A Theory of BOT Concession Contracts

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Abstract: In this paper, we discuss the choice for build-operate-and-transfer (BOT) concessions when governments and firm managers do not share the same information regarding the operation characteristics of a facility. We show that larger shadow costs of public funds and larger information asymmetries entice governments to choose BOT concessions. This result stems from a trade-off between the government's shadow costs of financing the construction and the operation of the facility and the excessive usage price that the consumer may face during the concession period. The incentives to choose BOT concessions increase as a function of ex-ante informational asymmetries between governments and potential BOT concession holders and with the possibility of transferring the concession cost characteristics to public firms at the termination of the concession.

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1 Introduction

In the last two decades, many governments have increased their reliance on public-private partnerships (PPP) to finance the acquisition of infrastructure assets and the operation of their facilities. A frequent form of PPP is the build-operate-transfer (BOT) concession under which the private sector builds and operates an infrastructure project for a well defined concession period and then transfers it to public authorities. In a majority of cases, such concession contracts have been used to finance transport infrastructure such as highways, tunnels, airports, ports, bridges, canals, railroads and railway transport systems. They are also frequently used to finance projects in power generation, water supply, dams, irrigation, sewerage and drainage, and to a lesser extent, solid waste management and telecommunications infrastructure. Despite their popularity and practical relevance, few academic works have studied BOT concessions. This paper intends to fill this gap by offering a theoretically investigation of these contracts.

The attractiveness of BOT concessions to governments and politicians stems from the possibility to limit government spending by shifting investment costs to private interests. Historically, the first BOT concessions were granted for the construction of turnpike roads in the UK in 1660, at a time of industrial expansion and embryonic public finances. Additional BOT concessions quickly followed for the construction and operation of canal and railway projects in both the UK and the US. In the water sector, the first French BOT concession was granted to the Périer Brothers in 1782 to pump and supply water to the city of Paris. It was quickly followed by similar concessions in France, Spain, Italy, Belgium, and Germany. The need to resort to private investors has been even more acute for international projects that require important funding commitments and challenging coordination amongst nations. This is the case of the Suez Canal and Channel Tunnel projects, which construction and operation were privately financed by the Suez Canal Company in 1859 and the Eurotunnel Group in 1988, respectively.

To induce private investors to sink their capital into very expensive and risky infrastructure projects, governments must leave rents to the concession holders during their activities. In the 17th and 18th centuries, many concessions were unregulated so that concession holders were given monopoly rights over their infrastructure. For example, some canal concession holders retained exclusive rights on the fleet moving on their canals. Nowadays, even when they are monitored by public authorities, BOT projects confer temporary control and cashflow rights to the private concession holders. The latter are indeed allowed to ask compensation from the users of the delivered goods or services and aim not only at recovering their investment costs but also at extracting the highest possible profits. Therefore, the choice between a private BOT concession and public management implies a trade-off between allocative efficiency and the cost of public funds, which is the focus of this paper.

Among concession contracts, a distinctive feature of BOT concessions lies in the transfer of operational responsibilities and profits to a private concession holder for a well defined time period. Concession periods vary in function of the time required to recover the assessed costs of the facilities. For example, in the above historical examples, the Périer Brothers obtained a 15-year concession (Delambre 1818, p. lxiij.), and Suez Canal Company a 99-year concession. The Eurotunnel Group has obtained a 55-year concession (Channel Tunnel Act 1987). As additional examples, the French Millau bridge was granted a 78-year concession, Australian Darwin-Alice Springs railway concession has a 50-year duration, the US concessions for the Southern Indiana Toll Interstate 69 and Trans-Texas road Corridor are granted for 75-year and 50-year (Congressional Budget Office 2008). Since concession periods vary with the nature and context of the projects, the present paper also aims to discuss the optimal concession periods.

Finally BOT concession contracts are close substitutes to build-own-operate-transfer (BOOT) contracts where the concession holder gets the ownership of the infrastructure in addition to the tasks to build and operate it. In BOT contracts, the public authority retains ownership over the infrastructure while it contractually confers *all* control and cashflow rights to the concession holder (e.g. the above French Millau bridge and US toll road examples). In BOOT contracts, the authority confers the ownership over the infrastructure to the private concession holder (e.g. Suez Canal, Channel Tunnel and

Australian Darwin-Alice Springs railway).[4] The choice between one or the other contract generally depends on the legal system that applies to the project. Nevertheless, from an economic viewpoint, the two forms of concession contracts are equivalent as long as they are associated with the same control and cashflow rights (Hart 2003). In this paper, we will therefore make no formal distinction between BOT and BOOT contracts.

In this paper, we present a simple theory of BOT concessions by considering a single project that can be implemented by a public firm's manager or a private concession holder. In the case of a publicly owned firm, the government makes the investment and keeps both cashflow and control rights over the infrastructure. The government is, therefore, accountable for its profits and losses. The government must subsidize the public firm in the event of losses, whereas it can tax it in the event of profits. In contrast, the BOT concession combines private and public management. The government auctions the BOT concession to potential concession candidates, who bid for the shortest concession period. During the concession period, the winning concession candidate keeps cashflow and control rights so that the government takes no responsibility for the firm's profits and losses. The government makes no cash transfer for the investment or to the concession holder's operations. The concession holder recoups its investment cost from the firm's profits during the concession period. For the sake of simplicity, we assume in most of the text that concession holders are allowed to set monopoly prices during the concession period.[5] However our results are robust to the possible existence of a price cap. Finally, at the end of the concession period, the government recovers the cashflow and control rights and delegates the operation to a public firm's manager.

We discuss the choice of BOT concession contracts for various degrees of information asymmetry that exist between firms and governments before the concession contract and for various levels of transferability of project characteristics at the end of the concession

[4] From a legal viewpoint, the latter option offers more protection to the concession holder as it limits the government' legal public authority to unilaterally change a concession contract. However, in practice such unilateral actions are rather unfrequent. We thank the editor for this remark.

[5] This is congruent with the fact that many outsourced facilities turn out to show excessive usage prices. See for instance Chong et al. (2006) and Estache (2006).

period. The paper is structured around two main cases. First, concession candidates may not hold better information about project characteristics before the concession contract signature (ex-ante information symmetry). As in the cases of the Suez Canal or Channel Tunnel, public authorities and concession holders may be equally uncertain about costs and demand prospects. Second, concession candidates may hold better information before the concession contract signature (ex-ante information asymmetry). For instance, many water distribution and sanitation concessions are held by specialized multinational corporations that have better technology expertise and project experience than local governments. We then also consider two subcases depending on whether project characteristics may or may not be physically transferred to public authority at the end of the concession. Indeed those characteristics may result either from the physical facility that is a transferable good (transferability) or from the concession holder's management that is not transferable to the government (non transferability). For example, the expertise and know-how required in sanitation or waste management projects are not easily transferred to the public local authorities whereas the cost and demand characteristics are naturally transferable at the end of a canal or tunnel concession.

In addition, as in Laffont and Tirole (1993), the government's financial constraint is summarized by its shadow cost of public funds, which measures the social cost of its economic intervention. Transfers to public firms are associated with social costs because every dollar spent on (re-)funding the project implies a decrease in the production of essential public goods, schooling, or health care or an increase in distortionary taxation or costly public debt. This shadow cost is usually high in developing countries that face structural difficulty in raising taxes.[6] Since the 2008 financial crisis, it is also very much likely to have drastically risen in developed countries facing a severe budgetary crisis (e.g. Greece, Spain, Portugal, Ireland, France, the UK, and the US). The paper provides insights on the impact of the financial crisis on the enactment of BOT concessions.

The results of the paper are as follows. We firstly show that governments always prefer

[6] It was also high in O.E.C.D. countries before and during the industrial revolution because governments had very few funding sources and under-developed taxation systems.

public management when they share the same information as concession holder during the entire project life. Indeed public management can always replicate and improve upon the decision of the concession holder in a context of symmetric information. However, the choice between BOT concession and public management depends on shadow costs of public funds when some information asymmetry arises between governments and public firm managers after the investment phase. We highlight two effects. On the one hand, BOT concessions relax governments' financial constraints but involve pricing strategies that decrease consumer surplus. On the other hand, public management involves financial costs that are associated not only with the investment costs but also with the costs of subsidizing the potential losses of public firms. The latter problem is exacerbated by informational asymmetries because public managers have incentives to inflate their cost reports to increase their rents. To mitigate such informational costs, governments reduce the output of public firms and, therefore, incur additional costs in terms of a fall in consumer surplus.

As mentioned above, we consider two cases of information contexts before the signature of a concession contract. In the first case, concession candidates do not hold better information about project characteristics before the concession contract signature (ex-ante information symmetry). We show that the costs of information asymmetries dominate for large project uncertainty and large shadow costs of public funds. This suggests that the reliance on BOT concessions should increase in time of financial crisis. We also show that the incentives to choose BOT concessions increase when the project characteristics can be transferred to the public authorities at the end of the concession period. In the second case, concession candidates may hold better information before the concession contract signature (ex-ante information asymmetry). We then show that the incentives to choose BOT concessions can also increase provided governments are able to implement an auction with the participation of a large enough number of concession candidates. For the sake of completeness, we also compare the above BOT contracts with a third case the least-present-value-of-revenue auction that is proposed by Engel *et al.* (2001). Finally, we use the specific class of linear demand functions and uniform cost distributions to compute theoretical values of shadow costs of public funds that would entice governments to choose BOT concession contracts. Comparing those theoretical values with the empirical values estimated for advanced and developing economies, we find that BOT concession contracts are likely to be preferred in many situations.

Finally the model allows us to discuss two interesting extensions. We first discuss the impact of price cap regulation during the concession periods and show that appropriate price caps make BOT contracts more valuable for governments. In a nutshell the introduction of a price cap can reduce the loss of consumer surplus during the concession more than it increases the cost of a longer concession period. We analyze next the impact of different opportunity costs of time for the government and the concession holder. We show that more impatient governments (i.e., those with shorter tenure) have more incentives to opt for BOT concessions.

This paper relates to several strands of economic literature. First, there exists a narrow strand of literature that is dedicated to the discussion of BOT concession contracts. By extending early discussions about auctions of natural monopolies (Williamson, 1976; Riordan and Sappington, 1987), a recent literature in this area has focused on the optimal way to auction monopoly contracts (Harstad and Crew, 1999; Engel *et al.* 2001) and on the renegotiation of concessions (Guasch *et al.* 2006). Second, because BOT concession contracts involve a special relationship between public and private entities, a discussion of BOT concession contracts also belongs to a more generic discussion regarding public-private partnerships and private finance initiatives. This literature generally discusses issues of moral hazard in project financing and firms' operations (Vaillancourt Rosenau, 2000; Dewatripont and Legros 2005; Engel *et al.* 2007), production complementarity (Martimort and Pouyet, 2008; Iossa and Martimort 2008), and political economics (Maskin and Tirole, 2008). Finally, this paper is related to the more general literature about privatization, which discusses soft budget constraint issues in public institutions and the effects of market discipline on the management of private firms (Kornai, 1980; Dewatripont and Maskin, 1995; etc.). To clarify our argument, we do not discuss such issues in the present paper. Rather, instead, we focus on the trade-off between governments' financial pressures and allocative inefficiencies in the particular case of concession contracts with variable terms (see also Auriol and Picard, 2008 and 2009).

The paper is organized as follows. Section 2 presents the model and Section 3 discusses the choice of a BOT concession contract in the case of symmetric information. Section 4 discusses this choice in the context of asymmetric information. It focuses on two main cases of ex-ante information structure and studies different subcases of project characteristic transferability. Section 5 offers the extensions to the presence of a price cap and to asymmetries in governments' and firms' opportunity costs of time. Section 6 concludes. Proofs are relegated to the appendices.

2 The Model

The government has to decide whether a facility/infrastructure project should be run publicly or under build-operate-and-transfer (BOT) scheme. In line with Laffont and Tirole (1993), the *public regime* is a regime in which the government makes the project investment and keeps control and cash-flow rights during the whole project life. As it is standard in the regulation literature the government's control rights are associated with accountability on profits and losses. That is, the government subsidizes the regulated firm in case of losses whereas it taxes it in case of profits. Such a combination of control rights and accountability duties by public authorities is typical of public ownership.

In contrast, the *BOT regime* is a combination of private and public management. The government grants a concession to a concession holder who invests and keeps control and cash-flow rights for a well-defined concession period. During this time period, the government takes no responsibility for the firm's profits and losses. The essence of BOT contracts is that the government does not have to make any cash transfer to the private investor; the investment is paid by the concession holder who recovers its cost from the operating profits generated during the concession period.[7] In what follow we simply

[7] There exists a conflict of interest between governments and concession holders about risk bearing. In the E.U. context, governments are required to make the concession holders bear the operation and/or

assume that the concession holder is allowed to operate under laissez-faire so that she is able to get its monopoly profit during the concession. As shown Subsection 5.1 a price cap or minimum output constraint does not qualitatively alter our analysis.

To avoid introducing a bias in favor or against BOT we assume that users' preferences and available technologies are the same under public management and BOT concession. We consider a continuous time model where the government, concession holders and public firm's managers have the same opportunity cost of time ρ. To simplify the exposition we assume that the demand and cost parameters remain constant for the whole life of the project once the investment is made.[8] In every time period t, the users of the project get an instantaneous gross surplus $S(Q_t)$ where Q_t is the quantity of consumed goods or services and where $S'(Q_t) > 0 > S''(Q_t)$. We assume that users cannot store and transfer those goods or services to the next time periods. So, the whole production must be consumed within the same time period and must be sold at the market equilibrium price $P(Q_t) \equiv S'(Q_t)$, which defines the inverse demand function.

The firm faces increasing returns to scale technology. After sinking an irreversible investment cost $K > 0$ at the initial time period $t = 0$, the firm begins to produce its good or service at a constant marginal cost during each subsequent time period $t > 0$. We assume that the investment cost K is constant and is verifiable. In our exposition, the uncertainty lies on the impact of the investment on the technology. That is, the marginal cost parameter β is idiosyncratic and independently drawn from the support $[\underline{\beta}, \bar{\beta}]$ according to the density and cumulative distribution functions $g(\cdot)$ and $G(\cdot)$. The expectation operator is denoted E so that $E[h(\beta)] = \int_{\underline{\beta}}^{\bar{\beta}} h(\beta)dG(\beta)$. For example, β captures the cost uncertainty inherent to the operation and maintenance of a road concession with variable traffic or to the hauling and handling of containers in a harbor. A larger variance corresponds to a more risky project. It is important to note that our discussion also relates

demand risks. This is the view adopted in this paper. For instance, the huge losses of Channel Tunnel project were borne by shareholders only. No subsidy was offered. Only an extension of the concession period was granted.

[8] The model can readily be interpreted to the case where the cost/demand parameter varies through time for $t > 0$ and is repeatedly drawn from the same cost/demand distribution.

to information asymmetry about demand as β can also be interpreted as a demand parameter. In our model, cost and demand information asymmetries are indeed isomorphic as one can normalize marginal cost to zero and define the demand as $P(Q) - \beta$ and the surplus as $S(Q) - \beta Q$ where $\beta \in [\underline{\beta}, \overline{\beta}]$ now defines a "demand shifter" (i.e., a higher β corresponds to a lower demand). All subsequent analysis and computations remain valid.

To avoid corner solutions in the sequel, we assume that the good or service generates a large enough surplus so that shutting down production is never optimal once the fixed cost has been sunk. This means that the willingness to pay for the first unit of the good or service must be sufficiently large to allow concession holders and public firms make a positive margin:

A1 $$P(0) > \overline{\beta} + G(\overline{\beta})/g(\overline{\beta})$$

As in Laffont and Tirole (1993), the government is assumed to be benevolent and utilitarian. It maximizes the sum of consumer's and producer's surpluses minus the social cost of transferring public funds to the firm. The government's intertemporal objective function is given by

$$\mathcal{W} \equiv -K - \lambda T_0 + \int_0^\infty \left[S(Q_t) - \beta Q_t - \lambda T_t\right] e^{-\rho t} dt$$

This objective includes the initial investment cost K and a transfer T_0 at $t = 0$ and the discounted value of subsequent net surplus $S(Q_t) - \beta Q_t$ and social cost of government transfers λT_t for all $t > 0$. The social cost of transfers includes either taxes paid by the firm ($T_t < 0$) or subsidies granted to the firm ($T_t > 0$), which are valued at the shadow cost of public funds λ. The government maximizes the net consumer surplus when the shadow cost of public funds λ is close to zero whereas it puts more weight on the social cost of transfers when this shadow cost becomes larger. When the latter becomes very large ($\lambda \to \infty$), the government is mainly interested in the impact of transfers on its budget: it taxes the firm in the event of profits and avoids any subsidy in the event of losses.

The shadow cost of public funds λ, which measures the social cost of the government's economic intervention, drives the results of the paper. In a setting in which governments implement many projects and have many funding sources, the shadow cost can be interpreted as the Lagrange multiplier of the government budget constraint. The shadow cost of public funds is positive because transfers to firms imply either a decrease in the production of public goods, such as schooling and health care, or an increase in distortionary taxation. Each euro that is transferred to the regulated firm costs $1 + \lambda$ euros to society. In developed economies, λ is mainly equal to the deadweight loss accrued to imperfect income taxation. It is assessed to be around 0.3 (Snower and Warren, 1996).[9] In developing countries, low income levels and difficulties in implementing effective taxation programs are strong constraints on the government's budget, which leads to higher values of λ. The World Bank (1998) suggests a shadow cost of 0.9. It is presumably higher in countries close to financial bankruptcy. For simplicity, we assume that government's funding conditions remains the same for the whole time period so that the shadow cost of public funds is constant through time.

Under public management, denoted by the superscript ^{p}, the firm is run by the public firm's manager.[10] She receives subsidies from the government, or pays cash transfers to it, according to the financial viability of her project. Her instantaneous utility is equal to

$$U_t = \begin{cases} -K + T_0 & \text{if} \quad t = 0 \\ P(Q_t)Q_t - \beta Q_t + T_t & \text{if} \quad t > 0 \end{cases}$$

where T_0 is an up-front transfer to the firm, and T_t is a transfer at time t. This utility can be positive when the public firm's manager is able to extract rents. However it cannot be negative as we assume that the public firm's manager has an outside option with value normalized to zero so that $U_t \geq 0$.[11] The government's cash-flow rights over the public

[9] The shadow cost of public funds λ reflects the macro-economic constraints that are imposed on national governments' surpluses and debts levels by supranational institutions (e.g. in the Maastricht treaty on E.U. member states, in the I.M.F. on many developing countries). It also reflects micro-economic constraints of government agencies that are unable to commit to long-term investment expenditures in their annual or pluri-annual budgets. In the context of PPP, the shadow cost of public funds reflects the short term opportunity gain to record infrastructure assets out of the government's book.

[10] The concept of public manager can be extended to any constituency within the firm that seeks to extract rents from the firms' activity.

[11] Allowing a positive outside option for the public manager (like an outside salary) would reduce the

firm hence come with the requirement that the firm breaks even at any point in time. The transfers cover the public firm instantaneous profits and losses so that $T_0 = K$ for $t = 0$ and $T_t = U_t - [P(Q_t)Q_t - \beta Q_t]$ for $t > 0$. Therefore, the government's objective function is given by

$$\mathcal{W}^{\mathrm{p}} \equiv -(1+\lambda)K + E\int_0^{\infty} [S(Q_t) + \lambda P(Q_t)Q_t - (1+\lambda)\beta Q_t - \lambda U_t] e^{-\rho t} dt$$

Under BOT concession contracts, denoted by the superscript ^{b}, the risk neutral concession holder receives no transfer, and the government does not pay or get any transfer until the end of the concession period. Therefore, $T_t = 0$ for any $t \leq t_1$, where t_1 is the concession period. The concession holder's instantaneous utility is :

$$\Pi_t^b = \begin{cases} -K & \text{if} \quad t = 0 \\ P(Q_t)Q_t - \beta Q_t & \text{if} \quad 0 < t \leq t_1 \\ 0 & \text{if} \quad t > t_1 \end{cases}$$

The concession holder gets a net present value equal to

$$\Pi^b = -K + E\int_0^{t_1} [P(Q_t)Q_t - \beta Q_t] e^{-\rho t} dt.$$

Under BOT, the government's objective function writes as

$$\begin{aligned} \mathcal{W}^{\mathrm{b}} \equiv & -K + E\int_0^{t_1} [S(Q_t) - \beta Q_t] e^{-\rho t} dt \\ & + E\int_{t_1}^{\infty} [S(Q_t) + \lambda P(Q_t)Q_t - (1+\lambda)\beta Q_t - \lambda U_t] e^{-\rho t} dt \end{aligned}$$

To guarantee the concavity of profits and government's objective we assume that the demand function is not too convex:

A2 $$P''(Q)Q + P'(Q) < 0.$$

Under BOT, the concession holder controls the firm during the concession period $(0, t_1)$ but relinquishes her control at the termination time of the concession, t_1. Therefore, the instantaneous output and surplus remain constant during the concession period and after

attractiveness of regulation compared to BOT and reinforce our results.

it. We denote each of those two time periods by the subscript 1 and 2 so that output is denoted as Q_1 during $(0, t_1)$ and Q_2 during $[t_1, \infty)$. Let us define the "concession duration" L as $L/\rho = \int_0^{t_1} e^{-\rho t} dt$. We have $\int_{t_1}^{\infty} e^{-\rho t} dt = (1 - L)/\rho$. Since the net present value of a dollar is equal to $\int_0^{\infty} e^{-\rho t} dt = 1/\rho$, the concession duration L corresponds to the net present value of a permanent income of one dollar during the BOT concession and $1 - L$ corresponds the net present value of this permanent income after the concession period. Finally it is convenient to use the following definition of the instantaneous welfare of government:

$$W(Q, \beta) \equiv S(Q) + \lambda P(Q)Q - (1 + \lambda)\beta Q \tag{1}$$

which is concave under assumption **A2**.

Using those definitions, we can re-write the government's objectives more compactly as

$$\rho \mathcal{W}^{\mathrm{p}} = -(1 + \lambda)\rho K + E[W(Q, \beta) - \lambda U] \tag{2}$$

$$\rho \mathcal{W}^{\mathrm{b}} = -\rho K + L\ E[S(Q_1) - \beta Q_1] + (1 - L) E[W(Q_2, \beta) - \lambda U] \tag{3}$$

and

$$\rho \Pi^{\mathrm{b}} = -\rho K + L\ E[P(Q_1)Q_1 - \beta Q_1] \tag{4}$$

3 Symmetric Information

Under symmetric information, both government and concession holder have perfect information about the cost parameter β during the project life. This means that the expectation operator can be removed in the expressions (2) to (4) (i.e. $E[h(\beta)] = h(\beta)$). We denote the values of the variables under symmetric information by the superscript *.

We first study the case of public management. The government has no incentives to raise the utility of the public firm's manager (or her organization) above her reservation value. In this informational context, it is able to set the transfers so that the public firm's manager gets no rent: $U = 0$. The government proposes a production level Q^* that maximizes

$$\rho \mathcal{W}^{\mathrm{p}} = -(1 + \lambda)\rho K + W(Q, \beta)$$

The first order condition is equal to

$$\frac{\partial}{\partial Q} W(Q, \beta) = 0 \iff P(Q^*) + \frac{\lambda}{1+\lambda} P'(Q^*) Q^* = \beta. \tag{5}$$

which yields the optimal output Q^*.

We now study the case of a BOT concession. The government's objective is then given by

$$\rho \mathcal{W}^{\mathrm{b}} = -\rho K + L \; [S(Q_1) - \beta Q_1] + (1 - L) \; W(Q_2, \beta)$$

During the concession period, the concession holder makes the profit

$$\rho \Pi^{\mathrm{b}} = -\rho K + L \; [P(Q_1) Q_1 - \beta Q_1]$$

Because she is allowed to run the firm under laissez-faire during the concession period, she chooses the monopoly output $Q_1 = Q^m$, which maximizes the above expression. The monopoly solution is given by the following first order condition:

$$\frac{\partial \Pi^{\mathrm{b}}}{\partial Q} = 0 \iff P(Q^m) + P'(Q^m) Q^m = \beta \tag{6}$$

Comparing expressions (5) and (6), it is obvious that $Q^* > Q^m$ for $\lambda > 0$ and $Q^* = Q^m$ for $\lambda \to \infty$. This output level converges towards the monopoly level when the shadow cost of public funds becomes very large. In this case, the government aims to tap the maximal profit from the firm.

At the concession term, the government maximizes the objective function $W(Q_2, \beta)$ which is equal to the function $\mathcal{W}^{\mathrm{p}}$ plus some constant. As a result, the optimal output is given by (5): $Q_2 = Q^*$. Finally, the government needs to set a concession contract. Because the government has no incentive to leave rents to the concession holder, it sets the concession termination time to t_1 so as to make the concession holder just breaks even: $\Pi^{\mathrm{b}} = 0$. Because t_1 is monotonically related to the concession duration L, this means that

$$L^* = \frac{\rho K}{P(Q^m) Q^m - \beta Q^m} \tag{7}$$

The concession is longer for larger investment costs and smaller operational profits, an intuitive result.

We are now equipped to compare public management and BOT concession under full information. The government prefers public management over the BOT concession if and only if $\mathcal{W}^{\mathrm{p}} \geq \mathcal{W}^{\mathrm{b}}$; using the definition (1), this condition is equivalent to

$$L^{*} \ \{W(Q^{*},\beta)-[S(Q^{m})-\beta Q^{m}]\} \geq \rho K \lambda \tag{8}$$

This inequality reflects the government's cost and benefit of a public management under symmetric information. On the one hand, the government must fund the investment K at the value of the shadow costs of public funds. On the other hand, it benefits from a higher welfare during the concession period. Note that the concession holder sets her bid on concession duration L^{*} in proportion to her investment cost K. Therefore, a rise in this cost augments proportionally both members of the above inequality. Any additional investment cost raises proportionally both the public funding cost of the project and the welfare advantage of public management. The investment cost has thus no impact on the government's decision to use public management and BOT concessions.[12] This property will remain true under asymmetric information provided that cost characteristics cannot be transferred. Using (1) and (7), the inequality (8) becomes

$$W(Q^{*},\beta) \geq W(Q^{m},\beta)$$

which is always satisfied because W is concave and reaches its maximum at $Q = Q^{*}(\beta) \leq Q^{m}(\beta)$ for all $\beta \in [\underline{\beta},\overline{\beta}]$. The BOT concession is at best equivalent to public management. This result remains true for any shadow cost of public funds. Indeed, whereas the concession holder is concerned only by her producer surplus, the government also considers the consumer surplus and the cost of public funding. The concession holder therefore chooses an output level that is always too high from the government's viewpoint. We collect this result in the following proposition.

Proposition 1 *Under symmetric information, a BOT concession never yields a higher welfare than public management.*

[12] We are grateful to Y. Spiegel for this remark.

Proposition 1 is a reminiscence of the standard result in regulation theory stating that a benevolent and fully informed government cannot perform worse than the market since it can at least replicate the market outcome. As in Auriol and Picard (2008) this result applies for any shadow cost of public funds. The fact that the government limits the laissez-faire period by restraining the concession period does not affect this result.

4 Asymmetric Information

As it is standard in the regulation literature, we take the view that the government faces difficulties in acquiring information about firm's cost and must rely on a public firm's manager to obtain this information. In contrast, concession holders face a much weaker information asymmetry with their own managers because they have expertise about facility projects and because they can provide better incentives. In particular, concession holders can tailor their managers' rewards to the concession profit levels while such an option is rarely applicable in publicly managed firms. As a consequence, the public management tends to inflate their costs to benefit from rents. Empirical evidences support this view that public firms are on average less productive and less profitable than their private counterparts (Megginson and Netter 2001).

The paper distinguishes two issues that naturally arise in the discussion of BOT concessions. The first issue, which is used to structure the paper, concerns the information asymmetry between public authorities and concession holders at the time of the concession contract signature and investment. Concession holders may indeed have better information about the project characteristics before the moment they sign and invest (ex-ante asymmetry) or after that moment (ex-ante symmetry). An ex-ante information asymmetry reflects government's information disadvantage, generally due to some lack of expertise and experience. Ex-ante information symmetry reflects a genuine project uncertainty. In this paper, the information asymmetry relates to the cost characteristic β, but it can be interpreted as an information asymmetry about demand (i.e., β can be a demand shifter). As noted above, cost and demand characteristics are two isomorphisms of the same model.

The second issue concerns the characteristics of the asset that is transferred to the public authorities at the end of the concession period. Project characteristics cannot be transferred if they are related to concession holder's management skills, business practices or synergies with other projects. Concession holders can indeed have technical expertise and experience that are not transferable. Information on their costs will not help the government to evaluate the public management's cost reports after the concession period. By contrast, project characteristics can be transferred if they are inherent to the physical nature of the facility. For instance, the traffic on a highway is likely to remain the same after the concession has ended. If the initial uncertainty lies on the volume of the demand, when the government inherits the project at the end of the concession period, it also inherits its demand characteristics, which in our setting simply means that it also learns β.

Before turning to the analysis of these different cases, we first study the case of public management.

4.1 Public Management

Under asymmetric information, the government proposes a production and transfer scheme $(Q(\beta, t), T(\beta, t))$ that entices the public firm's manager with cost β to reveal its private information through time t. Baron and Besanko (1984) have shown that the re-use of information by the principal generates a ratchet effect that is sub-optimal for the principal. Even though the cost remains constant over time, the principal is better off by committing to the repetition of the static contract and recurrently paying the information rent embedded in the static contract. Hence, in our context, the production and transfer scheme simplify to the time-independent scheme $(Q(\beta), T(\beta))$.[13] As a result, we can readily use expression (2) where outputs and transfers were set to be time independent.

[13] If the principal cannot credibly commit, the ratchet effect will lower the benefit of public management. This will reinforce our results showing that, even with the assumptions of perfect commitment and benevolence, public management is not always optimal.

By the revelation principle, the analysis can be restricted to direct truthful revelation mechanism where the concession holder reports its true cost β. To avoid the technicalities of 'bunching', we make the classical monotone hazard rate assumptions:

A3 $\qquad G(\beta)/g(\beta)$ is non decreasing.

Under asymmetric information the government maximizes the objective function:

$$\max_{\{Q(\cdot),U(\cdot)\}} \rho\mathcal{W}^{\mathrm{p}} = -(1+\lambda)\,\rho K + E\left[W(Q(\beta),\beta) - \lambda U(\beta)\right] \tag{9}$$

subject to

$$\frac{dU(\beta)}{d\beta} = -Q(\beta) \tag{10}$$

$$\frac{dQ(\beta)}{d\beta} \leq 0 \tag{11}$$

$$U(\beta) \geq 0 \tag{12}$$

Conditions (10) and (11) are the first and second order incentive compatibility constraints that entice the firm to reveal its private information β truthfully. Condition (12) is the public firm's manager's participation constraint. This problem is a standard adverse selection problem of regulation under asymmetric information (see Baron and Myerson 1982, Laffont and Tirole 1993). The public firm's manager with the highest cost $\beta = \overline{\beta}$ gets zero utility. Equation (10) implies that $U(\beta) = \int_{\beta}^{\overline{\beta}} Q(x)dx$. Using integration by part in the objective function yields $E\left[U(\beta)\right] = E\left[Q(\beta)G(\beta)/g(\beta)\right]$. Substituting this value in the objective function and differentiating pointwise gives the following first order condition which characterizes the optimal output Q^p:

$$P(Q) + \frac{\lambda}{1+\lambda}P'(Q)Q = \beta + \frac{\lambda}{1+\lambda}\frac{G(\beta)}{g(\beta)}. \tag{13}$$

Assumptions **A1** to **A3** guarantees that the second order condition is satisfied. Moreover under assumption **A2** the output Q^p is non increasing in β so that condition (11) is satisfied. Comparing equation (5) with equation (13), one can check that the output level under asymmetric information is obtained by replacing the marginal cost β by the virtual cost $\beta + (\lambda/(1+\lambda))\, G(\beta)/g(\beta)$ that is obviously larger than β. Because the LHS of (13) decreases in Q, we deduce that the output level under asymmetric information is lower than under symmetric information. In order to reduce the firm's incentive to inflate its cost report, the government requires high cost firms to produce less than it would do under symmetric information. The distortion increases with λ. For high shadow costs of public funds, the output can hence be lower than the monopoly laissez-faire level. For instance when $\lambda \to \infty$, one gets that $\lambda/(1+\lambda) \to 1$ so that $Q^p(\beta) \to Q^m(\beta + G(\beta)/g(\beta)) < Q^m(\beta)$ $\forall \beta \in (\underline{\beta}, \overline{\beta}]$.

Substituting Q^p in $\mathcal{W}^{\mathrm{p}}$, at the optimum the government's objective is equal to

$$\rho \mathcal{W}^{\mathrm{p}} = -\,(1+\lambda)\,\rho K + E\left[W(Q^p, \beta) - \lambda \frac{G(\beta)}{g(\beta)} Q^p\right] \tag{14}$$

This expression shows the two negative effects of information asymmetry on the government's objective. First, it introduces, through the term $-\lambda\,(G(\beta)/g(\beta))\,Q^p$, a rent to the public firm's manager (or her organization), which reduces total welfare. Second, it forces the government to distort output downwards so that $Q^p(\beta) \leq Q^*(\beta)$.

We now discuss BOT concession contracts under two main settings. In Subsection 4.2 we focus on concessions where there is a large uncertainty about the profitability of the project at the time of concession contract signature. In Subsection 4.3 we study concessions where the private sector has a technical advantage over the public to produce a commodity or service.

4.2 Ex-Ante Information Symmetry

In this subsection, we assume that the government has the same information as the concession holder at the time when she signs the concession contract and makes her investment. Yet the concession holder and the public firm's manager acquire private information about the cost parameter β once the investment K is sunk. The public management has hence the same informational context of Section 4.1 so that optimal contracts and expected welfare are simply given by expressions (13) and (14).

By contrast, under BOT concessions, the government's objective is given by (3). Before the concession contract, the concession holder does not know her cost parameter and gets the expected profit (4). During the concession period, the concession holder obtains information about her cost parameter just after sinking her investment and sets her output that maximizes her contemporaneous operational profit $P(Q_1)Q_1 - \beta Q_1$. This yields the monopoly output $Q_1 = Q^m(\beta)$ given by expression (6). Solving the problem backward the government computes the optimal concession duration. Because it has no incentive to leave rents to the concession holder, the government chooses the concession duration L^{s} so as to allow the concession holder to break even ex-ante (i.e., $\Pi^{\mathrm{b}} = 0$):

$$L^{\mathrm{s}} = \frac{\rho K}{E\left[P(Q^m)Q^m - \beta Q^m\right]}, \tag{15}$$

where the superscript s refers to the situation of ex-ante information symmetry. The concession period is longer for larger investment cost and smaller *expected* operational profits, which is fairly intuitive.

We can now study the conditions under which a BOT concession is better than public management in the cases where the project characteristics are transferable to the public sector and where they are not.

4.2.1 Non Transferability

We begin with the benchmark case where cost characteristics are specific to the concession holder and cannot be transferred to the public authorities at the end of the concession period. In this case we show that the government's choice for a BOT concession depends on the shadow cost of public funds. This benchmark case will be used as a basis of comparison in the next subsections.

In this benchmark case, the government does not know the value of β at the end of the concession period. When it takes over the facility, the government therefore faces the same information asymmetry as in the case of public management discussed in Subsection 4.1. More formally, the government sets the output level Q_2 that maximizes the after-concession objective function $(1 - L^{\mathrm{s}})\, E\left[W(Q_2, \beta) - \lambda U\right]$ subject to the same incentive and participation constraints as in expressions (10) to (12). Because L^{s} is independent of Q_2, the output level Q_2 is the same solution as in the program (9). That is, $Q_2 = Q^p(\beta)$ as defined in equation (13). The expected value of government's objective under BOT is given by:

$$\rho\mathcal{W}^{\mathrm{b}} = -\rho K + L^{\mathrm{s}}\ E\left[S(Q^m) - \beta Q^m\right] + (1 - L^{\mathrm{s}})\, E\left[W(Q^p, \beta) - \lambda\frac{G(\beta)}{g(\beta)}Q^p\right]. \tag{16}$$

We can thus compare public management and BOT concession contract. The government prefers public management over the BOT concession if and only if $\mathcal{W}^{\mathrm{p}} > \mathcal{W}^{\mathrm{b}}$. Plugging equations (14) and (16) this inequality is equivalent to

$$\mathcal{W}^{\mathrm{p}} - \mathcal{W}^{\mathrm{b}} = -\lambda K + \frac{L^{\mathrm{s}}}{\rho}\left\{E[W(Q^p, \beta) - \lambda\frac{G(\beta)}{g(\beta)}Q^p] - E\left[S(Q^m) - \beta Q^m\right]\right\} > 0. \tag{17}$$

The government trades off the social cost of financing the investment (i.e. the first negative term) with the social benefit of avoiding *laissez-faire* during the concession period (i.e. the second term in curly bracket). Substituting the optimal concession period L^{s} defined in (15), condition (17) then simplifies to

$$E\Big[W(Q^p, \beta) - \lambda\frac{G(\beta)}{g(\beta)}Q^p\Big] > E\left[W(Q^m, \beta)\right]. \tag{18}$$

The government prefers public management to a BOT concession contract for small enough shadow costs of public funds. Indeed, for $\lambda \to 0$, the output level Q^p is equal to the one obtained under symmetric information, $Q^p = Q^*$, which is always larger than the level under laissez-faire. Hence, condition (18) becomes $E\left[W(Q^*, \beta)\right] > E\left[W(Q^m, \beta)\right]$ which is true since $W(Q^*, \beta) > W(Q^m, \beta)$ for any $\beta \in [\underline{\beta}, \overline{\beta}]$. This is a reminiscence of Proposition 1. When subsidies to publicly managed projects involve no social costs, the government is willing to take the control and cash-flow rights at the expense of the information rents because the latter imply only redistributive effects. The following proposition shows that this conclusion is reversed for sufficiently high shadow costs of public funds.

Proposition 2 *Suppose that BOT concession contracts are signed under symmetric information and that the cost characteristics are not transferable at the end of the concession period. Then, there exists a unique $\lambda^{snt} > 0$ such that a BOT concession yields a higher welfare than public management if and only if $\lambda \geq \lambda^{snt}$.*

Proof. See Appendix A. ■

In this proposition the superscript ^{snt} refers to the present configuration with ex-ante information symmetry and non transferability of project characteristics. The above proposition is illustrated by Figure 1. It displays the value of the government's objective with respect to the shadow cost of public funds under public management and BOT concession contracts. In this figure the value of government objective increases under both settings. Indeed, as λ rises, the government put more weight on the investment cost as well as on the subsidies to the publicly managed firm. On the one hand, under the BOT concession, the investment cost is transferred to the concession holder and is not associated with the government's cost of raising public funds. On the other hand, under public management, managers tend to inflate their cost so that the government responds by lowering output levels. These effects are stronger when λ increases, explaining the result of Proposition 2.

INSERT FIGURE 1 HERE

It is finally important to note that the present analysis based on a non transferable cost β extends to the case where this parameter randomly fluctuates during the project life. This will for example be the case when β represents a fluctuating maintenance cost. More precisely, when β is repeatedly drawn from the same time-independent distribution $G(\cdot)$ over the support $[\underline{\beta}, \bar{\beta}]$, the government is unable to infer any relevant information from past outcomes and is constrained to offer the same contract to the public firm in any point of time. As shown by Baron and Besanko (1982), incentive contracts have the same structure when the parameter associated with asymmetric information is repeatedly and independently drawn or when it is drawn once at the beginning of a time period from a same probability distribution. Since a stochastic cost parameter β cannot be transferred from the concession holder to the public manager, it is therefore compatible only with the case where such costs are not transferable, as in this subsection and in the next Subsections 4.3 and 4.4.

4.2.2 Transferability

We turn now to the case where the cost characteristics are transferred to the public authorities at the end of the concession period. This setting fits particularly well the analysis of concession contracts where uncertainty lies on demand. Indeed many concession projects involve the same demand uncertainty for both governments and concession holders. Demand conditions are revealed after the construction and exploitation of the facility and are readily transferred to the public authorities at the end of the concession period. However, for the sake of consistency, we keep our discussion with cost uncertainty. In the case of transferability the cost parameter β is related to the physical investment, or the intrinsic nature of the project, rather than to the specific management by the concession holder.

At the end of the concession period the government inherits from the information on the project characteristics of the concession. The government is no longer harmed by information asymmetries and uncertainties. Knowing the true β, it can set the optimal output $Q_2 = Q^*(\beta)$ (instead of $Q_2 = Q^p(\beta)$ previously). A substantial benefit of the BOT concession is hence to able the government to exploit the information revealed during the concession time without the fear of the ratchet effect. This is an important additional benefit of the BOT concession. So, the expected value of government's objective under the BOT concession is now given by

$$\rho \mathcal{W}^{\mathrm{b}} = -\rho K + L^{sym}\ E\left[S(Q^m) - \beta Q^m\right] + (1 - L^{sym})\, E\left[W(Q^*, \beta)\right]$$

and must be compared to the corresponding value under public management (14). The government prefers public management over the BOT concession if and only if $\mathcal{W}^{\mathrm{p}} > \mathcal{W}^{\mathrm{b}}$. After some algebraic manipulation, this is equivalent to

$$\begin{aligned} E\Big[W(Q^p, \beta) - \lambda \frac{G(\beta)}{g(\beta)} Q^p\Big] &> E\left[W(Q^m, \beta)\right] \\ &\quad + \frac{1 - L^{sym}}{L^{sym}} \left\{ E\big[W(Q^*, \beta)\big] - E\Big[W(Q^p, \beta) - \lambda \frac{G(\beta)}{g(\beta)} Q^p\Big] \right\} \end{aligned} \tag{19}$$

The impact of cost transferability on the choice of a BOT concession is readily understood by comparing the latter inequality with the benchmark inequality (18). Indeed, because $W(Q^*, \beta) > W(Q^p, \beta) - \lambda \frac{G(\beta)}{g(\beta)} Q^p$, a BOT concession is always more valuable for the government with cost transferability than without it. The government can indeed avoid the information cost of the publicly managed firm at the end of the concession period. The value of this option increases as the concession duration L^{sym} gets smaller and as the welfare discrepancy between the first-best and second best in public management rises (i.e., the curly bracket in inequality (18) rises). BOT concessions are also likely to be preferred when cost uncertainty and therefore information costs become larger. More risky projects are then more likely to be given BOT concession contracts.

Proposition 3 *Suppose that BOT concession contracts are signed under symmetric information and that cost characteristics are transferred at the end of the concession period. Then, there exists $\lambda^{st} > 0$ such that a BOT concession yields a higher welfare than public management if and only if $\lambda > \lambda^{st}$. Moreover $0 < \lambda^{st} < \lambda^{snt}$.*

Proof. See Appendix B. ■

In this proposition the superscript $^{\mathrm{st}}$ refers to the present configuration with ex-ante information symmetry and transferability of project characteristics. In contrast to the previous configuration, the transferability of cost characteristics makes the choice for a BOT concession dependent on investment costs K. In particular, BOT concessions are more often preferred for smaller investment costs. Indeed, smaller investment costs shorten the concession durations L^{st} and increases the RHS of condition (19), making BOT concession more likely. This occurs because the government benefits from the transfer of cost characteristics and information at the end of the concession. *Ceteris paribus*, smaller investments result in shorter concessions, faster information revelation and shorter periods of allocation inefficiencies.

4.3 Ex-ante Information Asymmetry

In this subsection we assume that concession holders have private information about their marginal costs at the time they sign their concession contracts. For the sake of comparison and conciseness, we concentrate on the case where cost characteristics are not transferable at the end of the concession period. This realistically corresponds to the situation where the government has no specialized knowledge about the provision of the service or infrastructure and faces concession candidates who are specialized in that business (e.g., multinational firms specialized in waste management or water sanitization). In this configuration, each concession candidate acquires her private information before sinking her investment so that information asymmetry exists at any time including the contract signature date $t = 0$. In contrast to the previous setting in 4.2, the government can reduce its initial informational disadvantage if there exists more than one concession candidate. In this case, concession candidates are likely to differ in their cost possibilities or assessments. The government can take advantage of the heterogeneity of candidates by organizing an auction. We assume here that the object of the auction is the concession period.[14]

The set-up of public management is the same as in the previous subsection. The BOT concession is also quite similar. Indeed, during the BOT concession period, the concession holder is perfectly informed about her cost parameter. She runs her firm under laissez-faire and thus sets the monopoly output $Q_1 = Q^m(\beta)$. At the end of the concession period, the cost information is not transferred to the government so that the latter has the same informational problem as under public management. The optimal output is equal to $Q_2 = Q^p(\beta)$. The main difference between this set-up and the previous one lies in the way the BOT contract is attributed. Here the concession holder is the winner of an auction that alters the concession period and the cost probability distribution.

By virtue of the revenue equivalence theorem, we focus without any loss of generality on a second bid auction over the BOT concession period with $N \geq 1$ bidders. Each bidder $i \in \{1, ..., N\}$ has a cost parameter β_i independently drawn from the distribution G. The bidder with the shortest concession termination time t_i wins the concession and is allowed to operate during the second shortest term $t_j = \min_{k \neq i} t_k$. Because second bid auctions induce truthful revelation, each bidder β_i bids according to her own true cost parameter β_i. The bid of concession candidate i is therefore the shortest possible concession period

[14] Note that an auction over a franchise fee does not yield the same results. In this case, the government must set the concession termination time and faces no uncertainty about the duration of allocative inefficiencies (see subsection 4.4).

for a monopoly with cost β_i. It is given by the following concession duration:

$$L_i = \frac{\rho K}{P(Q_i^m)Q_i^m - \beta_i Q_i^m} \tag{20}$$

where $Q_i^m \equiv Q^m(\beta_i)$ is the monopoly output of a concession holder with cost β_i.

For the sake of conciseness, we rank the concession candidates according to their cost parameters so that $\beta_1 \leq \beta_2 \leq ... \leq \beta_N$. So, the winner of the auction is the concession candidate $i = 1$ who is granted a concession of duration L_2. This concession holder will set the monopoly output $Q_1^m = Q^m(\beta_1)$. Under BOT, the value of the government's objective then becomes equal to

$$\rho \mathcal{W}^{\mathrm{b}} = -\rho K + E_{12}\left[L_2\left(S(Q_1^m) - \beta_1 Q_1^m\right)\right] + E_2\left[1 - L_2\right] E\left[W(Q^p, \beta) - \lambda \frac{G(\beta)}{g(\beta)} Q^p\right]$$

where $E_2[\cdot]$ denotes the expectation that the second highest bidder has a cost β_2 and where $E_{12}[\cdot]$ denotes the expectation that the first and second highest bidders respectively have the costs β_1 and β_2 (see a full definition of those expectation operators in the Appendix). The government's objective includes the cost of the facility, the expected net present value of welfare during the concession and the expected net present value of public management after the concession termination time. Using (14) we can compare public management to BOT concessions. Public management is strictly preferred to BOT if and only if

$$-\lambda K \rho - E_{12}\left[L_2\left(S(Q_1^m) - \beta_1 Q_1^m\right)\right] + E_2\left[L_2\right] E\left[W(Q^p, \beta) - \lambda \frac{G(\beta)}{g(\beta)} Q^p\right] > 0.$$

Contrary to the previous cases it is not straightforward to compare the two regimes. We introduce new notations to ease the computations. Let $\Delta \mathcal{W}_0$ denote the expected welfare difference between public management and BOT concession when $\lambda = 0$. Using $Q_0^* \equiv \lim_{\lambda \to 0} Q^*$, one can write

$$\Delta \mathcal{W}_0 \equiv E_2\left[L_2\right] E\left[S(Q_0^*) - \beta Q_0^*\right] - E_{12}\left[L_2\left(S(Q_{\beta_1}^m) - \beta_1 Q_{\beta_1}^m\right)\right]$$

Let

$$v(\beta) = \beta + \frac{G(\beta)}{g(\beta)} \tag{21}$$

be the virtual cost of production of the publicly managed firm under asymmetric information when $\lambda \to +\infty$, and let

$$\pi^m(\beta) = [P(Q^m(\beta)) - \beta]\, Q^m(\beta) \tag{22}$$

be the concession holder's operational profit during the concession period. In order to get the next result it is sufficient to add the following assumption.

C1 $\qquad E\left[\pi^m\left(v(\beta)\right)\right] E_2\left[1/\pi^m\left(\beta_2\right)\right] < 1.$

A sufficient condition for C1 to hold is $E\left[v(\beta)\right] \geq \overline{\beta}$. This condition is for instance satisfied by uniform cost distributions.

Proposition 4 *Suppose that BOT concession contracts are signed under asymmetric information and that cost characteristics are not transferable at the end of the concession period. Suppose further that BOT contracts are awarded through an auction on concession period. Then, under condition C1, there exists a unique* $\lambda^{ant} > 0$ *so that BOT concessions yields a higher welfare than public management if and only if* $\Delta\mathcal{W}_0 \leq 0$ *or* $\lambda \geq \lambda^{ant}$.

Proof. See Appendix C ■

In this proposition the superscript $^{\text{snt}}$ refers to the present configuration with ex-ante information symmetry and non transferability of project characteristics. The condition $\Delta\mathcal{W}_0 > 0$ determines that the government prefers public management for small shadow costs of public funds and BOT concession contracts otherwise. Note that the condition depends on cost uncertainty. Indeed, if $\beta = \overline{\beta} = \underline{\beta}$ so that there is no risk then we have that $\Delta\mathcal{W}_0 = [S(Q_0^*) - \beta Q_0^*] - [S(Q^m) - \beta Q^m] > 0$. By continuity, the condition is satisfied for small enough cost uncertainty. Therefore, if both the ex-ante information asymmetry and shadow cost of public funds are small enough, the government prefers public management. More generally, a sufficient condition for $\Delta\mathcal{W}_0 > 0$ is given by $\left[S(Q_0^*(\overline{\beta})) - \overline{\beta} Q_0^*(\overline{\beta})\right] - \left[S(Q^m(\underline{\beta})) - \underline{\beta}\; Q^m(\underline{\beta})\right] > 0$. This condition implies that the net surplus generated by a public firm under the worst cost realization is larger than the net surplus generated by a concession holder under the best cost realization. It is equivalent to the condition that the lowest laissez-faire price $P(Q^m(\underline{\beta}))$ be larger than the highest marginal cost $\overline{\beta}$. By assumption A1, this is true under linear demands and uniform cost distributions.

By contrast, for negative $\Delta\mathcal{W}_0$ or large λ, it is always optimal to organize an auction for the attribution of the BOT concession. However, if the shadow cost of public funds is high and if the project profitability is low, although optimal, a BOT auction can fail to attract concession candidate because of a lack of interest from the private sector. This is a major problem in developing countries where the shadow cost of public funds is large and project profitability is generally limited.

To see what happens when the number of bidders varies, we now compare the choice for a BOT concession when the concession holder does and does not have more information before signing her concession contract. To sterilize the potential effects of characteristics transferability, we maintain throughout the assumption that cost characteristics cannot be transferred. Therefore, we compare the benchmark λ^{snt} defined in Proposition 2 to λ^{ant} defined in Proposition 4.

Proposition 5 *For $N = 1$, $\lambda^{snt} < \lambda^{ant}$ whereas $\lambda^{snt} > \lambda^{ant}$ for sufficiently large N.*

Proof. See Appendix D. ■

If the number of bidders is large enough, the government is able to extract a significant share of the concession holder's rent through the auction. This makes BOT concessions very attractive when concession holders are ex-ante informed on the production costs. However if the auction attracts few bidders, the winner gets a long concession period and collects a high rent. The government would then be better off with uninformed concession holders (i.e., with ex-ante symmetric information). As a result, if the government anticipates a large number of bidders, it should auction the BOT concession. By contrast if it anticipates few bidders, it should invest in studies to decrease its knowledge gap about project costs. Such preliminary studies would help level the playing field for concession contract negotiations.

4.4 Bidding on Concession Revenue

To avoid costly renegotiations, Engel *et al.* (2001) suggest to adopt an auction mechanism, where the BOT concession is granted to the candidate who bids the least present value of the concession revenues. With this type of allocation mechanism, the concession ends only when the concession holder has realized the revenue it has bid for: the franchise term endogenously adjusts to possible shock realizations. However, to be implemented such a mechanism requires that the concession holder's revenue be observable and non manipulable. This assumption may be far-fetched in some infrastructure projects, but be realistic for others. In this section we thus aim to compare the least-present-value-of-revenue auction with the foregoing concession contracts.

Note at the outset that both the auctions on concession period or revenue yield the same outcome when concession holders have private and certain information before submitting their bids and when the government is able to organize a competitive auction. Because of the competitive pressure, the government is indeed able to select the most efficient concession candidate and to reduce her rent to zero. The two auctions select the same candidate so that the bidden revenue exactly corresponds to the firm's proceeds for the bidden concession period. By contrast, the auctions yield different outcomes when the government and concession holder have no information on future cost realization at the time of the contract signature. The commercial risk faced by the concession holder is higher with the auction on concession period than with the one on revenue. In this section, we explore the revenue auction and compare it to the BOT concession contract discussed in Subsection 4.2.1. So, in both situations, cost information is symmetric ex-ante and cost characteristics are not transferable. For the sake of consistency, we assume that the private entrepreneur is free to set the monopoly price.

Revenue auction requires the concession candidates to bid the net present value of revenues that they will be allowed to earn from the facility. In practice, the concession candidates report their revenue flows and the government chooses the candidate reporting the smallest discounted value of those flows using a specific interest rate.[15] For the sake

[15] Public transparency would call for a non-discounted sum of revenues. In the present model, revenues

of simplicity, let this interest rate be equal to the government's and concession holder's opportunity cost of time ρ. Let then R be the net present value of revenue that is reported in the winning bid. During the concession period, the concession holder sets her monopoly output $Q^m(\beta)$ that depends on her cost realization β but remains constant through time. The revenue bid R determines the concession termination time $t_1(\beta, R)$ such that, ex-post, $R = \int_0^{t_1} P(Q^m(\beta))Q^m(\beta)e^{-\rho t}dt$. The concession termination time $t_1(\beta, R)$, which solves this equality, increases with larger R and higher β. Let the (cost contingent) concession duration be $L_1(\beta, R)/\rho = \int_0^{t_1(\beta,R)} e^{-\rho t}d\beta = R/[P(Q^m(\beta))Q^m(\beta)]$. In a competitive auction, the concession holder bids R so that its expected profit is nil. That is, the bid R should be equal to the expected revenue $(1/\rho)E\left[L_1(\beta, R)P(Q^m(\beta))Q^m(\beta)\right]$ and at the same time to the expected cost $K + (1/\rho)E\left[L_1(\beta, R)\beta Q^m(\beta)\right]$. The latter relationship implies that $R = K + RE\left\{\beta/P[Q^m(\beta)]\right\}$, which gives $R = K/\left[1 - E\left\{\beta/P[Q^m(\beta)]\right\}\right]$.

The welfare under BOT concession is then given by

$$\begin{aligned}\rho\mathcal{W}^{\mathrm{b}} &= -\rho K + E\left\{L_1(\beta, R)\left[S(Q^m(\beta)) - \beta Q^m(\beta)\right]\right\} \\ &\quad + E\left\{(1 - L_1(\beta, R))\left[W(Q^p, \beta) - \lambda\frac{G(\beta)}{g(\beta)}Q^p\right]\right\}\end{aligned}$$

which must be compared to the welfare under public management (14). Public management is preferred iff $\rho\mathcal{W}^{\mathrm{p}} > \rho\mathcal{W}^{\mathrm{b}}$, or equivalently, iff

$$E\left\{L_1(\beta, R)\left[W(Q^p, \beta) - \lambda\frac{G(\beta)}{g(\beta)}Q^p - W(Q^m, \beta)\right]\right\} > 0. \tag{23}$$

It can be shown that the square bracket in this expression is positive for $\lambda \to 0$ and negative for $\lambda \to \infty$.

Proposition 6 *Suppose that government and concession holder have the same information before the concession contract and that cost characteristics are not transferable at the end of the concession period. If the concession is granted on the basis of the least present value of revenue, then, there exists a unique $\lambda^{rev} > 0$ such that a BOT concession yields a higher welfare than public management if and only if $\lambda \geq \lambda^{rev}$.*

are constant. So, there is a one-to-one mapping between the discounted and the non-discounted sum of revenues.

Proof. See Appendix E. ■

Intuitively, when shadow costs of public funds are small or nil, the information rents yields only a wealth redistribution between taxpayers and public managers: those rents have no social cost. The government is then better off by allocating itself the firms' production rather than by letting a concession holder restrain its output to the monopoly level during the concession period. By contrast, when the shadow costs of public funds are sufficiently large, the government wants to tap the maximal profit from the public firm. Under full information, it would actually set the same monopoly price and output as would the concession holder. Under asymmetric information the government must give incentives to the public manager by distorting price and output levels. These information rents and the associated distortions limit the government's ability to tap profit from the project. As a result, the government has higher incentives to grant the project to the concession holder in compensation for the latter's investment.

Note that the choice for the BOT concession with a revenue auction does not depend on the investment cost and that it is thus more likely to be chosen than the concession with fixed termination time that we discussed in Section 4.2. Indeed, on the one hand, the state of condition (23) is independent of K because the concession duration L_1 is multiplicative of K. On the other hand, condition (23) is more stringent than condition (18). This is because the welfare difference $W(Q^p,\beta) - \lambda\,[G(\beta)/g(\beta)]\,Q^p - W(Q^m,\beta)$ decreases with both larger β and λ and because L_1 increase with β. As a result, the threshold λ^{rev} is smaller than λ^{snt}. The main difference between the auctions based on a fixed concession period and on least present value of revenue lies in the risk borne by the concession holder. Although in both types of concession, firms bear the risk of cost variability (they break even only in expectation), the least-present-value-of-revenue auction gives concession holders more flexibility about the end of the concession because of the guarantee of a fixed amount of revenues. The drawback of such a concession contract is that governments still need to monitor of firms' revenues to enforce their contracts, and that the contract does not eliminate the risk of renegotiation as the concession holder still bear a risk (i.e., they don't know their cost when they bid on the revenue target).

4.5 Linear demands and uniform cost distributions

Proposition 2, 3, and 4 state that BOT concessions are preferred to public management when the shadow cost of public funds is larger than the thresholds $\lambda^{\text{snt}}, \lambda^{\text{ant}}$ or λ^{st}. The practical relevance of this result depends on the value of these theoretical thresholds. If the latter are larger than the empirical values for shadow costs of public funds, BOT concessions will never be optimal. To assess the magnitude of those thresholds we focus on the classes of linear demand functions and the uniform distribution of cost β.[16] Appropriate normalization of output and price units allow us to focus on the inverse demand function $P(Q) = 1 - Q$ and on the interval $[0, \overline{\beta}]$ where we can set $\underline{\beta} = 0$ without loss of generality. This implies that the consumer surplus is equal to $S(Q) = Q(1 - Q/2)$, the cost probability distribution to $G(\beta) = \beta/\overline{\beta}$, and the hazard rate to $G(\beta)/g(\beta) = \beta$. Assumption **A1** simplifies to $\overline{\beta} \leq 1/2$ while assumptions **A2** and **A3** always hold under linear demands. Under this setting, one can explicitly compute the theoretical values of shadow costs of public funds above which BOT concessions are preferred (see Appendix F).

Table 1 presents the theoretical values for the thresholds when the highest cost parameter $\overline{\beta}$ varies in an interval between 0.05 and 0.5. A larger $\overline{\beta}$ implies a higher ex-ante uncertainty as well as stronger ex-ante and ex-post information asymmetry. To fix ideas, one computes that the ex-post output of a monopoly concession fluctuates with a standard deviation that increases from 1.4% to 19.2% of the expected output when $\overline{\beta}$ rises from 0.05 to 0.5. Such a cost uncertainty also implies fluctuations in operational profits whose standard deviations increase from 2.9% to 28.2% of the expected operational profit.[17] Table 1 also displays theoretical values of shadow costs of public funds for three levels of investment cost: $\rho K = 0.05$, 0.10 and $0, 15$. To fix ideas again, let us suppose an annual interest rate of 10% and that the opportunity cost of time is simply equal to a

[16] The reliability of this approach relies on whether demand and cost distribution can reasonably be approximated by linear functions, which is an empirical issue. Results nevertheless remains robust for alternative classes of demand and cost distribution functions (see Auriol and Picard 2009 and 2010).

[17] One readily computes that, for $\beta \in [0.05, 0, 5]$, $\sqrt{\text{var}[Q^m(\beta)]}/E[Q^m(\beta)] \in [0.014, 0.192]$ and $\sqrt{\text{var}[P(Q^m)Q^m - \beta Q^m]}/E[P(Q^m)Q^m - \beta Q^m] \in [0.029, 0, 282]$.

compound opportunity cost of capital of $\rho = \ln(1+10\%)^{-1} \simeq 0.095$. Applying (15), this implies that, as $\overline{\beta}$ rises from 0.05 to 0.5, the concession term increases from about 3 to 6 years if $\rho K = 0.05$ and from 5 to 13 years if $\rho K = 0.10$. If $\rho K = 0.15$, it increases from 11 to 38 years as $\overline{\beta}$ rises from 0.05 to 0.45 whereas, for $\overline{\beta} = 0.5$, the cost uncertainty is too large for the concession holder to make any non negative net present return from her investment K.

	λ^{snt}	λ_1^{ant}	$\lambda_\infty^{\mathrm{ant}}$	λ^{st}			λ^{rev}
ρK	-	-	-	0.05	0.10	0.15	
$\overline{\beta} = 0.05$	1.79	∞	0.87	0.63	1.03	1.33	1.78
0.1	1.15	∞	0.42	0.39	0.65	0.87	1.15
0.15	0.87	∞	0.22	0.29	0.50	0.68	0.87
0.2	0.71	∞	0.11	0.24	0.42	0.57	0.71
0.25	0.6	∞	0.03	0.20	0.36	0.50	0.60
0.3	0.52	∞	0	0.18	0.32	0.45	0.51
0.35	0.46	∞	0	0.16	0.30	0.41	0.45
0.4	0.41	∞	0	0.15	0.28	0.39	0.40
0.45	0.38	∞	0	0.14	0.26	0.37	0.36
0.5	0.35	∞	0	0.14	0.25	—	0.33

Table 1: Shadow costs of public funds above which BOT concessions are optimal.

Empirical estimates of shadow costs of public funds take values around 0.3 in O.E.C.D. countries and values larger than 0.9 in developing countries (see Snower and Warren, 1996; and World Bank, 1998). Comparing both theoretical and empirical values, we can firstly conclude that the theoretical thresholds λ^{snt}, $\lambda_\infty^{\mathrm{ant}}$ and λ^{st} are likely to lie below the range of the shadow costs prevailing in developing economies and about the values prevailing in developed economies. This means that BOT concession contracts are beneficial to governments in many situations.

Table 1 illustrates our earlier results. BOT concessions are preferred if project characteristics can be transferred at the end of the concession period ($\lambda^{\mathrm{st}} < \lambda^{\mathrm{snt}}$) and if governments lack ex-ante information but is able to organize fairly competitive auctions ($\lambda_{\infty}^{\text{ant}} < \lambda^{\text{snt}}$). BOT concessions are never preferred if the auction is not competitive and includes only one bidder ($\lambda_1^{\text{ant}} = \infty$). This is because the unique bidder has an incentive to bid the longest possible concession period as she were the least efficient concession candidate. A public manager with an uncertain cost parameter yields a higher welfare. By contrast, when concession candidates have no ex-ante information, they offer shorter concession periods because they all bid the concession period at which they can *expect* to break even.

By quantifying our previous results Table 1 also provides new insights on the trade-off at hand. First, under ex-ante asymmetric information and competitive auctions, the theoretical shadow cost of public funds falls to zero for high cost uncertainty ($\lambda_{\infty}^{\text{ant}} = 0$ for large enough intervals $[0, \overline{\beta}]$) so that BOT concessions are always optimal. The government indeed benefits from a strong sampling effect in the concession auctions because it can select the best concession holders amongst an infinite set of candidates whereas it is not able to do so under public management. Second, under ex-ante symmetric information and cost transferability, BOT concessions are more often preferred when the share of investment costs falls (λ^{st} increases with K). This is because less costly projects imply shorter concession periods and faster transfers of cost characteristics and information. The social cost of too high prices during a short concession period is much smaller than the social cost of the permanent rents accrued to the publicly managed firm. Third, although as predicted above, BOT concessions are more often preferred under revenue auctions ($\lambda^{\text{rev}} < \lambda^{\text{snt}}$),[18] the gain of revenue auctions is tiny and is very likely to vanish when the additional cost of monitoring the revenue flows in concessions is taken into account. The flexibility in concession periods to guarantee of a fixed amount of revenues does not significantly influence the decision to implement a BOT concession. Finally, more risky projects are more likely to be granted a BOT concession. Indeed, all theoretical values fall with larger cost uncertainty (larger intervals $[0, \overline{\beta}]$). This is because a larger cost uncertainty strengthens information asymmetries between governments and public firms'

[18] Those thresholds are equal only because of the 2-digit rounding.

managers. The latter then have a larger scope to inflate their cost reports and capture information rents.

5 Extensions

So far we have considered BOT concessions that were totally unregulated and that all parties shared the same opportunity cost of time. In practice many BOT concessions are subject to some price control. For example, many governments constrain toll road concessions with price caps. In the water treatment projects implemented in developing countries, most concession holders own the private water treatment plants and deliver drinkable water at a fixed price per cubic meter, a price that is set by the government before the concession period.[19] In Subsection 5.1, we extend our previous discussion of BOT concessions to the existence of price caps or regulated prices.

Another concern is that, in practice, governments' and firms' opportunity costs of time significantly differ. The nature of the opportunity cost of time depends on two aspects. First, the opportunity cost of time may be associated with the opportunity cost of capital for which governments and firms face different restrictions. On the one hand, it is often argued that governments get better lending conditions than concession holders because they hold more diversified portfolios of projects, have recourse to taxation for interest payment and therefore face no bankruptcy risks. On the other hand, governments face numerous credit restrictions imposed by the supra-governmental institutions or the tax payers to which they are accountable. For instance, the Maastricht Treaty imposes limits on national debts and deficits of E.U. member states; the I.M.F. restricts the debt positions of many developing countries and even of some developed countries since the 2008 financial crisis; and similarly, national governments restrict the debt capacity of regional and municipal agencies. Second, the opportunity cost of time may also be associated with the time span of the public and private decision makers. In democracies, politicians

[19] The payment of water consumption to the concession holder is generally made by non-profit agencies that distribute the water and pass through the prices to the users. We thank A. Blanc for this comment.

have short and uncertain tenures and therefore tend to highly discount the future costs and benefits of public projects. Similarly, firms' managers and their shareholders are also sometimes tagged for their short-term view. Hence, the ways in which politicians and private firms discount the future depend on the situation of each country and concession sector. Subsection 5.2 analyzes the impact of different opportunity costs of time on the choice of a concession.

5.1 Price Caps

In this subsection we study the effect of a price cap regulation on the choice for BOT concession contracts. Intuitively, price caps increase the consumer surplus during the concession period at the cost of a longer concession duration. It turns out that the rise in consumer surplus dominates if the price caps is appropriately chosen.

For the sake of conciseness, we focus on the set-up discussed in Subsection 4.2.1 where both the government and concession holder share the same information at the time they sign the concession contract and where cost characteristics are not transferable at the term of the concession. Price caps can be introduced in a similar way in the other set-ups studied in the paper. Suppose that, before the contract is signed, an independent regulation agency exogenously sets a price cap equal to $\overline{p}$. Note that too low price caps can lead to service breakdown when $\overline{p} < \beta$. In this case, the concession holder makes a contemporaneous loss and has incentives to shut her service down. As a result, the private concession holder and the government have incentives to renegotiate. For the sake of simplicity, we avoid such situations by assuming that $\overline{p} \geq \overline{\beta}$. The main issue is here that the concession holder may not be able to recoup her investment cost although she is never put in position to shut down.

The concession holder is constrained to set a price no higher than $\overline{p}$ for the whole concession period. If $\overline{p}$ is higher than the monopoly price $P\left(Q^m(\beta)\right)$, the concession holder is able to set the monopoly price and the output and surplus are given by $Q^m(\beta)$ and $S(Q^m(\beta))$. The contemporaneous profit and welfare during the concession are then equal to $\left(P\left(Q^m\right) - \beta\right) Q^m$ and $W\left(Q^m, \beta\right)$ as in the previous sections. A more interesting situation occur when the price cap $\overline{p}$ binds. Then, the demand reaches the level $\overline{Q}$ that solves $P(Q) = \overline{p}$ and the consumer surplus is given by $S(\overline{Q})$. The contemporaneous profit and welfare during the concession are equal to $\left(P\left(\overline{Q}\right) - \beta\right)\overline{Q}$ and $W\left(\overline{Q}, \beta\right)$. Let β^c be the threshold level so that the price cap just binds. This cost level solves the equality $\overline{p} = P\left(Q^m(\beta^c)\right)$. Concession holders with cost higher than this level are constrained by the price cap.

The concession duration, which makes the concession holder indifferent to invest ex-ante, is equal to

$$L^{\text{cap}} = \frac{\rho K}{E_{\beta>\beta^c}\left[(P\left(\overline{Q}\right) - \beta)\overline{Q}\right] + E_{\beta\leq\beta^c}\left[\left(P\left(Q^m\right) - \beta\right)Q^m\right]}$$

where the denominator expresses the concession holder's expected profit. The latter is equal to the sum of the expected profit for costs higher than β^c, $E_{\beta>\beta^c}\left[P\left(\overline{Q}\right) - \beta\overline{Q}\right]$ and the expected profit for costs lower than β^c, $E_{\beta\leq\beta^c}\left[\left(P\left(Q^m\right) - \beta\right)Q^m\right]$. The government prefers public management over the BOT concession with a price cap $\overline{p}$ if and only if $\mathcal{W}^{\text{p}} \geq \mathcal{W}^{\text{cap}}$. After some algebraic manipulations, this inequality is equivalent to

$$E\Big[W(Q^p, \beta) - \lambda\frac{G(\beta)}{g(\beta)}Q^p - W(Q^m, \beta)\Big] \geq E_{\beta>\beta^c}\left[W(\overline{Q}, \beta) - W(Q^m, \beta)\right] \tag{24}$$

The LHS has the same expression as in the condition (18) that applies with no price cap. It decreases with larger λ from a positive value at $\lambda = 0$, has a root at λ^{snt} and tends to $-\infty$ when $\lambda \to +\infty$ (see Appendix Proof of Proposition 2).

The main question here is whether the government prefers BOT concessions more often in the presence of a price cap or not. Comparing (24) with (18), it is readily observed that BOT concessions are preferred if and only if the RHS of condition (24) is positive. Because the latter is a decreasing function of λ, it is positive for any $\lambda \leq \lambda^{\text{cap}}$ where the threshold

$$\lambda^{\text{cap}} \equiv \frac{E_{\beta>\beta^c}\left[S(\overline{Q}) - \beta\overline{Q}\right] - E_{\beta>\beta^c}\left[S(Q^m) - \beta Q^m\right]}{E_{\beta>\beta^c}\left[P(Q^m)Q^m - \beta Q^m\right] - E_{\beta>\beta^c}\left[P(\overline{Q})\overline{Q} - \beta\overline{Q}\right]}$$

is the root of the above RHS. We can therefore infer that the implementation of a price cap favors the choice for a BOT concession if and only if $\lambda^{\text{snt}} \leq \lambda^{\text{cap}}$. This requires that the threshold λ^{cap} is positive and sufficiently large. The threshold λ^{cap} reflects the effects of the price cap on net surplus and concession period. On the one hand, the positive denominator expresses the concession holder' loss in expected operational profits and therefore the extension of the concession period caused by the price cap. On the other hand, the numerator represent the net surplus gain that the price cap permits during the concession period. This numerator is positive because the net surplus $S(Q) - \beta Q$ is an increasing function of Q for all $Q \in \left[Q^m(\beta), \overline{Q}\right]$; indeed, it has a derivative equal to $P(\overline{Q}) - \beta$ which is positive given that $\overline{p} = P(\overline{Q}) \geq \overline{\beta}$. Hence the implementation of a price cap favors the choice for a BOT concession when the expected net surplus under price cap is sufficiently larger than the expected net surplus under laissez-faire. Since the size of the net surplus gain depends on cost uncertainty, such a condition is likely to be satisfied when the range of costs is not too wide. By contrast, if this condition is not satisfied, the price cap, which cannot be adapted to each cost realization, may become a too rigid instrument and increases too much the concession period. Indeed, if the cost uncertainty becomes large, the expected net gain $E_{\beta>\beta^c}\left[S(\overline{Q}) - \beta\overline{Q}\right]$ diminishes, which makes public management more favorable for the government.

To sum up, the presence of an exogenous price cap does not alter previous results. It entices governments to prefer further BOT concessions when it is appropriately set and cost uncertainty is not too strong. We now turn to the discussion of opportunity costs of time for governments and concession holders.

5.2 Asymmetric Opportunity Costs of Time

So far we have assumed that governments and concession holders had the same opportunity cost of time ρ. We now analyze the impact of different opportunity costs of time on the choice of a concession. For the sake of conciseness, we extend the model discussed in Sections 3 and 4.2, which focuses on ex-ante symmetric information and non transferable cost. Other cases can easily be discussed in a similar way.

We assume that the governments' and concession holders' opportunity costs of time are given by ρ_G and ρ_F, respectively. Let the concession termination time be again t_1. As governments and concession holders discount time differently, they have different duration measures: $L_G(t_1)/\rho_G = \int_0^{t_1} e^{-\rho_G t}dt$ and $L_F(t_1)/\rho_F = \int_0^{t_1} e^{-\rho_F t}dt$. The government's objectives under public management and BOT concession are given by

$$\rho_G \mathcal{W}^{\mathrm{p}} = -(1+\lambda)\rho_G K + E\left[W(Q,\beta) - \lambda U\right]$$
$$\rho_G \mathcal{W}^{\mathrm{b}} = -\rho_G K + L_G\ E\left[S(Q_1) - \beta Q_1\right] + (1-L_G)\ E\left[W(Q_2,\beta) - \lambda U\right]$$

It is instructive to firstly discuss the case of symmetric information. In this case, the concession holder bids for the concession termination time t_1 that solves $L_F^*(t_1) = \rho_F K/[P(Q^m)Q^m - \beta Q^m]$. Under public management, the firm manager obtains no rent ($U = 0$) and implements the optimal output Q^*. The government prefers public management over the BOT concession if and only if $\mathcal{W}^{\mathrm{p}} \geq \mathcal{W}^{\mathrm{b}}$, or equivalently,

$$L_G^*(t_1)\ \ \{W(Q^*,\beta) - [S(Q^m) - \beta Q^m]\} \geq \rho_G K \lambda \tag{25}$$

This inequality reflects the same trade-off between government's cost and benefit of a public management as before. The main difference lies in the fact that the government does not discount time in the same way as concession holders: $L_G^*(t_1) \neq L_F^*(t_1)$. Let $T \equiv K/[P(Q^m)Q^m - \beta Q^m] > 0$ be the payback period, which measures the time to recover the investment cost in the absence of time discounting and which is therefore independent of opportunity costs of time. After some algebraic manipulations, the inequality (25) becomes

$$W(Q^*,\beta) - W(Q^m,\beta) \geq \lambda \frac{K}{T}\left[\Phi(\rho_G,\rho_F,T) - 1\right] \tag{26}$$

where

$$\Phi(\rho_G,\rho_F,T) \equiv \frac{L_F(t_1)/\rho_F}{L_G(t_1)/\rho_G} = \frac{\rho_G}{\rho_F}\frac{\rho_F T}{1-(1-\rho_F T)^{\rho_G/\rho_F}}$$

The second equality stems from the facts that the concession durations $L_F(t_1)$ is equal to $\rho_F T$ and that the concession durations $L_F(t_1) = \int_0^{t_1} e^{-\rho_F t}dt$ and $L_G(t_1) = \int_0^{t_1} e^{-\rho_G t}dt$ satisfy the equality $[1 - L_G(t_1)]^{\rho_G} = [1 - L_F(t_1)]^{\rho_F}$. The function Φ is independent from λ and is larger than 1 if and only if $\rho_G \geq \rho_F$. Moreover it increases with larger ρ_G and smaller ρ_F.

The inequality (26) allows us to determine the government's optimal choice under symmetric information. Note first that the RHS inequality (26) increases with larger λ if and only if $\Phi \geq 1$, or equivalently, $\rho_G \geq \rho_F$. Second, the LHS is positive at $\lambda = 0$ and decreases with larger λ because $(d/d\lambda)$LHS$= [P(Q^*)Q^* - \beta Q^*] - [P(Q^m)Q^m - \beta Q^m]$ is negative and tends to 0 since $Q^* > Q^m$ for all λ and $Q^* \to Q^m$ at $\lambda \to \infty$. As a result, if $\rho_G < \rho_F$ (i.e. $\Phi < 1$), the inequality (26) is satisfied for all λ so that BOT concessions are never preferred by governments. By contrast, if $\rho_G \geq \rho_F$.(i.e. $\Phi \geq 1$), the inequality (26) is fulfilled for small λ but cannot be satisfied for large enough λ. There then exists a unique threshold for the shadow cost of public funds, denoted $\lambda^{\mathrm{o}*}$, such that BOT concessions are preferred if and only if $\lambda \geq \lambda^{\mathrm{o}*}$. Because the function Φ increases with larger ρ_G and smaller ρ_F, the threshold $\lambda^{\mathrm{o}*}$ falls with larger ρ_G and smaller ρ_F.

This result contrasts with the discussion presented in Section 3 where governments and concession holders had symmetric opportunity costs of time. In this case, there was no scope for BOT concession contracts because the government could always replicate the concession holder's output decision and improve it. Here BOT concessions might become a better option for the government if the latter has a larger opportunity costs of time than the private sector. The incentives to grant BOT concessions are stronger for a more impatient or financially strapped government because the latter puts a higher weight on the short term cost of investment and a lower weight on the consumer's future losses. The government has therefore higher incentives to grant the project to a private concession holder at the cost of future price distortions.

This discussion extends to the case of information asymmetry between governments and concession holders. Indeed, under asymmetric information, a concession holder bids

$$L_F^{\mathrm{o}} = \frac{\rho_F K}{E\left[P(Q^m)Q^m - \beta Q^m\right]}.$$

The expected value of government's objective under BOT is given by

$$\rho_G \mathcal{W}^{\mathrm{b}} = -\rho_G K + L_G^{\mathrm{o}}\ E\left[S(Q^m) - \beta Q^m\right] + (1 - L_G^{\mathrm{o}})\, E\left[W(Q^p, \beta) - \lambda \frac{G(\beta)}{g(\beta)} Q^p\right].$$

Let $T^{\mathrm{o}} = K/E[P(Q^m)Q^m - \beta Q^m] > 0$ be the expected payback period under asymmetric information. After the same algebraic manipulations as above, the government prefers public management over the BOT concession if and only if

$$E\left[W(Q^p,\beta)-\lambda\frac{G(\beta)}{g(\beta)}Q^p-W(Q^m,\beta)\right]\geq\lambda\frac{K}{T^{\text{o}}}\left[\Phi\left(\rho_G,\rho_F,T^{\text{o}}\right)-1\right]. \tag{27}$$

We apply the same argument as in the case of symmetric information with the difference that the LHS can here become negative for large λ. We establish the following proposition:

Proposition 7 *Let ρ_G and ρ_F denote the opportunity cost of time of the government and the private concession holder respectively. Under asymmetric information, there exists a function $\rho_G^o(\rho_F)$ and a threshold λ^o such that BOT concessions are preferred to public management if and only if $\rho_G \geq \rho_G^o(\rho_F)$ and $\lambda \geq \lambda^o$. The threshold λ^o falls with larger ρ_G and smaller ρ_F while $\rho_G^o(\rho_F) < \rho_F$.*

Proof. See Appendix F. ■

Compared to the previous benchmark case, information asymmetry strengthens the incentives to choose a BOT concession. In particular, governments need not be more impatient than the concession holder to grant a BOT concessions. Indeed, when $\rho_G \in [\rho_G^o(\rho_F), \rho_F]$, BOT concession are the best options for governments under asymmetric information whereas they are not under symmetric information. It remains that more impatient governments have more incentives to opt for BOT concessions because they put a higher weight on the short term cost of investment than on the benefit of a larger consumer surplus during the concession period. Since governments that face high public deficits and tight budget constraints have simultaneously a large λ and a large ρ_G, we expect them to favor BOT concessions. This result may offer an explanation about why BOT concessions blossomed at the time of the industrial revolution. It also suggests that we should not be surprised to see a new wave of BOT concession contracts in countries that have recently faced a severe budgetary crisis.

6 Conclusion

In this paper, we discuss the choice between build-operate-and-transfer (BOT) concessions and public management when governments and firm managers do not share the same information regarding the operation characteristics of a facility. The analysis highlights the trade-off that exists between the public cost of financing the construction and operation of a facility and the loss of consumer surplus that the higher prices set by concession holders generate. We show that larger shadow costs of public funds, larger business risk and information asymmetries increase governments' incentives to choose BOT concessions. Such a result also applies in the case of concessions operating under regulated prices. Price caps increase governments' incentives to choose BOT concession contracts if they are set appropriately and if the cost uncertainty is not too large. We also show that the use of least-present-value-of-revenue auctions does not significantly alter government's choice for a BOT concession. Those theoretical results have some practical relevance. Using the class of linear demand functions and uniform cost distributions, we show that governments are likely to favor BOT concession contracts for relevant values of shadow costs of public funds in both advanced and developing countries.

We show that BOT concessions are more likely to outperform public management in projects where government and firms face the same uncertainty about their profitability at the time of the concession signature and where the project characteristics can be transferred at the end of the concession. The possibility to transfer project characteristics gives governments additional incentives to choose BOT concessions because the transfer of project characteristics reduces the informational asymmetry between the government and its public manager after the concession period. This result helps to explain why BOT concessions are so popular for transport infrastructures, where all parties find it difficult to predict traffic and costs, and where cost and demand characteristics are naturally transmitted to the public sector at the end of the concession. To give a grasp of the importance of such projects, we note that half of the 4,300 projects reported in the World Bank database on the Private Participation in Infrastructure (PPI) are concessions of the type discussed in this paper. Among those concessions the majority (i.e., 1040 projects) are transport infrastructure projects. [20] Similarly, in advanced economies, BOT

[20] The other concessions are in energy (699 projects), and in water and sewerage (552 projects). The PPI Project Database covers projects in 137 low-and middle-income countries, in the energy, telecommunications, transport, and water and sewerage sectors. We add the number of BOT concessions, with

concessions are primarily used to finance transport infrastructure. For instance in the United Kingdom, half of the 48.3 billion of pounds of BOT projects that had been signed between 1992 and 2006, were in transport (see Barrie 2006).[21]

Another situation where BOT concessions might outperform public management is when the government faces a large number of specialized corporations. To overcome its lack of expertise, the government may organize an auction to extract the concession holders' know-how and limit their informational rents. We show that the ex-ante information asymmetry between the government and concession candidates favors its choice for a BOT concession, provided that the auctions attract a sufficiently large numbers of participants. It is not enough that the private sector has efficient technology and low cost to make it the best option. In addition, it is necessary that competition for the concession reduces the cost of asymmetric information. The choice for a BOT concession contract over public management therefore depends on the number of bidders. This result helps to explain the French experience in the water sector that includes mostly concession contracts in large cities, and public management in rural areas. In large cities, several major firms compete to win the auction, while much fewer ones compete in low density area. Rural areas are hence publicly managed, which confirms our analysis. The lack of ex-ante competition undermines the benefit of outsourcing the service to the private sector.

Finally, our analysis shows that BOT concession contracts are more likely to be implemented when concession decisions are made by politicians who have higher opportunity costs of time than concession holders. When governments are more impatient they favor more often BOT concessions. Unexpectedly, the recent progress of democratic values in the world might thus have contributed to the success of BOT concessions in newly demo-

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the number of Build Rehabilitate Operate and Transfer, Rehabilitate Operate and Transfer, Rehabilitate Lease or Rent and Transfer concessions, since they all share the theoretical characteristics of the model.

[21] In rich countries BOT concessions have hence been used to finance highways and toll roads (e.g., in France, Italy, Spain, Portugal, the UK, and the US), tunnels (e.g., the Channel Tunnel Rail Link between England and France, the Port of Miami tunnel), airports (e.g., Abu Dhabi International Airport, Gatwick Airport), ports (e.g., in Adelaide, St Petersburg), bridges (e.g., the Golden Ears Bridge in Canada, the Baldwin County Bridge in Alabama, the Chicago Skyway Bridge), or railways (e.g., the automatic light metro line in Seoul, the high-speed train portion between Bordeaux and Tours in France).

cratic countries because their politicians may discount the future more heavily than their former entrenched dictators. Similarly, by emphasizing the trade-off that exists between allocative efficiency and the cost of public funds, we show that BOT concessions are particularly relevant in time of budgetary crisis, as faced today by many countries. These are periods where the opportunity cost of public funds rise sharply and unexpectedly, favoring BOT concession over public management. Further research is welcome on those new topics.

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Appendix A: Proof of Proposition 2

Proof. Let $\Omega^{\mathrm{b}}(\lambda) = E\left[W(Q^m,\beta)\right] = E\left[S(Q^m) + \lambda P(Q^m)Q^m - (1+\lambda)\,\beta Q^m\right]$ and let $\Omega^{\mathrm{p}}(\lambda) = E\left[W(Q^p,\beta) - \lambda\frac{G}{g}Q^p\right] = E\left[S(Q^p) + \lambda P(Q^p)Q^p - (1+\lambda)\,\beta Q^p - \lambda\frac{G}{g}Q^p\right]$. We know from the discussion in the main text that $\Omega^{\mathrm{b}}(0) < \Omega^{\mathrm{p}}(0)$. Simply differentiating $\Omega^{\mathrm{b}}(\lambda)$ we have $(d/d\lambda)\,\Omega^{\mathrm{b}}(\lambda) = E\left[P(Q^m)Q^m - \beta Q^m\right]$. Applying the envelop theorem (see (13)), we get $(d/d\lambda)\,\Omega^{\mathrm{p}}(\lambda) = E\left[P(Q^p)Q^p - \beta Q^p - \frac{G}{g}Q^p\right]$. Because Q^m maximizes the operational profit $P(Q)Q - \beta Q$, we have that $P(Q^m)Q^m - \beta Q^m \geq P(Q^p)Q^p - \beta Q^p$ for all β. Therefore, $(d/d\lambda)\left(\Omega^{\mathrm{b}}\right) > (d/d\lambda)\left(\Omega^{\mathrm{p}}\right) + c$ where c is a strictly positive constant larger than $\min_\lambda E\left[\frac{G}{g}Q^p\right] = E\left[\frac{G}{g}\lim_{\lambda\to\infty} Q^p\right] > 0$. As a result, $\Omega^{\mathrm{b}}(\lambda)$ begins below $\Omega^{\mathrm{p}}(0)$ and rises faster than $\Omega^{\mathrm{p}}(\lambda)$. So, it exists $\lambda^{\mathrm{snt}} > 0$ so that $\Omega^{\mathrm{b}}(\lambda) > \Omega^{\mathrm{p}}(\lambda)$ for $\lambda > \lambda^{\mathrm{snt}}$. ■

Appendix B: Proof of Proposition 3

Proof. Note firstly that by virtue of equation (13) when $\lambda \to \infty$, we have $Q^* \to Q^m$ and $W(Q^*,\beta) \to W(Q^m,\beta)$. So, the second term in the right hand side of (19) vanishes and Proposition 2 applies. As a result we can conclude that the BOT project is preferred for large enough λ. Note secondly that when $\lambda = 0$, $Q^p \to Q^*$ and inequality (19) reduces to $E[W(Q^*, \beta)] > E[W(Q^m, \beta)]$ which is always true. Therefore, it must be that $\lambda^{\mathrm{st}} > 0$. Note finally, that at $\lambda = \lambda^{\mathrm{snt}}$ we have $E\left[W(Q^p, \beta) - \lambda^{\mathrm{snt}} \frac{G}{g} Q^p\right] = E[W(Q^m, \beta)]$. So, inequality (19) can not be satisfied at λ^{snt}. Therefore, it must be that $\lambda^{\mathrm{st}} < \lambda^{\mathrm{snt}}$. Finally we prove that λ^{st} is unique. Let $\Omega^{\mathrm{b}}(\lambda) = E[W(Q^m, \beta)] + (1-L)\ \{E[W(Q^*, \beta)] - E[W(Q^m, \beta)]\} = (1-L)\, E[W(Q^*, \beta)] + LE[W(Q^m, \beta)]$. Let $\Omega^{\mathrm{p}}(\lambda) = E\left[W(Q^p, \beta) - \lambda \frac{G}{g} Q^p\right]$, which can be re-written as $\Omega^{\mathrm{p}}(\lambda) = (1-L)\, E[W(Q^p, \beta)$ $-\lambda \frac{G}{g} Q^p] + LE\left[W(Q^p, \beta) - \lambda \frac{G}{g} Q^p\right]$. We can break down the difference $\Omega^{\mathrm{p}} - \Omega^{\mathrm{b}}$ in two terms

$$\begin{aligned}\Omega^{\mathrm{p}}(\lambda) - \Omega^{\mathrm{b}}(\lambda) = (1-L)\left\{E\left[W(Q^p, \beta) - \lambda \frac{G}{g} Q^p\right] - E[W(Q^*, \beta)]\right\} \\ + L\left\{E\left[W(Q^p, \beta) - \lambda \frac{G}{g} Q^p\right] - E[W(Q^m, \beta)]\right\}\end{aligned}$$

where L does not depend on λ. From the proof of Proposition 1 we know that the second term is decreasing in λ. The first term is also decreasing in λ. Indeed, it is clearly smaller than zero and, using the envelop theorem, it has a slope that is proportional to

$$E\left[P(Q^p)Q^p - \beta Q^p - \frac{G}{g} Q^p\right] - E[P(Q^*)Q^* - \beta Q^*)]$$

This is negative for $\lambda = 0$ and $\lambda \to \infty$. To prove that this slope is always negative, let $v \equiv \beta + \frac{\lambda}{1+\lambda} \frac{G}{g} > \beta$. Then, we have $Q^p(\beta) = Q^*(v)$ and we can write the above slope as

$$\begin{aligned}\int_{\underline{\beta}}^{\overline{\beta}} [P(Q^*(v))Q^*(v) - vQ^*(v)]\, g(\beta)\, d\beta - \frac{1}{1+\lambda} \int_{\underline{\beta}}^{\overline{\beta}} \frac{G}{g} Q^p(\beta)\, g(\beta)\, d\beta \\ - \int_{\underline{\beta}}^{\overline{\beta}} [P(Q^*)Q^* - \beta Q^*)]\, g(\beta)\, d\beta\end{aligned}$$

where the first term is smaller than the last one. Hence this expression is negative. ■

Appendix C: Proof of Proposition 4

Proof. We rank the concession candidates according to their cost parameters; that is, $\beta_1 \leq \beta_2 \leq \ldots \leq \beta_N$. So, the winner of the auction is the concession holder $i = 1$ who is granted a concession of duration L_2. This concession holder will set the monopoly output $Q_1^m = Q^m(\beta_1)$. Let $g_1(\beta_1)$ be the probability density that the winner has a cost $\beta = \beta_1$; that is, Prob$[\beta_1 \leq \beta < \beta_1 + d\beta_1] = g_1(\beta_1)d\beta_1$. Because there are N possibilities that a bidder beats has all others, we have $g_1(\beta_1) \equiv Ng(\beta_1)\left[1 - G(\beta_1)\right]^{N-1}$. Let $g_2(\beta_2)$ be the probability that the second best bidder has a cost $\beta = \beta_2$; equivalently Prob$[\beta_2 \leq \beta < \beta_2 + d\beta_2] = g_2(\beta_2)d\beta_2$. Also, because there are $N(N-1)$ pairs of two bidders such that the second bidder looses against the first one and beats all the other $N-2$ bidders, we get $g_2(\beta_2) \equiv N(N-1)g(\beta_2)G(\beta_2)\left[1 - G(\beta_2)\right]^{N-2}$. When $N = 1$, we set $\beta_2 = \overline{\beta}$ and we use the cumulative distribution $G_2(\beta_2) = 0$ if $\beta_2 \in [0, \overline{\beta})$ and $G_2(\beta_2) = 0$ if $\beta_2 = \overline{\beta}$. Let $g_{12}(\beta_1, \beta_2)$ be the joint probability density that the winner has a cost β_1 and the second best bidder has a cost β_2 so that Prob$[\beta_1 \leq \beta < \beta_1 + d\beta_1$ and $\beta_2 \leq \beta < \beta_2 + d\beta_2] = g_{12}(\beta_1, \beta_2)\ d\beta_1 d\beta_2$. Let the respective expectation operators be denoted by $E_2\left[h\left(\beta_2\right)\right] \equiv \int_{\underline{\beta}}^{\bar{\beta}} h\left(\beta_2\right) g_2\left(\beta_2\right) d\beta_2$ and $E_{12}\left[h\left(\beta_1, \beta_2\right)\right] \equiv \int_{\underline{\beta}}^{\bar{\beta}} \int_{\underline{\beta}}^{\bar{\beta}} h\left(\beta_1, \beta_2\right) g_{12}\left(\beta_1, \beta_2\right) d\beta_1 d\beta_2$.

Let again $\Omega^{\mathrm{p}}(\lambda) = E\left[W(Q^p, \beta) - \lambda \frac{G}{g} Q^p\right]$. We prove that λ^{ant} exists and is unique by showing that

$$\Delta\mathcal{W}(\lambda) \equiv \rho\left(\mathcal{W}^{\mathrm{p}} - \mathcal{W}^{\mathrm{b}}\right) = -\lambda K\rho - E_{12}\left[L_2\left(S(Q_1^m) - \beta_1 Q_1^m\right)\right] + E_2\left[L_2\right]\Omega^{\mathrm{p}}(\lambda)$$

is strictly a decreasing function of in λ and that it admits at most one root.

First note that $E_{12}\left[L_2\left(S(Q_1^m) - \beta_1 Q_1^m\right)\right]$ is independent of λ because Q_1^m and L_2 are independent of it. The properties of $\Delta\mathcal{W}(\lambda)$ are determined by those of $\Omega^{\mathrm{p}}(\lambda)$. So, $(d/d\lambda)\,\Delta\mathcal{W}(\lambda) = -K\rho + E_2\left[L_2\right](d/d\lambda)\,\Omega^{\mathrm{p}}(\lambda)$ and $(d^2/d\lambda^2)\,\Delta\mathcal{W}(\lambda) = E_2\left[L_2\right](d^2/d\lambda^2)\,\Omega^{\mathrm{p}}(\lambda)$.

Second, note that $\Delta\mathcal{W}$ is convex in λ because $\Omega^{\mathrm{p}}(\lambda)$ is also convex in λ. We indeed get

$$(d/d\lambda)\,\Omega^{\mathrm{p}}(\lambda) = E\left[P(Q^p)Q^p - \beta Q^p - Q^p G(\beta)/g(\beta)\right]$$

and, applying the envelope theorem on equation (13), we further get that

$$\left(d^2/d\lambda^2\right)\Omega^{\mathrm{p}}(\lambda) = E\left\{-\left(dQ^p/d\lambda\right)\left[\left(G(\beta)/g(\beta)\right) - P'(Q^p)Q^p\right]\right\}/\left[(1+\lambda)\rho\right]$$

which is positive because $dQ^p/d\lambda < 0$ and $P'(Q) < 0$.

Third, we show that $\Omega^{\mathrm{p}}(\lambda)$ and therefore $\Delta\mathcal{W}(\lambda)$ are decreasing functions of λ for all $\lambda \geq 0$ if and only if

$$\textbf{C1:} \quad E\left[\pi^m(v)\right]\ E_2\left[\pi^m(\beta_2)^{-1}\right] < 1$$

Indeed, because $\Delta\mathcal{W}$ is convex, $(d/d\lambda)\,\Delta\mathcal{W}$ is a increasing function of λ. Hence, $(d/d\lambda)\,\Delta\mathcal{W}$ is negative for all $\lambda \geq 0$ if $\lim_{\lambda\to+\infty}(d/d\lambda)\,\Delta\mathcal{W} \leq 0$. We can compute that $\lim_{\lambda\to+\infty}(d/d\lambda)\,\Delta\mathcal{W}$ $= -K\rho + E_2[L_2]E\pi^m(v)$ where $\pi^m(\beta) \equiv Q^m(\beta)\Big[P(Q^m(\beta)) - \beta\Big]$ and $v \equiv \beta + G(\beta)/g(\beta)$. Because $L_2 = \rho K/\pi^m(\beta_2)$, we have that $(d/d\lambda)\,\Delta\mathcal{W} \leq 0$ if and only if **C1** is satisfied.

Fourth, under **C1**, we show that $\Delta\mathcal{W}$ has at most one positive root. Indeed, $\Delta\mathcal{W}$ is a decreasing function of λ. So, $\Delta\mathcal{W}$ has no root if $\lim_{\lambda\to0}\Delta\mathcal{W} \leq 0$ and a unique root otherwise, where $\lim_{\lambda\to0}\Delta\mathcal{W}$ is equal to $\Delta\mathcal{W}_0 \equiv -E_{12}\left[L_2\left(S(Q_1^m) - \beta_1 Q_1^m\right)\right] + E_2\left[L_2\right]E\left[W(Q_o^*,\beta)\right]$ where $Q_o^* = \lim_{\lambda\to0} Q^*$. This proves the proposition.

Finally, we prove that sufficient condition for condition **C1** is that $E[v] \geq \overline{\beta}$. When the number of bidders is $N = 1$, the distribution of β_2 collapses to a Dirac distribution centered on $\beta_2 = \overline{\beta}$ whereas it collapses to one centered on $\beta_2 = \underline{\beta}$ when $N \to +\infty$. Hence, for any given law of β_2 we must have that $\pi^m(\overline{\beta}) \leq E_2\left[\pi^m(\beta_2)\right] \leq \pi^m(\underline{\beta})$ and similarly that $\pi^m(\underline{\beta}) \leq E_2\left[\pi^m(\beta_2)^{-1}\right] \leq \pi^m(\overline{\beta})^{-1}$. Using the last inequality, a sufficient condition for **C1** is therefore $E\left[\pi^m(v)\right]\pi^m(\overline{\beta})^{-1} < 1$, or equivalently, $E\left[\pi^m(v)\right] < \pi^m(\overline{\beta})$. Applying the Jensen inequality to the convex function of profits $\pi^m(\beta)$, the latter condition is satisfied if $\pi^m(E[v]) \leq \pi^m(\overline{\beta})$, which is equivalent to the condition $E[v] \geq \overline{\beta}$ because $\pi^m(\beta)$ is a decreasing function of β. For instance, this condition is always satisfied for uniform distribution on $[\underline{\beta}, \overline{\beta}]$ because $v = 2\beta - \underline{\beta}$ and $E[v] = \overline{\beta}$. ■

Appendix D: Proof of Proposition 5

Proof. Let again $\Delta\mathcal{W} = \rho\left(\mathcal{W}^{\mathrm{p}} - \mathcal{W}^{\mathrm{b}}\right)$ and $\Omega^{\mathrm{p}}(\lambda) = E\left[W(Q^p,\beta) - \lambda\frac{G}{g}Q^p\right]$. Let now $\mathcal{Z}(\lambda, N) \equiv \Delta\mathcal{W}^{\mathrm{snt}} - \Delta\mathcal{W}^{\mathrm{ant}}$ so that

$$\begin{aligned}\mathcal{Z}(\lambda, N) = {} & L^{\mathrm{snt}}\left\{\Omega^{\mathrm{p}}(\lambda) - E\left[S(Q^m) - \beta Q^m\right]\right\} \\ & - \left\{E_2\left[L_2\right]\Omega^{\mathrm{p}}(\lambda) - E_{12}\left[L_2\left(S(Q_1^m) - \beta_1 Q_1^m\right)\right]\right\}\end{aligned}$$

Under condition **C1**, $\Delta\mathcal{W}$ are decreasing functions that accept at most one positive root. Therefore, $\lambda^{\text{snt}} \geq \lambda^{\text{ant}}$ if and only if one of the following conditions hold: $\mathcal{Z}(\lambda, N) \geq 0$ for all λ, $\mathcal{Z}(\lambda^{\text{snt}}, N) \geq 0$ or $\mathcal{Z}(\lambda^{\text{ant}}, N) \leq 0$.

First, $\lambda^{\text{snt}} < \lambda^{\text{ant}}$ for $N = 1$. Indeed, for $N = 1$ we have $\beta_2 = \overline{\beta}$, $E_{12}\left[h(\beta_1, \beta_2)\right] = E\left[h(\beta, \overline{\beta})\right]$ and $E_2\left[h(\beta_2)\right] = h(\overline{\beta})$. So, $L^{\text{snt}} = \left(E\left[\pi^m(\beta)\right]\right)^{-1}$ and $E_2\left[L_2\right] = \left(\pi^m(\overline{\beta})\right)^{-1}$. Therefore,

$$\begin{aligned}\mathcal{Z}(\lambda^{\text{snt}}, 1) &= \left(E\left[\pi^m(\beta)\right]\right)^{-1}\left\{\Omega^{\text{p}}(\lambda^{\text{snt}}) - E\left[S(Q^m) - \beta Q^m\right]\right\}\\ &\quad - \left(\pi^m(\overline{\beta})\right)^{-1}\left\{\Omega^{\text{p}}(\lambda^{\text{snt}}) - E\left[(S(Q^m) - \beta Q^m)\right]\right\}\end{aligned}$$

is negative because $\left(E\left[\pi^m(\beta)\right]\right)^{-1} < \left(\pi^m(\overline{\beta})\right)^{-1}$ and because, by (17), at λ^{snt}, $\mathcal{W}^{\text{p}} - \mathcal{W}^{\text{b}} = 0 \iff \Omega^{\text{p}}(\lambda) - E\left[S(Q^m) - \beta Q^m\right] = \lambda^{\text{snt}} K\rho / L^{\text{snt}} > 0$

Second, $\lambda^{\text{snt}} > \lambda^{\text{ant}}$ for $N \to \infty$. For $N \to \infty$, we have $\beta_1 = \beta_2 = \underline{\beta}$ so that

$$\begin{aligned}\mathcal{Z}(\lambda^{\text{snt}}, \infty) &= \left(E\left[\pi^m(\beta)\right]\right)^{-1}\left\{\Omega^{\text{p}}(\lambda^{\text{snt}}) - E\left[S(Q^m) - \beta Q^m\right]\right\}\\ &\quad - \left(\pi^m(\underline{\beta})\right)^{-1}\left\{\Omega^{\text{p}}(\lambda^{\text{snt}}) - \left(S(Q^m\left(\underline{\beta}\right)) - \underline{\beta} Q^m\left(\underline{\beta}\right)\right)\right\}\end{aligned}$$

is positive because $\left(E\left[\pi^m(\beta)\right]\right)^{-1} > \left(\pi^m(\underline{\beta})\right)^{-1}$ and $S(Q^m\left(\underline{\beta}\right)) - \underline{\beta} Q^m\left(\underline{\beta}\right) > E[S(Q^m) - \beta Q^m]$ whereas, by (17), at λ^{snt}, $\mathcal{W}^{\text{p}} - \mathcal{W}^{\text{b}} = 0 \iff \Omega^{\text{p}}(\lambda^{\text{snt}}) - E\left[S(Q^m) - \beta Q^m\right] = \lambda^{\text{snt}} K\rho / L^{\text{snt}} > 0$ ■

Appendix E: Proof of Proposition 6

Proof. For a least net present value of revenue auction, the expression (23) writes as

$$E\left\{L_1(\beta, R)\left[\Omega^p(\lambda) - \Omega^{\text{b}}(\lambda)\right]\right\} > 0 \tag{28}$$

where $\Omega^p(\lambda) = W(Q^p, \beta) - \lambda \frac{G(\beta)}{g(\beta)} Q^p$ and $\Omega^{\text{b}}(\lambda) = E\left[W(Q^m, \beta)\right]$ are the values used in the proof to Proposition 2. We here show that the expression in this condition falls from positive values to negative value as λ rises from zero to infinity. Indeed, from the proof of Proposition 2, we know that $(d/d\lambda)\left(\Omega^{\text{b}}\right) > (d/d\lambda)\left(\Omega^{\text{p}}\right)$. So that this inequality falls with larger λ. At $\lambda = 0$, we get that $\Omega^p(0) \to W(Q^*, \beta)$ which is larger than $\Omega^{\text{b}}(0) = W(Q^m, \beta)$

for any β. For $\lambda \to \infty$, using $v_\infty(\beta) = \beta + G(\beta)/g(\beta) \geq \beta$ and $Q^p_\infty(\beta) = Q^m(v_\infty(\beta))$, the LHS of inequality becomes

$$E\left\{L_1(\beta, R)\left[\left[P(Q^p_\infty(\beta)) - \beta\right] Q^p_\infty(\beta) - \frac{G(\beta)}{g(\beta)} Q^p_\infty - \left[P(Q^m(\beta)) - \beta\right] Q^m(\beta)\right]\right\}$$

and, it can be written as

$$E\left\{L_1(\beta, R)\left[\left[P(Q^m(v_\infty(\beta))) - v_\infty(\beta)\right] Q^m(v_\infty(\beta)) - \left[P(Q^m(\beta)) - \beta\right] Q^m(\beta)\right]\right\}$$

This is negative because $v_\infty \geq \beta$ and therefore $\left[P(Q^m(v(\beta))) - v(\beta)\right] Q^m(v(\beta)) \leq \left[P(Q^m(\beta)) - \beta\right] Q^m(\beta)$ for any β. ■

Appendix F: Linear example

Under linear demands and uniform cost distributions, the monopoly output and prices are given by $Q^m(\beta) = (1 - \beta)/2$ and $P(Q^m(\beta)) = (1 + \beta)/2$. Under public management we get $Q^p(\beta) = (1 + \lambda)/(1 + 2\lambda) - \beta$. Cumbersome calculations yield the following thresholds when the government has no ex-ante information disadvantage:

$$\lambda^{\text{snt}} = \frac{\sqrt{\overline{\beta}^2 + 9/\overline{\beta} - 9} - 3 + 2\overline{\beta}}{6\left(1 - \overline{\beta}\right)}$$

$$\lambda^{\text{st}} = \frac{\sqrt{36\rho K\left(1 - \overline{\beta}\right)\overline{\beta} + \left(3 - 2\overline{\beta}\right)^2 \overline{\beta}^2} - \overline{\beta}\left(3 - 2\overline{\beta}\right)}{6\left(1 - \overline{\beta}\right)\overline{\beta}}$$

When the government has an information disadvantage, the number of potential bidders N has important implications. We consider the two polar situations where the government faces either a single applicant ($N = 1$) or an infinite set of applicants ($N \to \infty$, i.e. perfectly competitive auction). It is intuitive that the former situation yields a smaller welfare benefit of BOT concessions. We get

$$\lambda_1^{\text{ant}} = \max\left[0, \frac{12-5\overline{\beta}-\sqrt{3\left(44-24\overline{\beta}+3\overline{\beta}^2\right)}}{4\overline{\beta}}\right]$$

$$\lambda_\infty^{\text{ant}} = \max\left[0, \frac{\sqrt{3\overline{\beta}\left(6-\overline{\beta}\right)}-\overline{\beta}\left(9-4\overline{\beta}\right)}{4\overline{\beta}\left(3-2\overline{\beta}\right)}\right]$$

We finally compare the fixed duration concession with the least net present value of revenue auction. In the least net present value of revenue auction we get

$$\begin{aligned} R &= K/\left[1-\int_0^{\overline{\beta}}\frac{\beta}{P(Q^m(\beta))}\frac{1}{\overline{\beta}}d\beta\right] \\ &= K/\left[1-2\overline{\beta}+2\ln\left(\overline{\beta}+1\right)\right] \end{aligned}$$

$$\begin{aligned} \text{while}\quad L_1(\beta,R)/\rho &= R/[P(Q^m(\beta))Q^m(\beta)] \\ &= \frac{4K}{(1+\beta)(1-\beta)}\left[1-\int_0^{\overline{\beta}}\frac{\beta}{(1+\beta)/2}\frac{1}{\overline{\beta}}d\beta\right]^{-1} \\ &= \frac{4K}{(1+\beta)(1-\beta)}\left[1-2\overline{\beta}+2\ln\left(\overline{\beta}+1\right)\right]^{-1} \end{aligned}$$

The condition $\int_0^{\overline{\beta}} L_1(\beta,R)/\left[W(Q^p,\beta)-\lambda\beta Q^p-W(Q^m,\beta)\right]d\beta \geq 0$ becomes

$$\int_0^{\overline{\beta}}\frac{\left(12\lambda^2+8\lambda+1\right)\beta^2+\left(-8\lambda^2-8\lambda-2\right)\beta+1}{1-\beta^2}d\beta \geq 0$$

This expression accepts one root λ^{rev}

$$\lambda^{\text{rev}} = \frac{8\log\left(\overline{\beta}+1\right)-8\overline{\beta}-\sqrt{\Gamma}}{4\left[6\overline{\beta}+\log\left(1-\overline{\beta}\right)-5\log\left(\overline{\beta}+1\right)\right]}$$

where $\Gamma = 64\left[\log\left(\overline{\beta}+1\right)-\overline{\beta}\right]^2-4\left[12\overline{\beta}+2\log\left(1-\overline{\beta}\right)-10\log\left(\overline{\beta}+1\right)\right]\left(\overline{\beta}-2\log\left(\overline{\beta}+1\right)\right)$.

Appendix G: Proof of Proposition 7

Proof. The LHS of the inequality (27) is a decreasing function of λ and has a bounded negative slope $\lim_{\lambda\to\infty}(\text{LHS}/\lambda)$ (see proof of Proposition 2). Let $\Phi^o < 1$ solves $\lim_{\lambda\to\infty}(\text{LHS}/\lambda) =$

$(K/T^{\text{o}})\,(\Phi^o - 1)$. As a result, if $\Phi < \Phi^o$, the inequality (27) is never fulfilled whereas, if $\Phi \geq \Phi^o$, it is not fulfilled for $\lambda = 0$ but it is satisfied for large enough λ. Therefore there exists a threshold λ^{o} such that BOT concessions are preferred if $\lambda \geq \lambda^{\text{o}}$. Let the function $\rho_G^o(\rho_F)$ solves the equality $\Phi\,(\rho_G, \rho_F, T^{\text{o}}) = \Phi^o$. Then $\Phi \geq \Phi^o$ is equivalent to $\rho_G \geq \rho_G^o(\rho_F)$. Note that $\rho_G^o(\rho_F) < \rho_F$ because $\Phi^o < 1$. Finally the threshold λ^{o} falls with larger ρ_G and smaller ρ_F because Φ increases with larger ρ_G and smaller ρ_F. ■

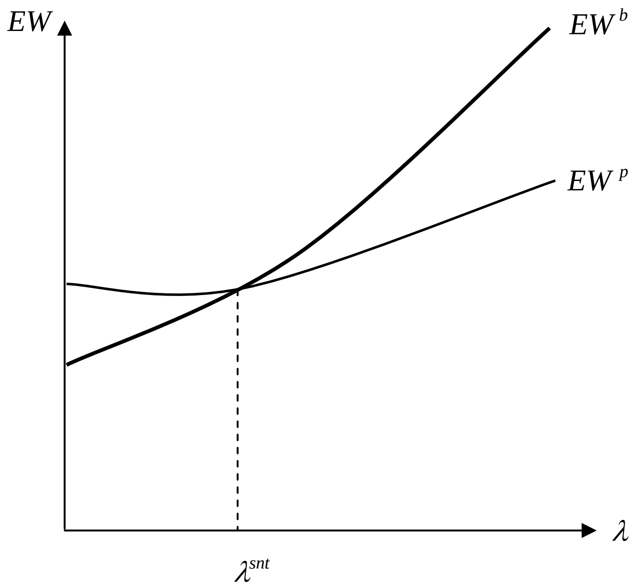

Figure 1 : Welfare under BOT and Public Management