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The joy of flying: Efficient airport PPP contracts[☆]

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ABSTRACT

We derive the optimal concession contract for an airport where the concessionaire's effort impacts either non-aeronautical revenue (shops, restaurants, parking lots and hotels) or aeronautical revenues (passenger and airline fees). Our first model assumes that demand for the infrastructure is exogenous whereas demand for non-aeronautical services depends both on passenger flow and on the concessionaire's effort and diligence. We show that the optimal principal-agent contract separates exogenous and endogenous risks. First, the term of the concession varies inversely with passenger flow, so that the concessionaire bears no exogenous demand risk. Second, the concessionaire bears part or all of non-aeronautical risk, which fosters effort. We also study a model where the concessionaire's effort affects demand for aeronautical services and focus on the case where the contract includes a demand trigger for investment as an incentive. Both optimal contracts can be implemented with a Present-Value-of-Revenue (PVR) auction in which firms bid on the present value of aeronautical revenue and the concession ends when the bid is collected. PVR auctions have been used to auction airport PPP contracts in Chile, and demand triggers for investment have been used both in Brazil and Chile.

1. Introduction

> "What sets airports apart from most investments in infrastructure is their dual income stream: they bring in money both on the aeronautical side (landing fees, contracts with carriers) and from passengers (parking, shopping, hotels). If you own a toll road and traffic dwindles, there's not much you can do. But with an airport there are lots of levers to pull, such as cutting capital costs, firing staff and upping the price of parking."
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> The Economist, June 6th, 2015.

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In recent years PPPs have become the main mechanism for airport procurement.[2,3] Indeed, according to the PPIAF database, in 2014 there were 141 airport PPPs around the world (Farrell and Vanelslander, 2015). One of the main features of an airport PPP is that it has two sources of revenue, aeronautical (e.g. landing or airport fees) and non-aeronautical such as sales in duty-free shops, restaurants, airport hotels, parking and rental cars. Recent data show that non-aeronautical revenues represent 40% of global airport revenues (Calleja, 2017) and that the contribution of non-aeronautical services to total profits is even larger (Graham, 2009).

The main advantage of PPPs over public provision of airport services is that they provide better incentives to attract demand, allocate risks and foster innovation. In this paper we study airport PPP contracts that provide optimal incentives to the concessionaire. In the first model, demand for non-aeronautical services is responsive to non-observable effort exerted by the concessionaire. In the second model, the concessionaire's effort affects the demand for aeronautical services. The first model corresponds to a monopoly airport, while the second model analyzes airports that compete in facilities investment. Both types of airports are important. Many airports face little competition and our first model is relevant in this case. By contrast, hub airports as well as some regional airports, compete with each other. In these cases our second model is relevant.[4]

In our first model, a risk neutral planner hires a risk-averse concessionaire to build and operate an airport.[5] The concessionaire can exert costly effort which increases ancillary revenue per passenger with positive probability. Each passenger pays a user fee and aeronautical revenue is random, exogenous and price inelastic. These assumptions allow us to focus on the optimal incentive and risk sharing contract while abstracting from explicit pricing considerations.[6]

We find that the optimal airport contract when effort affects non-aeronautical revenue has three characteristics. First, the concessionaire does not bear any of the demand risk caused by exogenous variations in passenger volume.[7] Second, the concessionaire bears ancillary profit risk, which provides incentives to invest in ancillary services and exert costly effort. Third, the contract can be implemented with a present-value-of-revenue (PVR) auction in which participants bid on the present value of aeronautical revenue and there is a proportional sharing rule for non-aeronautical revenues. Note that the bidding variable does not include the proceeds of ancillary revenues. As in other PVR contracts, the duration is variable and the concession ends when the concessionaire collects aeronautical fees equal to the winning bid.

To understand the economics of the optimal contract, assume first that exogenous aeronautical revenue is the only source of income. As we have shown elsewhere (see Engel et al., 2001; Engel et al., 2013), in this case it is optimal to allocate the concession to the lowest PVR bid. The concession ends when the bid revenue has been collected. Because the concessionaire is risk averse and demand risk is exogenous, it is optimal to fully transfer risk to the planner.

Now add ancillary services to the concession and note that the number of potential customers is roughly proportional to the number of passengers at the airport, as documented in Calleja (2017).[8] The reason is that passengers visit an airport with the primary objective of traveling and that parking or buying in the shops at the airport is at most a subsidiary objective. The optimal contract exploits the high correlation between the two types of airport PPP revenues by tying the term of the concession for non-aeronautical services to the term of the concession for aeronautical services and thus making it also variable. As the term of the concession of non-aeronautical services is variable (it is part of the same contract), the revenue from these services depends only on effort and investment, and thus under the contract the concessionaire bears no *exogenous* demand risk.

At the same time, once a passenger is at the airport, she will spend more, on average, if the concessionaire dedicates resources to increase demand for non-aeronautical services. Finding the right combination of service types and service providers is a problem similar to that of managing a shopping mall and can have a significant impact on overall profits. Thus the demand for non-aeronautical services has an endogenous random component, which depends on the concessionaire's investment and effort. As is standard in principal-agent model, the optimal contract is such that the concessionaire receives more revenue and profits if the project succeeds. But because exogenous risk can be fully separated from the endogenous risk component by varying the term of the concession, the variation in the reward of the concessionaire depends only on the fate of the ancillary project and not on the realization of the exogenous demand component.[9] Thus the regulator can exploit the relation between demand for aeronautical and non-aeronautical services to concession both services using

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[2] On airport reform and privatization see, for example, Gillen (2011) and Winston and de Rus (2008).

[3] Engel et al. (2014) define a PPP as "an agreement by which the government contracts a private company to build or improve infrastructure works and to subsequently maintain and operate them for an extended period in exchange for a stream of revenues during the life of the contract." Under this definition the concessionaire is remunerated with a combination of user fees and government transfers.

[4] Czerny et al. (2016b) show that airport demand is responsive to rental car prices while Ivaldi et al. (2015) find that demand is responsive to parking charges. Both these cases can be incorporated into our second model as a form of effort by the concessionaire.

[5] Assuming a risk averse concessionaire and a risk neutral government is standard when applying principal-agent models to PPPs. See, for example, Martimort and Pouyet (2008); Iossa and Martimort (2012) and Iossa and Martimort (2015).

[6] The latter assumption can be relaxed as shown in the working paper version of Engel et al. (2013) (see http://www.nber.org/papers/w13284).

[7] Demand risk may be macroeconomic or due to variations in regional growth, but if the airport has few close-by substitutes, passenger demand is exogenous from the point of view of the concessionaire.

[8] This a common assumption in the theoretical literature, see Zhang and Zhang (1997).

[9] The intuition is obvious in the case of no discounting. In that case, the contract always ends when a predetermined number of passengers have arrived. These passengers are exposed to the investment effort of the concessionaire in ancillary services, and thus their demand for ancillary services is endogenous to the concessionaire's effort.

a single auction. Moreover, in a competitive auction, the rents of the concessionaire from both services can be extracted efficiently. The authority sets optimal prices for aeronautical services and the concessionaire uses take-it-or-leave-it auctions (see Kidokoro et al., 2016) for non-aeronautical services.

A second feature of the optimal contract is that it can be implemented with a PVR auction, where participants bid on the present value of aeronautical revenue only. To explain the intuition for this result we first note that a competitive auction with symmetric bidders always extracts all rents. To implement the optimal contract, however, the bidding variable must replicate the contract described above by not assigning exogenous demand risk to the concessionaire and providing efficient incentives to exert effort. This is the case when participants bid on the present value of aeronautical revenue. In contrast, if firms bid on the minimum airport fee in a fixed term contract (or alternatively on the shortest concession term), the concessionaire is forced to bear exogenous demand risk and the contract is not optimal. Alternatively, if participants bid on total discounted revenues from both aeronautical and non-aeronautical services, the incentives to exert effort disappear. The reason is that in this case successful effort shortens the contract but does not change total discounted revenues, which are fixed and equal to the winning bid.

We also examine a specific case of airports with endogenous demand for aeronautical services. In this case, which is applicable to hub airports or other airports that face competition, the PPP owner can increase demand through effort and the question is how to provide incentives to the concessionaire to increase demand optimally. The situation we model is similar to the Sao Paulo airport PPP contract, which includes a trigger that requires additional investments once demand exceeds a threshold. The additional investment by the PPP can be interpreted as a reward for successfully increasing demand because the additional investment is usually very profitable for the PPP. In this setting, we find the optimal PPP contract and we show that, as in the case of the first model, it can be implemented by a PVR auction.

The key characteristic of the utility function that drives our results in both cases — demand for non-aeronautical services, and effort-responsive demand for the airport itself—is that the agent wants to exert more effort when his net income falls (i.e. in equilibrium effort is decreasing in net income). Then there is no tradeoff between effort and rent extraction and the planner can stimulate the agent's effort by auctioning the concession to the lowest bid in aeronautical revenues.

Our paper contributes to a large literature that studies the complementarity between infrastructure and ancillary services in airports. One strand of the literature characterizes efficient pricing across aeronautical and non-aeronautical revenues. In an early paper, Zhang and Zhang (1997) showed that a regulatory authority with a break-even constraint may want to cross-subsidize airport operations with revenues from commercial services.[10] Similarly, Kratzsch and Sieg (2011) examined the regulation of airports with market power. They show that when there is sufficient complementarity between aeronautical and non-aeronautical revenues, the monopolist will charge less than the monopoly price for aeronautical services. Gillen (2011) noted that an airport is a two-sided platform where passengers and airlines meet. Therefore neither cost-based pricing for airline services is optimal in general, nor are prices above marginal costs evidence of market power. Ivaldi et al. (2015) tested whether hub airports are double sided markets, and how airports can maximize profits by acting on both sides of the market. Czerny et al. (2016a) in turn, examined the optimal regulation of monopoly airports with both aeronautical and non-aeronautical revenues. They compared single-till and dual-till regulation, and examined the conditions under which one type of regulation dominates the other.[11] Wan et al. (2015) studied how congestion in terminals and on the runways interact and how concession revenues affect the optimal pricing to deal with congestion. Last, Zhang et al. (2010) examine how airports and airlines can share non-aeronautical revenue to attract traffic and increase joint profits.[12]

A second strand of the literature, which is closely related to the first, studies the optimal regulation of an airport with market power. For example, Yang and Zhang (2011) investigated single and dual till regulation with a price-cap in a congested airport where airlines have market power. Yang and Fu (2011) compared the performance of ex ante price-cap regulation with ex post light-handed regulation when demand is uncertain. Oum et al. (2004) studied the interaction between concession profits and aeronautical price regulation and concluded that while rate-of-return regulation may lead to over-investment in capacity, price-cap regulation is prone to under-investment.

A third strand of the literature studies the interaction between aeronautical and non-aeronautical services and investment decisions. For example, Zhang and Zhang (2010) studied airport decisions on pricing and capacity investment with both aeronautical and concession operations when airlines have market power. Xiao et al. (2017) analyzed the effect of demand uncertainty on airport investment decisions and how they interact with concession revenue. Kidokoro et al. (2016), in turn, studied jointly optimal investments in aeronautical and non-aeronautical capacity. Last, Xiao et al. (2017) modeled airport capacity choice when a real option for expansion can be purchased.[13]

In our previous work (Engel et al., 2001; 2013) we studied PPPs with a single and exogenous source of revenue and found conditions under which a PVR contract is optimal. Here we complement this literature by considering the case with

[10] But see Kidokoro et al. (2016).

[11] Under the single till principle of airport regulation, both aeronautical and non-aeronautical revenues are considered when regulating airport charges. Under the dual till principle, by contrast, only aeronautical revenues are considered.

[12] See also Fu and Zhang (2010) and Zhang and Zhang (2010).

[13] Quite a number of papers have investigated airport capacity investment. See for example Zhang and Zhang (2003), Oum and Zhang (1990), Oum et al. (2004), Basso and Zhang (2007), Basso and Zhang (2008), Zhang and Zhang (2010) and Xiao et al. (2017).

two sources of revenues and moral hazard, and show how a PVR auction can be used to implement the optimal contract in this environment.

Several papers study the principal-agent relationship in a PPP contract; see, for example Bentz et al. (2005), Martimort and Pouyet (2008), Iossa and Martimort (2011), Iossa and Martimort (2012), Iossa and Martimort (2015) and Auriol and Picard (2013). Our paper contributes to this literature with an analysis that separates and optimally distributes endogenous and exogenous risks in transport PPPs by exploiting the intertemporal nature of a concession contract. We are not aware of other studies of optimal PPP contracts where there is ancillary revenue.

Several airports PPP contracts in Chile and Brazil include features we examine here. Major airports in both countries have had triggers for additional investment in exchange for term extensions, as in our second model. In Chile, several airports in major cities have been awarded on the basis of PVR contracts like the one derived here.[14]

Finally, our paper is related to the literature on the economics of malls. Malls obtain their income from their contracts with storeowners, and must therefore provide efficient incentives for effort by these agents. However, in the case of malls, there is the additional problem of attracting consumers to a mall. Thus demand is endogenous, as in our second model; see, for instance, Pashigian and Gould (1998), Gould et al. (2005), Ivaldi et al. (2015) and Ersoy et al. (2016).

The remainder of the paper is organized as follows. The next section develops the model and the main results for the case where effort affects demand for non-aeronautical services, the third section studies airports where effort impacts on the demand for aeronautical servces and the final section concludes.

2. Effort and non-aeronautical revenue

A risk-neutral benevolent social planner must design a contract for a public-private partnership to provide infrastructure services that are contractible.[15] Demand for these services is exogenous and the concessionaire collects a fee from users. The concessionaire also receives ancillary revenues, which increase both with costly effort and with demand for the infrastructure services. For example, in the case of an airport, landing fees correspond to user fees while shopping and parking revenues are examples of ancillary revenues.

The planner hires a concessionaire to finance, build and operate the facility. The technical characteristics of the facility are exogenous, there are neither maintenance nor operation costs, the up-front investment does not depreciate, and there are many identical risk-averse expected utility maximizing firms with preferences represented by the strictly concave utility function u that can build the project at cost $I > 0$.[16]

Demand for infrastructure services is uncertain and described by a probability density over the present value of user fee revenue that the infrastructure can generate over its entire lifetime, v. This density does not depend on actions of the concessionaire and is defined over $v_{\min} \le v \le v_{\max}$ and denoted $f(v)$, with c.d.f. $F(v)$.[17] This density is common knowledge to firms and the planner, and satisfies $v_{\min} \ge I$ so that the project is self-financing in all states of demand. Also, for simplicity we assume that v equals the present value of private willingness to pay for the project's services.

While the exogenous demand assumption does not apply to important metropolitan airports that compete with each other, or for airports well served by high speed rail links to other cities, it is a reasonable assumption for other airports where there are no other efficient alternatives. In the Appendix we provide some facts that show that these airports represent a large fraction of travel worldwide.

The concessionaire exerts non-observable effort $e \ge 0$ before the facility begins operating. With probability $p(e)$ this generates non-aeronautical revenue θv, observable to the planner; otherwise it generates no value. The positive constant θ is common knowledge.[18] That is, the extensive margin of the PPP (e.g., the number of potential shoppers in the case of an airport) is determined by the exogenous demand component, but the intensive margin (how much each potential shopper buys) depends on the concessionaire's effort, for instance, the mix of shops, or the bargaining effort with independent shops. The intuition behind this formulation is that sales at airport stores depend mainly on the demand for the terminal where the store is located: It is uncommon to choose a restaurant at an airport for dinner on a Saturday night. Thus, given effort, there is a proportionality between the demand for the shops and the demand for the airport, the two sources of revenue for the concessionaire.[19]

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[14] In the case of El Tepual airport of Puerto Montt, in Chile, the best bid for a short term franchise that began in 2014 asked for zero user fees, and thus all revenues are ancillary.

[15] This assumption is reasonable in the case of an airport while less so for health and educational services.

[16] If the cost I depends on the firm, a second price auction leads to a rent for the winning firm equal to the cost difference with respect to the second most efficient firm. By the revenue-equivalence theorem of auction theory, this rent cannot be reduced. For simplicity we assume identical costs in the model.

[17] We also assume that demand is perfectly inelastic to prices. In previous papers (see working paper version of Engel et al., 2013), we have shown that removing this assumption does not affect the main economic results.

[18] This simplification of the effects of effort on project value is standard in the literature.

[19] We are assuming that all the value generated by a successful effort is appropriated by the firm that builds the facility, that is, that owners of ancillary businesses obtain no rents. With symmetric shopowners, this will be the case when ancillary businesses are allocated via the often used mechanism of take-it-or-leave-it offers, as long as information on shop owner's cost structure is known to the firm building the facility (Kidokoro et al., 2016). The assumption also holds when shopowners are selected via a competitive auction.

Denote by $R_f(v)$ and $R_s(v)$ the total revenue received by the concessionaire under failure and success, respectively. Thus $R_s(v)$ represents user fees plus sales revenue while $R_f(v)$ corresponds to user fees only. Since the planner can observe whether the concessionaire is successful, the contract specifies two schedules $\{R_f(v), R_s(v)\}$, with $R_f(v) \le v$ and $R_s(v) \le (1+\theta)v$, since we rule out subsidies by assumption. In each case, the planner receives the complement: $v - R_f(v)$ if she fails and $(1+\theta)v - R_s(v)$ if she succeeds.

The probability of success depends on the effort exerted by the concessionaire. More formally, the probability of success, given effort $e \ge 0$, is denoted $p(e)$ and satisfies $0 \le p(e) < 1$, $p' > 0$ and $p'' < 0$. The cost of effort is linear in effort: ke, with $k > 0$.

2.1. Planner's problem

The planner faces the problem of designing a contract for a concessionaire who will operate and maintain the infrastructure, while at the same time providing him with incentives to exert the efficient amount of effort.

We assume that, as in Laffont and Tirole (1993, Ch. 1), the regulator puts no value on the rents of the concessionaire. Reasons may be redistributive concerns or that the private party is foreign-owned. Thus the planner ignores the welfare of the concessionaire in the maximand, the participation constraint holds with equality and the planner solves

$$\max_{\{R_f(v), R_s(v), e\}} p(e) \int [(1+\theta)v - R_s(v)] f(v) dv \; + \; (1-p(e)) \int [v - R_f(v)] f(v) dv \tag{1}$$

$$\text{s.t. } u(0) + ke = p(e) \int u(R_s(v) - I) f(v) dv \; + \; (1-p(e)) \int u(R_f(v) - I) f(v) dv, \tag{2}$$

$$e = \underset{e' \ge 0}{argmax} \left\{ p\left(e'\right) \int u(R_s(v) - I) f(v) dv + \left(1 - p\left(e'\right)\right) \int u\left(R_f(v) - I\right) f(v) dv - ke' \right\}, \tag{3}$$

$$0 \le R_s(v) \le (1+\theta)v, \tag{4}$$

$$0 \le R_f(v) \le v, \tag{5}$$

$$e \ge 0, \tag{6}$$

where we use the convention that integrals with respect to v with no explicit lower and upper limits are over the entire set of values taken by this variable, that is, from $v_{\min}$ to $v_{\max}$.

The planner maximizes the net expected value of the project, which in demand state v is equal to $p(e)[(1+\theta)v - R_s(v)] + (1-p(e))[v - R_f(v)]$. The first and second constraints are, respectively, the participation constraint and the incentive compatibility constraint (ICC) of the concessionaire. The third and fourth constraints are the no-subsidy constraints.

The solution is found by solving the same problem without imposing the no-subsidy constraints (4) and (5). In this simplified problem, the planner's decision variables enter symmetrically, hence the corresponding first order conditions will not depend on v and we may denote $R_f(v) = R_f$ and $R_s(v) = R_s$ for all v, obtaining a much simpler problem because the number of decision variables has decreased substantially.[20] Next we solve this simpler problem and show that the solution satisfies the no-subsidy constraints and therefore also solves the original problem. We assume that $R_s \le (1+\theta)R_f$, which is equivalent to putting a lower bound on the degree of risk aversion of the concessionaire.[21]

A second important assumption is that we can use the first order conditions of the incentive compatibility constraint instead of the original constraint; this will be useful in Section 2.3. Thus, denoting $\bar{v} \equiv \int v f(v) dv$ we can rewrite the planner's problem as:[22]

$$\max_{\{R_f, R_s, e\}} p(e)[(1+\theta)\bar{v} - R_s] \; + \; (1-p(e))[\bar{v} - R_f] \tag{7}$$

$$\text{s.t. } u(0) + ke = p(e) u(R_s - I) \; + \; (1-p(e)) u(R_f - I), \tag{8}$$

[20] Formally we are using the following result: Consider maximizing a real valued function $F(x, y)$, defined over $\mathbb{R}^{2n}$, subject to k constraints $L_i(x, y) = 0$, $i = 1, 2, \dots k$, where $x, y \in \mathbb{R}^n$. Assume F and the L_i are symmetric in the components of x and in the components of y, that is, if $\tilde{x}, \tilde{y} \in \mathbb{R}^n$ denote permutations of $x, y \in \mathbb{R}^n$, then $F(x, y) = F(\tilde{x}, \tilde{y})$ and $L_i(x, y) = L_i(\tilde{x}, \tilde{y})$, $i = 1, \dots, k$. Then, if there exists a unique solution to the maximization problem, (x^*, y^*), all the coordinates of x^* will take the same value and all the coordinates of y^* will take the same value. The proof follows from noting that if (x^*, y^*) satisfies the first-order conditions then the vector with permutations $(\tilde{x}, \tilde{y})$ also satisfies the first-order conditions. In our model, the role of x is played by the $R_f(v)$ and the role of y by the $R_s(v)$, where v varies over all possible realizations.

[21] We need this assumption to ensure that the solution to the simpler problem described above also solves the problem of interest.

[22] To go from (1) to (7), and from (2) to (8), we use that R_s and R_f do not depend on v and the definition of $\bar{v}$. The transition from (3) to (9) also considers the first-order condition.

$$k = p'(e)\big[u(R_s - I) - u\big(R_f - I\big)\big], \tag{9}$$

$$e \geq 0. \tag{10}$$

2.2. Optimal contract under public provision

Following Hart (2003), where PPPs are characterized as long term contracts with bundling of activities, in our setting a PPP is a contract in which the concessionaire decides how much effort to exert during the construction phase and can share in the extra revenues that result, i.e., it bundles the construction and operational phases. In the public sector it is standard to separate construction from operation. It is therefore natural to define 'public provision' as the case where it is not possible to provide compensation for unobservable effort during construction.

It is straightforward to show that under public provision the optimal contract sets $e = 0$, since the planner cannot transfer rents to the concessionaire.[23] Hence there is no incentive o for the concessionaire to bear demand risk and thus the optimal contract sets $R_f = R_s = I$.[24]

Proposition 1. *Under public provision $R_s = R_f = I$. The concessionaire bears no risk and exerts no effort.*

2.3. Improving on public provision

We begin by finding conditions that ensure that a PPP contract improves upon public provision. To this effect we define $e^* > 0$ as the level of effort needed to satisfy the incentive compatibility constraint (9) when $R_f = I$ and $R_s = (1+\theta)I$:

$$k = p'(e^*)[u(\theta I) - u(0)]. \tag{11}$$

This combination of effort and revenues will improve upon public provision if it increases the planner's objective function (7) and satisfies the concessionaire's participation constraint (8). The first condition is easier to satisfy when the probability of success is very responsive to increases in effort so that welfare gains from an increase in effort are large. By contrast, the second condition is easier to satisfy when the probability of success is unresponsive to increases in effort.

It follows from (7) that the increase in consumer surplus is equal to:

$$\begin{aligned}\Delta CS &= \{p(e^*)[(1+\theta)\overline{v} - (1+\theta)I] + (1-p(e^*))[\overline{v} - I]\} - \{p(0)[(1+\theta)\overline{v} - I] + (1-p(0))[\overline{v} - I]\} \\ &= (p(e^*) - p(0))\theta\overline{v} - p(e^*)\theta I \\ &\geq p'(e)e\theta\overline{v} - p(e)\theta I,\end{aligned}$$

where the inequality uses concavity of $p(e)$. It follows that consumer surplus increases if

$$\frac{p'(e^*)e^*}{p(e^*)} \geq \frac{I}{\overline{\overline{v}}}.$$

From (8) it follows that the concessionaire's participation constraint will hold if

$$p(e^*)[u(\theta I) - u(0)] \geq ke.$$

Substituting k by the expression that follows from (11) yields

$$\frac{p'(e^*)e^*}{p(e^*)} \leq 1.$$

We have established the following result:

Lemma 1. *Denote by $\eta(e) \equiv p'(e)e/p(e)$ the effort-elasticity of the probability of success and define e^* via (11). Assume*

$$\frac{I}{\overline{\overline{v}}} < \eta(e^*) \leq 1.$$

Then the contract with zero effort and $R_f = R_s = I$ is not optimal and there exists a PPP contract with strictly positive effort that does better than public provision.

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[23] Here we denote by public provision the approach of Hart et al. (1997). For simplicity we consider the extreme case where the division of authority leads to zero effort.

[24] Note that this contract satisfies the planner's problem described in (7)–(10). Since $e = 0$ is a corner solution, the first order condition from the incentive-compatibility constraint (10) must be replaced by the original constraint (before taking the first order condition), which is satisfied by the solution offered.

2.4. Optimal contract under PPP

Next we fix $0 \le \alpha \le 1$ and find the optimal contract among those that set $R_s(v) = (1+\alpha\theta)R_f(v)$, that is, among those contracts where the concessionaire receives a fraction α of ancillary revenues in return for effort. We refer to this contract as the "optimal α-contract." We only consider values of α for which the optimal contract entails strictly positive effort and from Lemma 1 we know when this is the case for $\alpha = 1$. We also show that the optimal α-contract can be implemented with a simple auction.

First, observe that by competition among bidders we must have that the efficient values of R_f satisfies:

$$\frac{I}{1+\alpha\theta} < R_f^* < I.$$

The second inequality holds because otherwise, from (9) we have $R_s > R_f$, and the concessionaire would make non-negative profits in both states, even with no effort, which is incompatible with competition. The first inequality holds because otherwise the concessionaire would have losses even when successful. The inequality is strict because even in the case with no effort, $p(0) < 1$, i.e., there is a positive probability of failure.

The next step in the proof is to find conditions under which, given α, there is a strictly decreasing relationship between effort e and the reward R_f. We denote by $e(R_f)$ the solution to the incentive compatibility conditions (12), i.e., $e(R_f)$ solves

$$k = p'(e)[u((1+\alpha\theta)R_f - I) - u(R_f - I)]. \tag{12}$$

If we can find conditions ensuring that the expression within the square parenthesis $u((1+\alpha\theta)R_f - I) - u(R_f - I)$ is decreasing in R_f, then $p'(e)$ must be increasing for the equation to continue to hold. By the properties of p, this requires that e be decreasing in R_f. Thus, we have found a condition ensuring that $e'(R_f) < 0$. To simplify the notation, let $R_\alpha \equiv (1+\alpha\theta)R_f$, for $\alpha \in [0, 1]$.

Definition 1. Let $\rho(z) = -zu''(z)/u'(z)$ be the coefficient of relative risk aversion of the concessionaire.

Lemma 2. *A sufficient condition for $e'(R_f) < 0$ is that*

$$\rho(R_\alpha - I) > \frac{\alpha\theta}{(1+\alpha\theta)}, \ \forall R_\alpha \in [I, (1+\alpha\theta)I].$$

Proof. Let

$$J(R_\alpha, \theta) \equiv u((1+\alpha\theta)R_f - I).$$

Since $J \in \mathcal{C}^2$, it is submodular if

$$\frac{\partial^2 J}{\partial R_f \partial\theta}(R_f, \theta) < 0,$$

Since this condition is satisfied,

$$J(R_\alpha, \theta) - J(R_\alpha, 0) = u((1+\alpha\theta)R_f - I) - u(R_f - I)$$

is decreasing in R_f. By the reasoning following (12), this implies that $e'(R_f) < 0$. Thus we require conditions ensuring that

$$\frac{\partial^2 J}{\partial R_f \partial\theta}(R_f, \theta) < 0.$$

Now,

$$\frac{\partial^2 J}{\partial R_f \partial\theta}(R_f, \theta) = \alpha R_\alpha u''(R_\alpha - I) + \alpha u'(R_\alpha - I)$$

and thus, for this expression to be negative, we require

$$-\frac{R_\alpha u''(R_\alpha - I)}{u'(R_\alpha - I))} > 1 \Longrightarrow \rho(R_\alpha - I) > \frac{R_\alpha - I}{R_\alpha}$$

Thus

$$\rho(R_\alpha - I) > 1 - \frac{I}{(1+\alpha\theta)R_f}.$$

As $R_f < I$, we can replace the RHS by the stricter condition

$$\rho(R_\alpha - I) > 1 - \frac{1}{1+\alpha\theta} = \frac{\alpha\theta}{1+\alpha\theta}.$$

Hence this condition ensures that $e'(R_f) < 0$. □

The intuition for Lemma 2 is that incentives for effort are blunted as the reward in the case of failure increases. Given $\alpha \in (0, 1]$, we can rewrite both the planner's and the firm's utility, when the Incentive Compatibility Constraints (ICC) holds, as functions of R_f:

$$V(R_f) = [1 - p(e(R_f))](\overline{v} - R_f) + p(e(R_f))[(1+\theta)\overline{v} - (1+\alpha\theta)R_f], \tag{13}$$

$$U(R_f) = p(e(R_f))u((1+\alpha\theta)R_f - I) + [1 - p(e(R_f))]u(R_f - I) - ke(R_f). \tag{14}$$

We have

$$V'(R_f) = \theta p'(e(R_f))e'(R_f)[\overline{v} - \alpha R_f] - 1 - \alpha\theta p(e)$$

which implies that $V'(R_f) < 0$ for $R_f \in (I/(1+\alpha\theta), I)$. Also, using the ICC we have that $U'(R_f)$ simplifies to:

$$U'(R_f) = \alpha\theta p(e(R_f))u'((1+\alpha\theta)R_f - I) + (1 - p(e(R_f)))u'(R_f - I) > 0.$$

The fact that the utility functions of the planner and the concessionaire are monotone functions of R_f, the first decreasing and the second increasing, is a key property of the problem, and uncommon in more general moral hazard settings. This fact explains why the solution we obtain has a relatively simple characterization and why it can be implemented with a simple competitive auction.

We showed before that bidding competition implies that $U(I/(1+\alpha\theta)) \le u(0) < U(I)$.[25] By continuity and because $U'(R_f) > 0$, $U(I/(1+\alpha\theta)) < u(0)$ and $U(I) > u(0)$, there exists a unique $R_f^* \in (I/(1+\alpha\theta), I)$ that solves $U(R_f) = u(0)$. This value of R_f solves the planner's problem: smaller values do not satisfy the firm's participation constraint (this follows from $U' > 0$) while larger values lead to lower social welfare (this follows from $V' < 0$). As $R_f^* < I$ it also satisfies the self-financing constraint $R_f^* \le v$, which we had omitted when solving the problem. We also have $R_s = (1+\alpha\theta)R_f \le (1+\theta)v$. The associated level of effort along the ICC is $e^* = e(R_f^*) > 0$. Maximizing this solution over $\alpha \in [0, 1]$ we obtain the optimal contract, with $R_f^* < I$.

Proposition 2. *Assume $\alpha \in (0, 1]$ fixed and $\rho(c) > \theta/(1+\theta), \forall c \in [0, \theta I]$. Also assume that optimal effort is strictly positive, and denote by $R_f^*(\alpha)$ the unique solution to the planning problem. We then have that $R_f^*(\alpha)$ is the unique solution to $U(R_f; \alpha) = u(0)$ and the planner's solution is obtained by finding the value of α for which $V(R_f^*(\alpha); \alpha)$ is maximum.*[26] *Furthermore, if the condition of Lemma 1 holds, there exist values of α for which the contract thus obtained is better than the optimal contract under public provision.*

The proposition implies that the contract that solves the program (7)–(10) is obtained by finding the value of $\alpha \in (0, 1]$ for which the optimal α-contract attains the highest social welfare. The solution to this program must entail positive effort, since a value of α for which the optimal contract entails zero effort is dominated by public provision, which in turn is dominated by a contract with strictly positive effort, as shown in Lemma 1.

The optimal effort level in the solution of the planner's problem will depend on the response of the probability of success to effort, $p(e)$, and on the sharing rule, α. In the optimal contract, the concessionaire does not assume exogenous risk, i.e., risk that depends on the demand for the project. However, the firm assumes endogenous risk, because the ancillary revenue depends on the effort e made by the private party The extent to which it assumes endogenous risk is determined by the value of α. Since R_f^* is independent of the state of demand v, and competition leads to $U(R_f) = u(0)$,[27] we also have that:

Corollary 1. *If the planner sets the optimal value of α, the optimal contract is implemented by any competitive auction where firms bid on R_f, i.e., a Present-Value-of-Revenue (PVR) auction. In this auction firms bid on R_f and the lowest bid wins the concession. The contract lasts until the present value of user fees collected by the concessionaire reaches the value of the winning bid. Income from ancillary services are not included in the winning bid nor do they influence the duration of the concession contract.*

2.5. Optimal choice of α

This section examines the optimal choice of α, i.e., the share of ancillary revenues that is appropriated by the concessionaire. The optimal choice of this parameter is a difficult problem, because α not only affects the revenues directly, but also the effort of the concessionaire. Moreover, since the other source of funds for the concessionaire varies exogenously, the ratio of the two sources of revenue will affect the choice of effort through the risk aversion of the concessionaire.

We have established conditions under which a small amount of effort is always preferred to zero effort, and thus the optimal value of α is strictly positive. However, it is difficult to solve the problem analytically, so we use numerical calcu-

[25] Recall that $u(0)$ is the outside option.
[26] $V(R_f; \alpha)$ and $U(R_f; \alpha)$ are defined by (13) and (14) where now we make explicit the dependence on α.
[27] The fact that U is strictly increasing in R_f is crucial here.

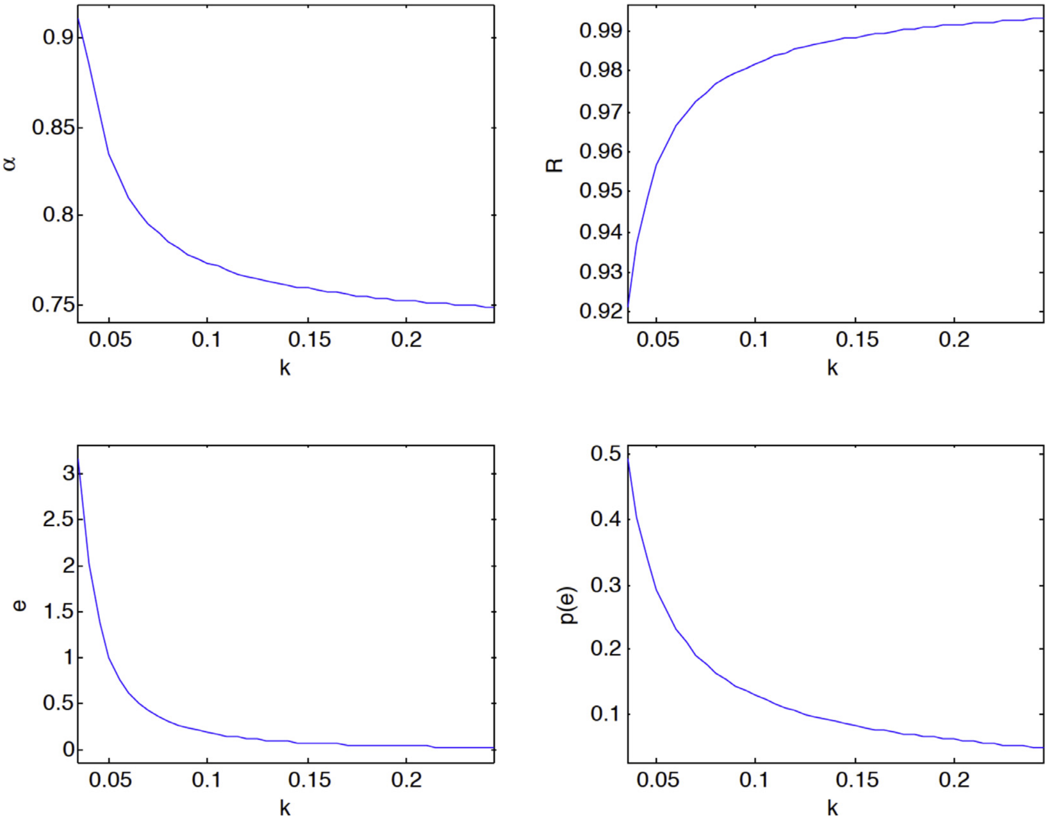

Fig. 1. Optimal α, R, e and $p(e)$ as a function of k.

lations. We use the utility function $u(c)=\frac{(c+1)^{(1-\rho)}}{1-\rho}$ and the probability of success function $p(e)=p_0e^{\gamma}$,[28] which increases with effort.[29]

The figures below show the planner's optimal choice of α as a function of k, ρ and p_0. They also show the value for R that results from the competitive auction for the franchise contract, the firm's optimal level of effort and the resulting probability of success.

Fig. 1 considers variations in the cost of effort parameter, k. As k increases, the optimal risk sharing arrangement assigns less risk to the firm, since the benefits of effort in terms of a higher probability of success become more costly. It follows that α is decreasing in k as shown in the top-left panel. Since the firm bears less risk for larger values of k, the guaranteed level of income R must grow, as shown in the top-right panel. Also, as shown in the bottom panels and consistent with a decreasing α, both effort exerted by the firm and the probability of success decrease with k.

Fig. 2 shows how the optimal values of α, R, e and $p(e)$ vary with the degree of risk aversion parameter ρ. The analysis is very similar to that of Fig. 1 once we notice that the only difference is that in this case it is a higher value of ρ, and not of k, that makes effort more costly.

Fig. 3 shows what happens when the probability scaling parameter, p_0, increases. As shown in the upper-left panel, larger probabilities of success increase the returns to having the firm bear risk, leading to higher values of α. As p_0 increases, the firm exerts more effort, the probability of success increases and the guaranteed revenue R decreases, as depicted in the bottom-left, bottom-right and top-left panels, respectively. Note that the firm assumes more risk as p_0 grows.

2.6. Practical application

Typically, optimal contracts in principal-agent models are too stylized and complicated to be implemented in practice. By contrast, and in an example of practice running ahead of economic theory, a particular case of our optimal airport concession contract has been implemented several times before this paper was written. Based on the many advantages of PVR auctions

[28] Strictly speaking, $p(e)=\min(1, p_0e^{\gamma})$

[29] Parameter values common across all figures are: $I=1$, $\bar{v}=1.2$ and $\gamma=0.5$. And in the two figures where their value remains fixed we have $p_0=0.3$, $\rho=2$ and $k=0.1$.

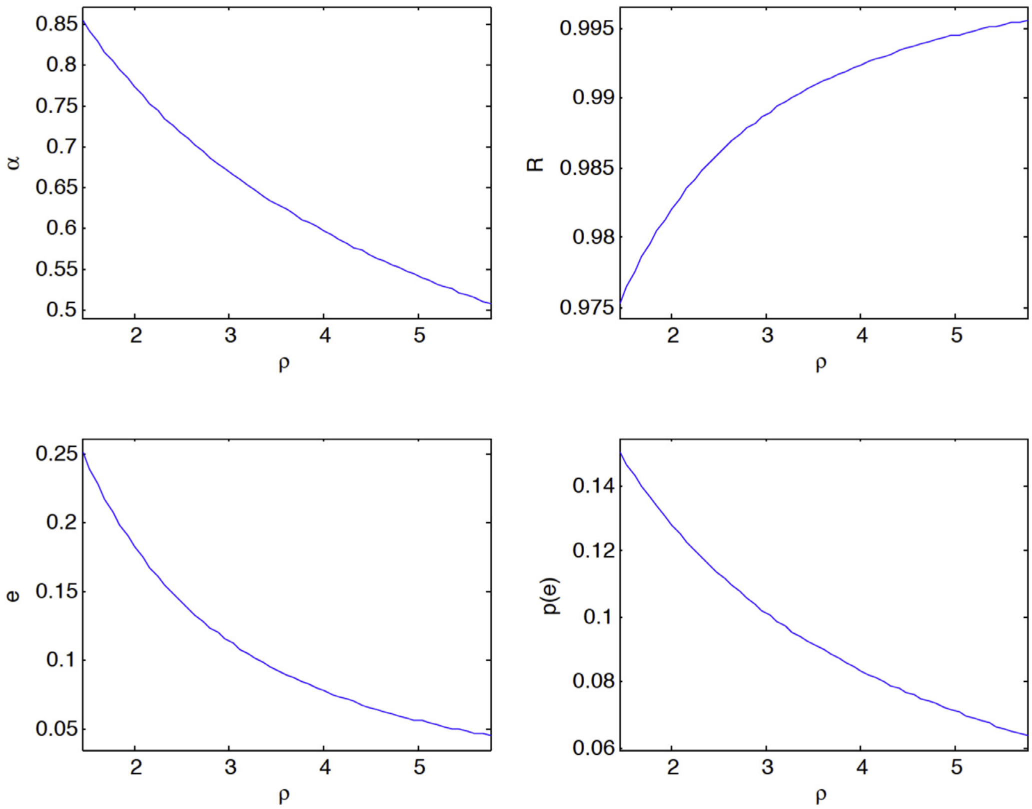

Fig. 2. Optimal α, R, e and $p(e)$ as a function of ρ.

Table 1
Airports auctioned with Present Value of Revenue mechanism, ($\alpha = 100\%$).

Airports concession	Date (month-year)	Winning bid//Investment (MM USD)
Diego Aracena 2, Iquique	11-2007	12.8/15.3
El Tepual 2, Puerto Montt	01-2008	15.5/23.4
Carlos Ibánez, Punta Arenas	11-2009	6.9/13.1
Aeropuerto de la Araucanía, Temuco*	03-2010	16.3/102.9
El Loa 2, Calama	01-2011	23.1/58.9
Cerro Moreno 2, Antofagasta	10-2011	11.2/32.1
Diego Aracena 3, Iquique	07-2012	0.0/8.0
La Florida 2, La Serena	09-2012	4.7/6.8
El Tepual 3, Puerto Montt	02-2014	-1.0/3.8
Total		89.6/264.3

Source: Data from Dirección de Concesiones, MOP. We assume 1UF=39.3USD. When the winning bid is zero or negative, the concession term is 48 months. *The winner received an annual subisdy of 15.9 MM USD during eight years.

for highway concessions,[30] the Chilean government has used auctions where firms bid on the present-value of aeronautical revenues and the firm that makes the lowest bid is awarded the airport. The resulting flexible term contract ends when aeronautical revenues collected are equal, in present value, to the winning bid. In these contracts there is no sharing of non-aeronautical revenues, i.e., $\alpha = 100\%$ which would be optimal if the concessionaire's risk aversion is relatively low.

Table 1 shows the airports that have been concessioned using PVR contracts on aeronautical revenues with $\alpha = 1$. The winning bid should be interpreted as a lower bound on investments made by the concessionaire, since non-aeronautical revenues will subsidize investments contemplated in the concession contract. This explains why some of the winning bids are so low.

[30] See section 3.3 in Engel et al. (2014) for a summary.

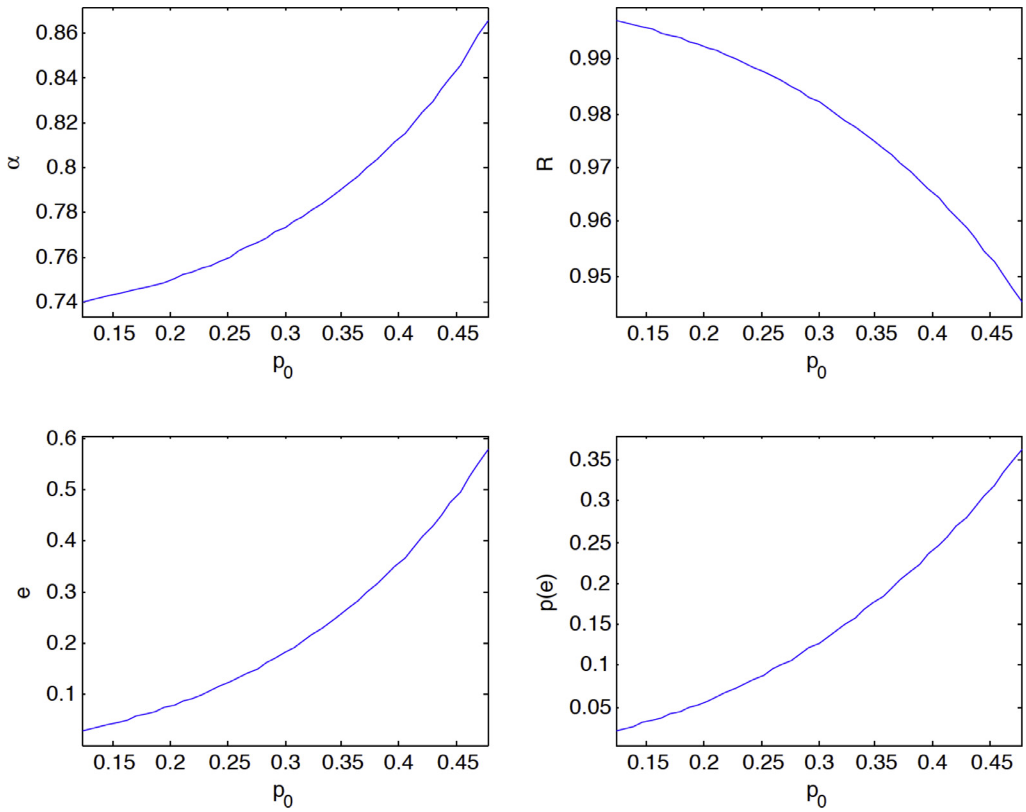

Fig. 3. Optimal α, R, e and $p(e)$ as a function of p_0.

3. Effort and aeronautical revenues

We have assumed that the airport concessionaire cannot affect the demand for aeronautical services. However, sometimes airports compete for passengers either with other major airports or with other modal means of transportation such as fast trains. In this case, which we consider in this section, an optimal contract should provide incentives to attract demand for the airport. In this extension we focus on the impact of the concessionaire's effort on demand for aeronautical services. For simplicity we ignore non-aeronautical revenues.[31]

The inspiration for our modeling structure are the contracts for airport PPPs in Sao Paulo and Rio de Janeiro in Brazil and in Santiago de Chile, which are hubs and compete with other hubs.[32] These contracts are fixed term contracts, with the obligation of mid-period expansion if a congestion trigger is reached. In Santiago's airport PPP contract, the cost of the expansion is paid either directly by the government or by reducing the revenues of the government and transferring them to the concessionaire, or through a mix of both if the revenues are insufficient.[33] The Santiago airport contract tries to ensure that no rents are collected by the concessionaire by mandating auctions for construction but it is very likely that the concessionaire can obtain rents by skillfully manipulating the terms of the auction. While the Public Authority can review the terms of auction for the construction contract, it cannot hope to eliminate all sources of rent. This means that attaining the demand that triggers the expansion of the airport results in a reward for the concessionaire. Thus the concessionaire will make investments and effort that increase the likelihood of attracting more passengers.[34]

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[31] The case where the concessionaire exerts two types of effort, one that affects demand for aeronautical services as in this section and another that impacts on demand for non-aeronautical services, as in Section 3, can be modeled combining insights from this and the preceding section. We have some preliminary results for this model, but the expressions obtained are rather complicated and do not add significant economic insight.

[32] Santiago competes against Buenos Aires and Lima, the Brazilian airports compete among themselves.

[33] The condition on congestion appears as point 1.15.1 in the PPP contract and the repayment mechanisms in 1.15.6 of the Santiago Airport PPP contract. For the case of the Brazil airports, see Mattos and Tokeshi (2016).

[34] As one participant in the concessions in the Sao Paulo and Rio airports puts it:

> "They might not compete that often on aeronautical fees (many times regulated anyway) but will offer better deals on VIP rooms, fast-track queuing arrangements for business passengers and better management of gate assignment reducing fuel costs by reducing how much airplanes have to move around once they land (to name some of the mechanisms used)." Helcio Tokeshi, personal communication.

One question is whether this type of contract provides efficient incentives. It is always possible to severely punish the failure to attain the congestion level, thus inducing the optimal effort level (Mirrlees, 1974). However, these punishments are rarely seen, because they are very sensitive to the preferences and beliefs of agents, as well as their ability to control the probability of events (Holmstron and Milgrom, 1987). In a dynamic setting, it is more robust to use linear reward schemes on variables such as revenue or traffic.

In our setting the linear demand schemes of Holmstron and Milgrom (1987) translate into a fixed reward when demand surpasses a given level. There is another dimension in which this type of reward may be appropriate: investment in airport expansion is not continuous but proceeds by discrete jumps in capacity. Thus the reward structure that we use is consistent with the technology of airport expansion in response to congestion.

We assume that an initial effort by the concessionaire increases the probability of higher demand and therefore revenues. In particular, the c.d.f. of v can be either F_1 or F_2, with F_1 FOSD F_2, i.e., $F_1(v) \le F_2(v)$, $\forall v$, with strict inequality at some v and where both distributions have common support $[\underline{v}, \bar{v}]$. The probability densities corresponding to F_1 and F_2 are denoted by f_1 and f_2. We assume that effort increases the probability $p(e)$ that v follows F_1, where $0 \le p(e) < 1$ and $p' > 0$, $p'' < 0$. For simplicity we assume that income from ancillary services is constant (and equal to zero).

The reward structure is as follows: there is a demand level $v_s \in (\underline{v}, \bar{v})$ that triggers a prize for the concessionaire if $v > v_s$. If R is the reward when $v \le v_s$ then $R(1+\alpha)$ is the reward if $v \ge v_s$. We show below that the efficient contract in this setting is induced by a PVR auction. We assume the assumptions made in Section 2 hold for all aspects we have not specified above, in particular, we assume that the planner maximizes expected consumer surplus.

The planner's problem is:

$$\begin{aligned} \max_{\{R,e\}} \quad & p(e)\left\{\int_{v_s}^{\bar{v}} [v-(1+\alpha)R]\, f_1(v)dv + \int_{\underline{v}}^{v_s} [v-R]\, f_1(v)dv\right\} \\ & +(1-p(e))\left\{\int_{v_s}^{\bar{v}} [v-(1+\alpha)R]\, f_2(v)dv + \int_{\underline{v}}^{v_s} [v-R]\, f_2(v)dv\right\} \end{aligned} \tag{15}$$

$$\begin{aligned} \text{s.t.} \quad u(0)+ke \le\ & p(e)\left\{\int_{v_s}^{\bar{v}} u((1+\alpha)R-I) f_1(v)dv + \int_{\underline{v}}^{v_s} u(R-I) f_1(v)dv\right\} \\ & + (1-p(e))\left\{\int_{v_s}^{\bar{v}} u((1+\alpha)R-I) f_2(v)dv + \int_{\underline{v}}^{v_s} u(R-I) f_2(v)dv\right\}, \end{aligned} \tag{16}$$

$$\begin{aligned} e = \ & argmax_{e'\ge 0}\, p(e')\left\{\int_{v_s}^{\bar{v}} u((1+\alpha)R-I) f_1(v)dv + \int_{\underline{v}}^{v_s} u(R-I) f_1(v)dv\right\} \\ & +(1-p(e'))\left\{\int_{v_s}^{\bar{v}} u((1+\alpha)R-I) f_2(v)dv + \int_{\underline{v}}^{v_s} u(R-I) f_2(v)dv\right\} - ke', \end{aligned} \tag{17}$$

$$R \le \underline{v}, \tag{18}$$

$$(1+\alpha)R \le v_s, \tag{19}$$

$$e \ge 0. \tag{20}$$

The planner's objective function (15) is the expected consumer surplus. This function is increasing with the concessionaire's effort, decreasing in the concessionaire's remuneration if unsuccessful, R, and increasing in the threshold v_s. The role played by whether non-aeronautical revenues materialize or not in the planner's problem (1)–(6) considered in Section 3 is now played by whether the concessionaire's effort yields high or low demand for aeronautical services. Constraints (16) and (17) are the participation and incentive compatibility constraints and (18) and (19) capture the self-financing constraints under both reward scenarios.

Now let $\mu_i \equiv \int_{\underline{v}}^{\bar{v}} v f_i(v)dv$, $\Delta\mu \equiv \mu_1 - \mu_2 > 0$; $F_i \equiv F_i(v_s)$; $\Delta F \equiv F_2 - F_1 > 0$; $u_h \equiv u((1+\alpha)R-I)$, $u_l \equiv u(R-I)$, $\Delta u \equiv u_h - u_l > 0$. We can rewrite the problem as:

$$\begin{aligned} \max_{\{R,e\}} \quad & p(e)(\mu_1 - R - \alpha R(1-F_1)) + (1-p(e))(\mu_2 - R - \alpha R(1-F_2)) \\ \text{s.t.} \quad & u(0)+ke \le p(e)[u_h(1-F_1)+u_lF_1] + (1-p(e))(u_h(1-F_2)+u_lF_2) \\ & e = argmax_{e'\ge 0}\, p(e')\{u_h(1-F_1)+u_lF_1\} + \left(1-p(e')\right)\{u_h(1-F_2)+u_lF_2\} - ke', \\ & R \le \underline{v}, \\ & (1+\alpha)R \le v_s, \\ & e \ge 0. \end{aligned}$$

Next we prove an analogue of Proposition 2 for this setting:

Proposition 3. *Given values of α and v_s, assume $\rho \equiv \min_{c\in[0,\theta I]}\rho(c) > \frac{\alpha}{1+\alpha}$ with $\rho(c)$ as in Definition 1. Then the optimal contract among those that pay R when $v < v_s$ and $(1+\alpha)R$ when $v > v_s$ has positive effort $e^* > 0$ and $R = R^*$ determined by $U(R^*) = u(0)$ with $\frac{I}{1+\alpha} < R^* < I$.*

Proof. Consider the planner's problem without the no-subsidy constraints (we check at the end if the solution satisfies the constraints). We also assume that the conditions for the application of the first-order approach are satisfied. Therefore, the planner's problem can be rewritten as:

$$\max_{\{R,e\}} \quad \mu_2 - (1+\alpha)R + p(e)[\Delta\mu - (\alpha R)\Delta F] + \alpha R F_2$$

$$s.t.$$

$$u(0) + ke \le u_h(1-F_2) + u_l F_2 + p(e)(\Delta u)(\Delta F)$$

$$k = p'(e)(\Delta u)(\Delta F)$$

$$0 \le e$$

To show the result, note that $I/(1+\alpha) < R < I$. Otherwise, effort would lead to losses always (if $R < I/(1+\alpha)$) or the concessionaire would have rents without effort ($R > I$). We ensure that positive effort is optimal when $R = I$ (and therefore when $R < I$) by the condition that $k \le p'(0)(\Delta u)(\Delta F)$ (see FOC of the incentive constraint).

Let $e(R)$ be the functional relationship obtained from the incentive compatibility constraint. Implicit differentiation of the ICC, combined with the properties of p and the assumption that $\rho > \alpha/(1+\alpha)$ (which, via an analogous argument to the one used to derive Lemma 2, implies that $(1+\alpha) < u_l'/u_h'$), show that $e'(R) < 0$. Then we can write the planner's and the firm utility as functions solely of R:

$$V(R) \quad = \mu_2 - (1+\alpha)R + p(e(R))[\mathrm{R}\Delta\mu - (\alpha R)\Delta F] + \alpha R F_2, \tag{21}$$

$$U(R) = u_h(R)(1-F_2) + u_l(R)F_2 + p(e(R))(\Delta u(R))(\Delta F) - ke(R). \tag{22}$$

V is decreasing in R if the condition $\Delta\mu > (\alpha R)\Delta F$ holds; that is, if the planner's expected benefit from successful effort is larger than the expected revenue foregone by providing the incentives. There is no reason why the planner should consider contracts that do not satisfy this condition since the planner only considers consumer surplus in her objective function.

The utility function of the concessionaire is increasing in R, since

$$U'(R) = (1+\alpha)u_h'[1 - pF_1 - (1-p)F_2] + u_l'[pF_1 + (1-p)F_2] - ke'(R) > 0.$$

Thus, when $R \in [I/(1+\alpha), I]$, the utility of the concessionaire falls with reductions in R, while that of the planner rises. It follows that there exists $R^* \in [I/(1+\alpha), I]$ such that $U(R^*) = u(0)$ and at that value, the objective function is maximized. Note also that the no-subsidy conditions are satisfied. □

Moreover, since $U(I/(1+\alpha)) < 0$ and $U(I) > 0$, a second price auction with identical bidders and with R as bidding variable implements the optimal contract, since by competition the expected utility of the concessionaire is 0. We have shown:

Corollary 2. *The optimal contract is implemented by a competitive auction where firms bid on R, i.e., a Present Value of Revenue (PVR) auction.*

Thus, this contract provides incentives for firms to exert optimal effort in airports which face an elastic demand.[35]

4. Conclusion

A major extension of El Loa Airport in northern Chile was tendered as a PPP by the Ministry of Public Works in January, 2011, after the expiration of the first PPP contract. The El Loa airport serves about 1.2 million passengers a year. The project considered 8.100 m^2 of new terminal space for shops and other ancillary businesses. Nonetheless, the winning firm concluded that the optimal increase in commercial space required an additional 2.000 m^2. The concessionaire obtained permission from the ministry to build a larger terminal. According to the concessionaire, the enlargement of the commercial area played a major role in the high profits reported by the concession during 2014, its first year of operation.

This example illustrates the motivation for this paper. Under a PPP the provider of airport services has strong incentives to invest during the construction phase to enhance the value of non-aeronautical services. These incentives are likely to be weaker, if present at all, under public provision.

In this paper we have shown that the optimal PPP contract when there are observable ancillary revenues –linear in demand– has the same form as the efficient contract when there are no ancillary revenues. The contract eliminates all

[35] Observe that there is another interpretation for these results. Assume that demand is fixed (as in Section 2). Then e could be effort (or investment) in non-observable cost reduction.

Table A1
Industry revenue (billion USD).

Region	Total	Aeronautical	Non-aeronautical	% Non-aero.
Africa	2.8	1.9	0.9	32
Asia-Pacific	31.6	15.8	15.8	50
Europe	44.3	26 0.1	18.2	41
LA+Carib	6.5	4.2	2.3	35
North America	25.3	14.3	11.0	43
Total	117.0	65.8	51.2	44

Notes: 2013 ACI Economics Report, Preview Edition.

exogenous risk for the concessionaire, while retaining a fraction of the endogenous risk which is required for efficient effort on ancillary revenues. Moreover, this contract can be implemented with a simple bidding procedure, a variant of the PVR auction proposed by Engel et al. (2001). We also show that, unless the concessionaire is very risk averse, he shares ancillary revenues with the Planning Authority .[36]

When the probability of success of effort is higher, the fraction of revenues needed to provide incentives is smaller, so a smaller fraction of ancillary revenues goes to the concessionaire. The same thing happens if the cost of effort goes down. Finally, as risk aversion increases, the concessionaire receives a larger share of ancillary revenue.

In an extension, we examined a simple case where demand for travelers depends on efforts by concessionaires (hubs or other important airports), but without ancillary revenue. We considered PPP contracts such as those for the airports of Sao Paulo, Rio de Janeiro and Santiago, which are characterized by additional investment if the airport reaches demand thresholds. This additional investment is profitable for the concessionaire, as it is associated to direct payments from the Treasury or to term extensions. We show that the optimal contract can be attained with a PVR auction, which provides efficient incentives to increase demand, in contrast to fixed term contracts.

Appendix A. Airport background

A1. Non-aeronautical revenues in airports

Airport revenues are usually divided into two classes, aeronautical and non-aeronautical. Aeronautical revenues are those directly related to the airport business. They include passenger charges, landing charges, terminal rental, security charges, ground handling, with the remaining covering items such as boarding bridge, cargo, fueling, airplane parking, utility and environmental and other minor charges. Non-aeronautical revenues are the other important source of income for airports. In 2012 U.S. airports had total revenues of $ 17,2 Billion and 45.2% came from non-aeronautical services.[37,38] According to the GAO report, since 2004 non-aeronautical revenues have been growing at 4% annually, while aeronautical revenues grew at the slower rate of 1.5%.

Table A.3 shows that the share of non-aeronautical revenue varies from a low of 32% in Africa to a high of 50% in Asia-Pacific. Because these numbers are for airports *in toto*, which are managed by a Transport Authority, they probably underestimate the share of non-aeronautical revenues. Indeed, most airport PPPs do not report all aeronautical revenue in their accounts, because landing fees are usually still assigned to the Authority responsible for air security and navigation. In Chile's main airport, for example, non-aeronautical fees represented 62.8% of total revenues of the PPP in 2011 (up from 58.3% in the previous year). Another reason for the importance of non-aeronautical revenues is that, as we have mentioned before, Graham (2009) shows that non-aeronautical revenues are more profitable for airports, and thus have more influence in their behavior.

A2. The relevance of airports with exogenous demand

Fig. A1 Thi shows that most trip segments in the world are served by one or two airlines, and there is no competition among these airports. Table A2 shows the airports per city. Table A3 shows the number of pairs of cities served by one or more airport-airline links.

[36] Even though our model assumes symmetric firms, it can be easily extended to the case with of bidders with heterogeneous costs when the mechanism to assign the concession is a second-price auction. The winner will receive rents equal to its cost advantage relative to the second lowest cost, but the remaining results are unchanged (see Krishna, 2010).

[37] Government Accounting Office, "Airport Funding: Aviation Industry Changes Affect Airport Development Costs and Financing," Washington DC: Government Accounting Office, 2014. Similarly, the 2013 ACI-NA Concessions Benchmarking Survey of November 2013 shows that of US$16.87 billion in total operational revenues at all airports in 2012, 44.8% was non-aeronautical revenue.

[38] The composition of non-aeronautical revenues is as follows: parking and transportation charges: 40.9%; rental car services: 19.7%; retail and duty free: 8,3%; food and beverages, 6,9%; terminal services, 5%; other services, 10.4%.

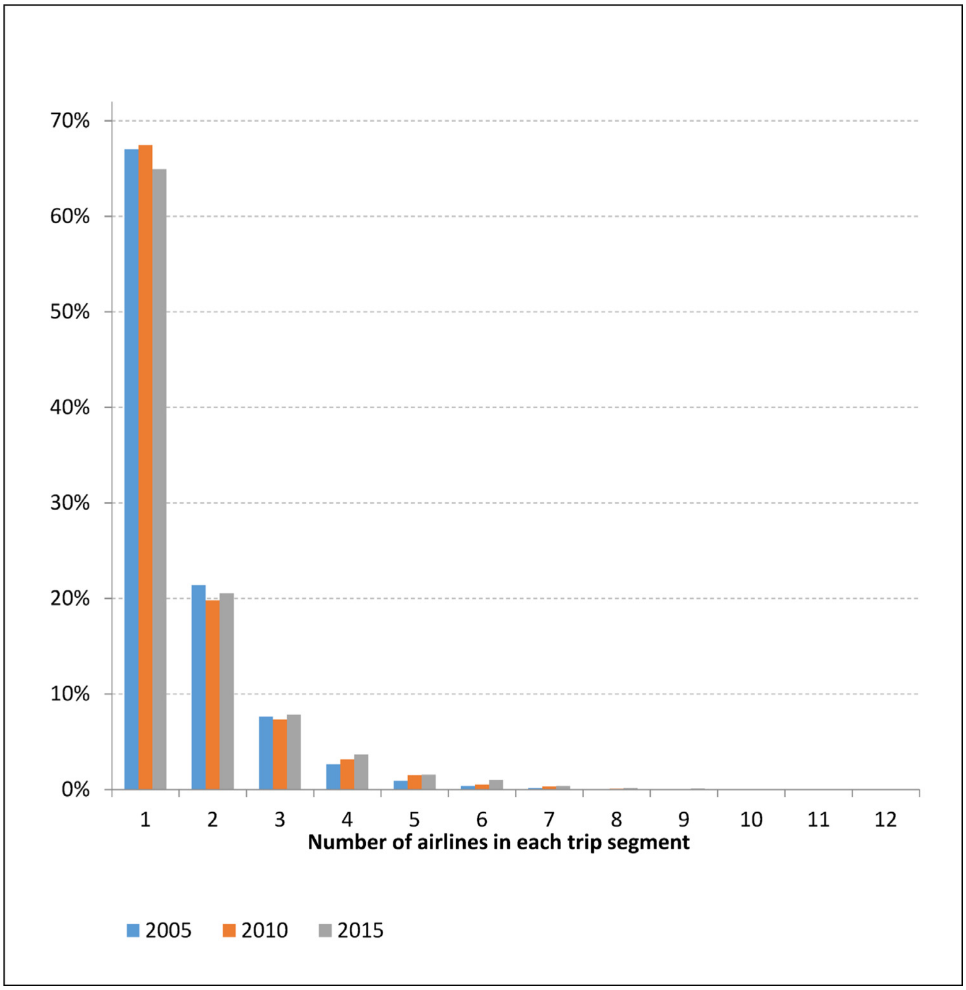

Fig. A1. Distribution of the number of airlines flying trip segments worldwide in several years. Source: A. Galetovic, using the *Data in, Intelligence Out* database.

Table A2
Number of airports per city.

# airports per city	Number of cities	%	Total airports
1	3,434	97.50	3.434
2	77	2.19	154
3	8	0.23	24
4	2	0.06	8
6	1	0.03	6
Total	3.522	100.00	3.626

Source: Ibid.

Table A3
Pairs of cities linked by one or more airline-airport pair.

City Pairs	Airports in city-pairs	Airport pairs	%
1,224	1	1,224	77%
71	2	142	9%
1	3	3	0%
2	4	8	1%
No information	213	213	13%
Total	**1,590**	**100%**	

Supplementary material

Supplementary material associated with this article can be found, in the online version, at 10.1016/j.trb.2018.05.001.

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