maturely terminated. The Channel Tunnel Raillink is one example of the government bailing out the *PPP* contractor. More generally, empirical evidence supports that risk allocation in practice often departs from what laid out in theory (see e.g. Lobina and Hall, 2003). As stressed by The World Bank, “*whether PPPs perform better than full provision by state-owned enterprises depends in particular on whether performance risk is effectively shifted from taxpayers to the private shareholders of the company that enters into a concession-type arrangement*”.⁵³

7. THE ROLE OF INSTITUTIONS: REGULATORY AND POLITICAL RISKS

7.1. *Under-Investment and Opportunistic Governments*

The non-stationary path of incentives described in Proposition 7 is highly dependent of G 's ability to commit to increase subsidies in the second period to reward BO 's initial investment. Assume now that such commitment power is absent and that renegotiation takes place at date $t = 2$ with G still having all bargaining power at that stage and extracting all surplus that BO could withdraw from renegotiation.

At date 2, BO 's investment a^0 is sunk and the second-period cost reimbursement rule is renegotiated to reach the optimal trade-off between maintenance effort and risk that would arise in a static context, i.e., *conditionally* on the investment level a^0 .⁵⁴ This yields the standard expressions for the second period maintenance effort and the slope of the renegotiated incentive scheme:

$$\beta_2^0 = e_2^0 = e_u^{SB} = \frac{1}{1 + r\sigma_\varepsilon^2}.$$

Under limited commitment, G can still adjust the second-period fixed-fee to extract all surplus of the firm given his expectation over the investment level a^0 at this date and, of course, expectations are correct in equilibrium.

Anticipating the slope of date 2 incentive scheme, and knowing also the slope of the first-period incentive scheme, BO chooses his investment so that

$$(7.1) \quad e_u^{SB} = e_1 a.$$

With an opportunistic government, welfare is obviously lower than with full commitment. The second-period contract also entails lower powered incentives because, at date 2, G does not take into account the impact of the second-period contract the first-period investment. Since $e_2^0 = e_u^{SB} < e_2^{SB}$, (7.1) implies that BO enjoys less of the benefits of its investment. To maintain incentives, BO must be even more reimbursed for its first-period costs than under full commitment. This tilts first-period incentives even further towards cost-plus contracts.

⁵³World Bank (2002, pp. 23-24).

⁵⁴One word of clarification on the space of contracts allowed is needed. Indeed, at date 2, the investment level a is private information for the firm. This suggests two things: First, the second period renegotiated contract should aim at screening this piece of information; second, anticipating this screening possibility the firm should create endogenous uncertainty by randomizing among several possible levels of investments. This would certainly bring our analysis closer to the framework of renegotiation under moral hazard due to Fudenberg and Tirole (1990) but at the cost of much complexity. Even if such larger class of second period contracts was allowed, we feel rather confident that the insight that we develop in this section, namely the systematic move towards cost-plus contracts, would be preserved.

PROPOSITION 9 *With an opportunistic government, investment is lower and cost-reimbursement rules are even more tilted towards cost-plus contracts than under full commitment:*

$$e_1^0 < e_1^{SB}, \quad e_2^0 < e_2^{SB} \quad \text{and} \quad a^0 < a^{SB}.$$

Regulatory risk. Assume now that renegotiation takes place at date 2 only with probability p . This parameter is a measure of institutional quality, with higher values of p meaning weaker enforcement. For instance, the government may change between dates 1 and 2 with some probability due to elections or renegotiation takes place due to exogenous events. In some cases, *PPP* contract clauses indeed seek to insure the private operator against aggregate risks, but episodes have occurred where governments have reneged on these clauses when a severe macroeconomic crisis occurred. The assumption of limited commitment also fits quite well the case of developing countries with weak enforcement power.

At date 2, *BO*'s investment a^0 is sunk and with probability p the second period cost reimbursement rule is renegotiated to implement the conditionally optimal maintenance effort e_u^{SB} through an incentive scheme having slope β_u^{SB} . This leads to the following expression of *BO*'s incentive constraint:

$$(7.2) \quad pe_u^{SB} + (1-p)e_2 = e_1a.$$

The effort levels in this model with political risk are intermediary between the full commitment and the case of an opportunistic government viewed above. An increase in regulatory risk (i.e., p greater) thus lowers incentives for investment and induces more low powered incentives.

Other scenarios. In the case of *Contractible Profits* or of *Contractible Revenues*, where infrastructure-improving investment in the first period enhances second period's quality and service demand, similar insights are obtained. With an opportunistic government, investment is lower and incentives are even less high-powered in both periods than under full commitment.⁵⁵

7.2. Related Literature

In a pure adverse selection framework, Aubert and Laffont (2002) analyzed the mechanism through which a government can affect future contracting by distorting regulatory requirements to take into account possible political changes and renegotiation. Assuming that the current contract binds all future governments, imperfect commitment implies that the amount information revealed in the first period is strategically determined to affect the beliefs of the future governments.

Several political motives have been proposed to explain why governments may want to renegotiate *PPP* contracts. A government may increase its chances to be re-elected by expanding spending or by promoting investment in public works that create jobs and boost economic activity (Guasch, 2004, Engel, Fisher and Galetovic, 2006).

⁵⁵Iossa and Martimort (2011a).

7.3. *Implications*

Institutional quality plays a critical role in the provision of public services by the private sector. Hammami, Ruhashyankiko and Yehoue (2006) indeed found that private participation (in the form of *PPP*, privatization or traditional procurement) is more prevalent in countries with less corruption and with an effective rule of law. For *PPP* contracts, the benefit of whole-life management cannot be realized in the absence of strong governance and minimal risk of unilateral changes of contract terms by the government.

Governments' failure to honor the terms of concession contracts is a pervasive phenomenon. In LAC Countries, it is common for a new administration to decide not to honor tariffs increase stated in the concession contract granted by previous administrations. Examples include the Limeira water concession in Brazil which was denied a tariff adjustment allowed by a contract signed by a previous administration. There are also cases where legislation was passed to nullify contractual clauses. The Buenos Aires water concession indexed local-currency denominated tariffs to the US dollar to protect the contractor against currency risk. However, after a devaluation of the local currency, Congress passed an economic emergence law that nullified these guarantees (Lobina and Hall, 2003). Using a sample of 307 water and transport projects in 5 Latin American countries between 1989 and 2000, Guash, Laffont and Straub (2006) found that 79% of the total government-led renegotiations occurred after the first election that took place during the life of the project. In many cases the central or local government during a re-election campaign decided in a unilateral fashion to cut tariffs or not to honor agreed tariff increases to secure popular support.

Political risk has also played a crucial role in Central and Eastern Europe. As reported by Brench, Beckers, Heinrich, and von Hirschhausen, (2005), a major obstacle to the *PPP* policy in Hungary was the frequent change in political attitudes towards *PPPs* and user tolls. Since 1990 each change in government resulted in a different attitude and a different institutional framework for *PPPs*.

The impact of regulatory risk in *PPPs* is significant as it discourages potential investors and raises the cost of capital and the risk premium (higher tariffs, or smaller transfer price) paid for a *PPP* contracts. Guasch and Spiller (1999) estimate that the cost of regulatory risk ranges from 2 to 6 %age points to be added to the cost of capital depending on country and sector. An increase of 5 %age points in the cost of capital to account for the regulatory risk leads to a reduction of the offered transfer fee or sale price of about 35% or equivalently it requires a compensatory increase in tariffs of about 20%. Regulatory risk also discourages investors. In the £16 billion London Underground project of 2002-03 a high level of political controversy made lenders nervous, with the result that 85% of the debt had to be guaranteed by the public sector at a fairly late stage in the procurement process.

Renegotiation by the government of concession contracts in Latin American and Caribbean Countries is also widespread. Considering a compiled data set of more than 1,000 concessions granted during 1985–2000, Guash (2004) showed that 30 % of the concessions were renegotiated and in 26 % of the cases, the government initiated the renegotiation. Using a data set of nearly 1000 concessions awarded from 1989 to 2000 in telecommunications, energy, transport and water, Guash, Laffont and Straub (2008) showed that the probability of firm-led renegotiation is positively related to the characteristics of the concession contract among other things. Firm-led renegotiation on average tend to favor contractors. Guash, Laffont and Straub (2007) showed that the role of an experienced and independent regulator (or in general the quality of bureaucracy) is especially important in

contexts characterized by weak governance and high likelihood of political expropriation. In Latin America and Caribbean countries, regulatory agencies were rarely given training and instruments adequate to their mandate and even lacked political support from the government.

To improve governance, a number of countries have created dedicated *PPP* units - centre of expertise - to manage the contract with the private contractor.⁵⁶ Different approaches have been taken with regard to the governance of these units as some of them have been set up within the public sector (e.g. Central *PPP* Policy Unit in the Department of Finance 1 in Ireland or the Unita' Tecnica della Finanza di Progetto in Italy), others outside (Partnership UK in the UK which is a joint venture between the public and private sector with a majority stake held by the private sector).

8. CONCLUSIONS

Notwithstanding the policy relevance, still little theoretical and empirical work has been carried on the topic of *PPPs*. We have reviewed and unified in a common and flexible framework the existing literature on *PPPs* in an attempt to fill this gap. The benefits of his framework is that it can be extended beyond a basic set-up to address the performances of *PPPs* in more complex contractual and institutional environments.

In the basic set-up, our analysis has pointed at the efficiency gains that *PPP* arrangements can bring over traditional forms of procurement. However, we have also emphasized how *PPPs* may be unsuitable in a variety of more complex circumstances. Bundling of project phases that characterizes *PPPs* provides incentives to the private contractor to take into account the long-term project costs, from building to maintenance and operation as well as the impact of better infrastructure on the demand for the service. When the externality across project stages is positive, bundling improves incentives and, through appropriate risk transfer, yields better quality and less expensive projects. This result holds under a large class of schemes where complete contracts contingent on some profit dimension can be signed with both the builder and the operator. But, with a negative externality across project stages, bundling may increase agency costs, making traditional forms of procurement preferable. *PPP* contracts also lack the flexibility to adjust to new circumstances, user needs, or technologies, which points to the unsuitability of *PPPs* in very uncertain environments.

Our analysis suggests that *PPPs* are more beneficial when a better quality of the infrastructure can significantly reduce costs (including maintenance cost), when infrastructure quality has a great impact on the quality of the service and service demand, and when demand for the service is stable and easy to forecast. This points to the suitability of *PPPs* in the transport and water sectors, where infrastructure quality is key and demand is relatively stable, whilst it suggests that *PPPs* are less likely to deliver efficiency gains for nursing homes and schools, where service quality is mainly determined by human capital investment, or for IT services, where demand evolves quickly over time.

We have seen that in a *PPP* contract, although this is not specific to *PPPs*, satisfaction of consumer's needs and better service quality can be incentivized through the allocation of demand risk. In particular, the contractor should bear more demand risk in sectors such as transport, where users pay for the service and demand levels are affected by the

⁵⁶Bennett and Iossa (2006b) used an incomplete-contract approach to compare contract management by a public-sector agency with delegation of contract management to a *PPP* that is a joint venture between private and public sector agents. They showed that delegation may be desirable to curb innovations that reduce the cost of provision but also reduce social benefit.

contractor's effort. Contractors should bear less risk in sectors such as prisons, where users do not pay and usage is mainly determined by government's policy. Thus, welfare under *PPPs* is higher when service quality is verifiable, demand risk is low or the firm can diversify risk, and when there are government contributions or the initial capital investment is low. Recourse to private finance can however improve the operator's incentives if lenders bring their expertise in monitoring effort. In this respect, *PPPs* might be suitable also for high capital value projects.

Bundling project phases and long-term contracting allow *PPPs* to provide efficient long-term incentives and to optimize the trade-off between investment and maintenance along the life of the project. This helps to prevent cost overruns but it requires institutions with strong commitment power. As the risk of regulatory opportunism increases, the case for *PPPs* becomes weaker.

Two important issues have been left out of the analysis. The first relates to the award procedure. As *PPP* contracts must cover the design, building, operation and finance of the infrastructure, scoring rules need to account for a variety of quality and cost dimensions. Further, communication between procurement authority and potential contractors is needed to match project proposals with authority's needs. In Europe, the auction procedure for awarding *PPP* contracts, the so-called "Competitive Dialogue", was indeed designed to combine communication with competition.⁵⁷ Research on the topic however remains limited.⁵⁸

Second, beyond the case of regulatory risk, we have been silent about much of the institutional contexts in which *PPP* contracts are designed. There are at least two aspects that deserve more attention. The first one is related to the internal organization of the public sphere and its consequences on the likely important delay in having the various public entities involved (local governments, the central State, various Ministries) agreeing on a public demand.⁵⁹ The second important omission of this paper on the political economy side is that we disregarded the risk and cost of corruption in the different stages of the *PPP* process, though some research exists on the topic.⁶⁰ This like other important issues on the design and usefulness of *PPP* contracts await further research.

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⁵⁷In private procurement, Bajari, McMillan and Tadelis (2009) showed that contracts where communication is important are more likely to be awarded by negotiation than by auction.

⁵⁸See Doni (2007) for a brief discussion of the alternative procedures for *PPP* contracts.

⁵⁹See Dobrescu, Friebel, Grosjean and Robeck (2008) on this issue.

⁶⁰Martimort and Pouyet (2008) and Iossa and Martimort (2012b and 2012c).

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APPENDIX

PROOF OF PROPOSITION 2. Consider first the case of unbundling with the incentive constraints (3.2) and (3.11). Taking into account the risk premiums paid to induce participation by both the builder and the operator, G 's optimization problem becomes:

$$\max_{(a,e)} b_0 - \theta_0 + e + (b + \delta)a - \frac{(1 + r\sigma_\varepsilon^2)a^2}{2} - \frac{(1 + r\sigma_\varepsilon^2)e^2}{2}.$$

Optimization leads to:

$$a_{uq}^{SB} = \frac{b + \delta}{1 + r\sigma_\varepsilon^2} > a_u^{SB} = 0, \text{ and } e_{uq}^{SB} = e_u^{SB}.$$

Consider now the case of bundling with the incentive constraint (3.12). Since G has all bargaining power in designing the consortium's contract and extracts all its ex ante surplus, its optimization problem becomes:

$$\max_{(a,e)} b_0 - \theta_0 + e + (b + \delta)a - \frac{a^2}{2} - \frac{r\sigma_\varepsilon^2}{2}(a - \delta e)^2 - \frac{(1 + r\sigma_\varepsilon^2)e^2}{2}.$$

The maximand above is greater than under unbundling for a positive externality. The reverse holds for a negative externality.

The optimal effort levels are given by:

$$a_{bq}^{SB} = a_{uq}^{SB} + \frac{\delta r\sigma_\varepsilon^2 e_{bq}^{SB}}{1 + r\sigma_\varepsilon^2}, \text{ and } e_{bq}^{SB} = e_{uq}^{SB} + \frac{\delta r\sigma_\varepsilon^2 (b(1 + r\delta^2) + r\delta\sigma_\varepsilon^2)}{(1 + r\sigma_\varepsilon^2)D}$$

where $D = (1 + r\sigma_\varepsilon^2)^2 + r\delta^2\sigma_\varepsilon^2$. One can check that $a_b^{SB} > a_u^{SB}$ and $e_b^{SB} > e_u^{SB}$ since $\delta > 0$. *Q.E.D.*

PROOF OF PROPOSITIONS 3 AND 4. Under private ownership and unbundling, G extracts all the owner's surplus because he has all bargaining power ex ante. Given the effort levels defined in (3.13) and (3.14), we get the following expression of social welfare and inequality imply that Proposition 3 holds:

$$(A1) \quad W_u^{pr} = W_u^{SB} + \frac{(b + s + \delta)(1 - \pi)s}{2} - \frac{(1 - \pi)^2 s^2}{8} > W_u^{SB} = W_u^{pu}.$$

Under private ownership and bundling, ownership has still some value. Observing that G extracts now all ex ante surplus from the consortium by raising the fixed fee α by an amount that covers the extra net benefit that the owner can withdraw from his investment, and finally, aggregating the two incentive constraints in (3.15), we obtain the following expression of G 's maximization problem:

$$\max_{(e,a)} b_0 - \theta_0 + (b + s + \delta)a + e - \frac{a^2}{2} - \frac{(1 + r\sigma_\varepsilon^2)}{2}e^2 \text{ subject to } a = \delta e + \frac{(1 - \pi)}{2}s.$$

We use this last equality to express G 's objective function under unbundling and private ownership *before optimization with respect to e* as:

$$(A2) \quad W_b^{pr}(e) = W_u^{pr}(e) + \left(b + \delta + \frac{1 + \pi}{2}s\right)\delta e - \frac{\delta^2 e^2}{2} - \frac{r\sigma_\varepsilon^2 \beta^2}{2}$$

where

$$W_u^{pr}(e) = b_0 - \theta_0 + (b + \delta + s)a_u^{pr} - \frac{(a_u^{pr})^2}{2} + e - \frac{(1 + r\sigma_\varepsilon^2)}{2}e^2.$$

The result of Proposition 4 immediately follows.

Q.E.D.

PROOF OF PROPOSITION 5. Taking into account the risk premium borne by BO and the coalitional incentive constraint (4.5), we obtain the expression of the G 's problem as:

$$\max_e b_0 - \theta_0 + e - \left(1 + r \frac{\sigma_\varepsilon^2 \sigma_\zeta^2}{\sigma_\varepsilon^2 + \sigma_\zeta^2}\right) \frac{e^2}{2}.$$

The optimal effort level is $e^{BO} = \frac{1}{1 + r \frac{\sigma_\varepsilon^2 \sigma_\zeta^2}{\sigma_\varepsilon^2 + \sigma_\zeta^2}} \geq e_u^{SB}$. Q.E.D.

PROOF OF PROPOSITION 6. Consider the case of bundling. The expected welfare is still given by (A2). In particular, when δ is small, we already know that $W_b^{SB} - W_u^{SB}$ is of order δ .

Consider now the case of unbundling. The optimal effort depends now on γ . Easy computations yield $e_u^R(\gamma) = \frac{\gamma}{1 + \frac{r\sigma_\varepsilon^2}{\gamma^2}} < \gamma$. The expected welfare becomes:

$$(A3) \quad W_u^R = b_0 - \theta_0 + E_\gamma \left(\frac{\gamma^4}{2(\gamma^2 + r\sigma_\varepsilon^2)} \right) > W_u^{SB}$$

where the last inequality follows from Jensen inequality and the fact that $\frac{\gamma^4}{2(\gamma^2 + r\sigma_\varepsilon^2)}$ is convex in γ . Note that W_u^R differs from W_u^{SB} by a term of order zero in δ . Q.E.D.

PROOF OF PROPOSITION 7. G has still all bargaining power and uses accordingly the intertemporal fee $\alpha_1 + \alpha_2$ to extract all BO 's surplus. Aggregating the three incentive constraints (6.1) into a single one, G 's optimization problem becomes:

$$\max_{(a, e_1, e_2)} 2(b_0 - \theta_0) + \left\{ \sum_{i=1}^2 e_i - \frac{(1 + r\sigma_\varepsilon^2)e_i^2}{2} \right\} + (1 + b)a - \frac{a^2}{2}$$

$$(A4) \quad \text{subject to } e_2 = ae_1.$$

Denote by μ the multiplier of (A4). The first-order conditions w.r.t. (e_1, e_2, a) are:

$$1 - (1 + r\sigma_\varepsilon^2)e_1 = \mu a, \quad 1 - (1 + r\sigma_\varepsilon^2)e_2 = -\mu, \quad \text{and } 1 + b - a = \mu e_1.$$

From this, we can express (e_1, e_2, a) as functions of μ :

$$e_1(\mu) = \frac{1 - \mu(1 + b)}{1 + r\sigma_\varepsilon^2 - \mu^2}, \quad e_2(\mu) = \frac{1 + \mu}{1 + r\sigma_\varepsilon^2}, \quad \text{and } a(\mu) = \frac{(1 + b)(1 + r\sigma_\varepsilon^2) - \mu}{1 + r\sigma_\varepsilon^2 - \mu^2}$$

which are all positive effort levels when $0 \leq \mu \leq \frac{1}{1+b}$.

Inserting into (A4), we get that μ solves:

$$(A5) \quad \varphi(\mu) = (1 + r\sigma_\varepsilon^2)(1 - \mu(1 + b))((1 + b)(1 + r\sigma_\varepsilon^2) - \mu) - (1 + \mu)(1 + r\sigma_\varepsilon^2 - \mu^2)^2 = 0.$$

Since $\varphi(0) > 0 > \varphi\left(\frac{1}{1+b}\right)$, there is a root $\mu \in \left(0, \frac{1}{1+b}\right)$, which yields the result. Q.E.D.

PROOF OF PROPOSITION 8. Contracting taking place ex ante, i.e., before the firm learns its innate costs, the following ex ante participation constraint must hold:

$$(A6) \quad \nu u(U(\underline{\theta})) + (1 - \nu)u(U(\bar{\theta})) \geq 0,$$

where $u(x) = \frac{1}{r}(1 - \exp(-rx))$ because of constant risk aversion.

G 's problem can now be written as:

$$\max_{(U(\cdot), \beta(\cdot))} b_0 + E\theta_0 \left(-\theta_0 + \beta(\theta_0) - \frac{(1 + r\sigma_\varepsilon^2)\beta^2(\theta_0)}{2} - U(\theta_0) \right) \text{ subject to (6.5) and (A6).}$$

Observing that both (6.5) and (A6) are binding yields the following expressions of the certainty equivalent for the firm's payoff for each realization of θ_0 as:

$$U^{SB}(\underline{\theta}) = \Delta\theta\beta^{SB}(\bar{\theta}) + \frac{1}{r}\ln(1 - \nu + \nu\exp(-r\Delta\theta\beta^{SB}(\bar{\theta}))) > 0,$$

$$U^{SB}(\bar{\theta}) = \frac{1}{r}\ln(1 - \nu + \nu\exp(-r\Delta\theta\beta^{SB}(\bar{\theta}))) < 0.$$

The levels of effort are respectively given by:

$$e^{SB}(\underline{\theta}) = \beta^{SB}(\underline{\theta}) = e_u^{SB} \text{ and } e^{SB}(\bar{\theta}) = \beta^{SB}(\bar{\theta}) = \frac{1}{1 + r\sigma^2} \left(1 - \frac{\nu\Delta\theta(1 - \exp(-r\Delta\theta e^{SB}(\bar{\theta})))}{1 - \nu + \nu\exp(-r\Delta\theta e^{SB}(\bar{\theta}))} \right) < e_u^{SB}.$$

Q.E.D.

PROOF OF PROPOSITION 9. Following the same steps as in the proof of Proposition 7, G 's maximization problem can be now written as:

$$\max_{(a, e_1, e_2)} 2(b_0 - \theta_0) + \left\{ \sum_{i=1}^2 e_i - \frac{(1 + r\sigma_\varepsilon^2)e_i^2}{2} \right\} + (1 + b)a - \frac{a^2}{2} \text{ subject to } e_2 = e_u^{SB} \text{ and}$$

$$(A7) \quad e_u^{SB} = ae_1.$$

Clearly, this problem is more constrained than under full commitment and achieves a lower intertemporal payoff for G . Denote by λ the multiplier of (A7). The first-order conditions w.r.t. (e_1, a) are:

$$1 - (1 + r\sigma_\varepsilon^2)e_1 = \lambda a \text{ and } 1 + b - a = \lambda e_1.$$

From this, we can express (e_1, a) as functions of λ :

$$e_1(\lambda) = \frac{1 - \lambda(1 + b)}{1 + r\sigma_\varepsilon^2 - \lambda^2}, \text{ and } a(\lambda) = \frac{(1 + b)(1 + r\sigma_\varepsilon^2) - \lambda}{1 + r\sigma_\varepsilon^2 - \lambda^2}$$

which are all positive effort levels when $0 \leq \lambda \leq \frac{1}{1+b}$.

Inserting into (A7), we get that λ solves:

$$\vartheta(\mu) = (1 + r\sigma_\varepsilon^2)(1 - \lambda(1 + b))((1 + b)(1 + r\sigma_\varepsilon^2) - \lambda) - (1 + r\sigma_\varepsilon^2 - \lambda^2)^2 = 0.$$

Since $\vartheta(0) > 0 > \vartheta\left(\frac{1}{1+b}\right)$, there is a root $\lambda \in \left(0, \frac{1}{1+b}\right)$. Moreover, it is easy to check using (A5) that $\vartheta(\mu) > 0$. Thus $\lambda > \mu$ which yields the result on the comparison of efforts. *Q.E.D.*