How to Regulate Airports?

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Abstract

Modern airports provide commercial services to passengers in addition to aeronautical services to airlines. We analyze how the airport's market power impacts the pricing of services when the airport also invests in the quality of its infrastructure. There is a need to regulate the airport and the optimal regulation can be implemented with a price-cap and a subsidy scheme targeted to the investment. The choice between a single-till and a dual-till approach does change neither the optimal regulation nor its implementation. We also investigate the consequences on the optimal regulation of the nature of the airport-airline relationship and of the observability of investment.

Keywords: airports; regulation; commercial services; investment.

JEL Code: L51, L93, L22.

1. Introduction

Motivation. Until the 1980s, most airports were publicly-owned companies. Airport privatization began with the privatization of seven airports in the UK, and notably three in the London area (Heathrow, Gatwick, and Stansted). Since then, this trend has gained traction all over the world.[1] According to the Airports Council International, over 40% of European Airports were partially or fully privatized in 2016 and those account for about three-quarters of total passenger traffic in Europe. The motive for privatization has generally been to improve operational efficiency and access to private sector financing.[2] However, unregulated privately-owned airports operate on a relatively captive market of both passengers and airlines and control "an essential facility" (runways, terminal buildings, navigational services). They thus have substantial market power that must be tamed in one way or another. Furthermore, non-aeronautical services such as commercial

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[1] See for instance Oum et al. (2004), Oum et al. (2006) and Hooper (2002).

[2] See Iossa and Martimort (2011).

activities (retailing services, car parking, office rental) are now a major source of revenues for airports.[3] This further raises concerns about the risk of market power abuse.

Accordingly, various forms of regulations have been adopted. Price-cap regulation has been widely used in Europe (UK, France, Spain, Germany, for instance) and consists in setting a cap on the prices that airport charge for providing services.[4] Some scholars have pointed out that such price-cap regulation might not even be needed because the presence of commercial activities provide airports with incentives to set relatively low aeronautical prices;[5] or that it distorts airports' incentives to invest.[6] Rate-of-return regulation is applied to foster investment in airports in Geneva, Zurich, Athens, Amsterdam among others.[7] It is however well-known that rate-of-return regulation leads to socially inefficient over-investment.[8] Last, whether commercial services ought to be included in the regulation of airports is a question that remains hotly debated.[9]

Main results. In this paper, we develop a simple framework to investigate these questions. An airport runs two activities. It supplies aeronautical services that an airline relies upon to provide transportation services to passengers. It also grants access to its facility to businesses that sell commercial services to passengers while they are at the airport. The airline company sets the final price for transportation services to passengers. To take into account the specific complementarity between demands of aeronautical and commercial services, we make two assumptions. First, only passengers may buy commercial services in the vicinity of the airport. Second, the decision whether to fly is solely based on the passenger's valuation for aeronautical services. The airport also invests in its infrastructure, which boosts the demand for aeronautical services.

Our results are as follows. First, we characterize the optimal regulatory policy, assuming that investment is observable and hence contractible. Socially optimal prices for aeronautical and commercial services obey a Ramsey-Boiteux pricing rule. In particular, both prices are above their corresponding social marginal cost to limit the use of costly public funds that are needed to ensure the industry breaks even. The socially optimal level of investment equates the marginal cost of investment and its marginal benefit, where the latter accounts for the increase in both the industry profit and the passengers' surplus when investment increases. We then compare the socially optimal outcome with the one that would obtain in an unregulated environment. As expected, prices tend to be excessive in the absence of regulation. However, two findings are worth mentioning. First, the unregulated airport may either over- or under-invest. This stems from the fact that the unregulated airport cares about the impact of investment on the marginal passenger whereas the regulator accounts for all infra-marginal passengers. Second, there is no straightforward connection between the socially optimal price for the airport's aeronautical services and the corresponding private marginal cost. It can be indeed socially optimal to price aeronautical services below the marginal cost since these services generate a positive externality on commercial services (but not the other way around).

[3] By now, they represent 40% of total airport revenues (ACI, 2017).

[4] Oum and Fu (2009) and Reynolds et al. (2018) discuss price-cap regulation for airports.

[5] See Beesley (1999) and Starkie (2001) for instance.

[6] See Czerny (2006) and Oum et al. (2004).

[7] See Reynolds et al. (2018).

[8] See Averch and Johnson (1962), and Tretheway (2001) and Kunz and Niemeier (2000) in the case of airports.

[9] This is generally referred to as "single-till" versus "dual-till" question.

When investment is not observable by the regulator, prices of both services have to be further distorted in order to provide the airport with incentives to invest. We then provide a numerical illustration that allows to compute welfare with and without regulation. We find that as commercial services grow, the unregulated airport invests excessively, reduces the price of aeronautical services but increases that of commercial services. Overall, regulation brings larger welfare gains when commercial services become a larger source of profits for the airport. However, that gain substantially shrinks when investment is not observable by the regulator and prices have to be distorted for incentives reasons.

Next, we focus on the implementation of the optimal regulation. We first show that a price-cap regulation alone does not provide enough incentives to invest. We then propose a scheme that fully implements the optimal regulation. It consists in a price-cap that encompasses both services supplied by the airport and a subsidy scheme that provides the airport with the optimal incentives to invest in the infrastructure. Indeed, when the firm is regulated on the prices of its services, it tends to under-invest; providing the correct incentives to invest requires then to subsidize the firm for its investment.

In passing, we touch upon the debate between the single-till and the dual-till approaches to airport regulation. In a dual-till regulation, the regulator decides that each service has to cover a given share of the investment cost. By contrast, in a single-till regulation all the airport's revenues contribute to finance the investment. The key point is that in a dual-till approach the regulator chooses the fraction of the investment cost covered by each service, leading to two budget constraints rather then one. At the optimum of a dual-till regulation, it must be that the opportunity cost of allocating one additional unit of investment is the same for both budget constraints. Hence, a dual-till approach is actually equivalent to a single-till one.

We then analyze the situation in which the vertical relationship between the airport and the airline company is plagued with some inefficiencies. More precisely, if the airport has a sufficiently large set of pricing instruments when dealing with the airline company, then everything happens as if they were integrated. The optimal regulation would then be unchanged. If, however, the relationship between the airport and the airline company creates some frictions (through a phenomenon of double marginalization in our context), then the optimal regulation has to be adapted accordingly.

Literature review. Most of the recent literature on airport regulation takes into account the interdependence between aeronautical and non-aeronautical services. Whether prices of each activity should be regulated and whether revenues from non-aeronautical services should cover a portion of airports' costs has been studied in Beesley (1999) and Starkie (2001). They conjecture that the interdependence of aeronautical and non-aeronautical services suffices to temper airports' abuse of market power and therefore advocate for the abolition of price-cap regulation. However, several contributions (including Zhang and Zhang 2003; Oum et al. 2004; Zhang et al. 2010; Yang and Zhang 2011) have shown that the presence of commercial activities only partially mitigates the incentives to set excessive prices of aeronautical services for unregulated airports. These studies build on the same interdependence assumption, which was firstly introduced by Zhang and Zhang (1997). Similarly to our approach, they assume that commercial activities do not affect individuals' decisions to fly and that their consumption is restricted to passengers. However, in our approach, we provide a micro-foundation for the pattern of demands and the complementarity between services. Czerny (2006), on the other hand, assumes that individuals take into account the consumption of commercial services when they decide whether to fly.[10] Under this assumption, he shows that price-cap regulation can implement optimal prices only if both aeronautical and commercial services are regulated. We broaden these analyses in various directions, most notably by taking into account the endogenous incentives of the airport to invest and the corresponding regulatory response.

Concerning revenues generated from commercial services, both theoretical and empirical works tend to favor the single-till regime at non-congested airports (Zhang and Zhang 1997; Czerny 2006; Yang and Zhang 2011; Czerny et al. 2016) whereas the dual-till regime seems preferable at congested airports (Oum et al. 2004; Lu and Pagliari 2004; Yang and Zhang 2011). We provide a different perspective, showing that these approaches are essentially equivalent once the sharing of the investment financing is chosen endogenously by the regulator.

Another recent strand of the literature, such as Ivaldi et al. (2015), Malavolti (2016) and Malavolti and Marty (2017) investigates airport regulation by adopting a two-sided market perspective. Finally, vertical relationships and arrangements between airports and airlines have notably been investigated by Zhang et al. (2010), Fu et al. (2011) and Yang et al. (2015).

Roadmap. Section 2 presents the model. Section 3 derives the optimal regulation and compares it with the unregulated airport case. Section 4 examines how the optimal regulation is modified when investments are non-verifiable. Section 5 uses a numerical example to discuss the extent to which regulation improves welfare. Section 6 shows that the optimal regulation can be implemented with a price-cap on both services augmented with a subsidy-penalty scheme targeted to the airport's investment. Section 7 investigates the consequences of the vertical separation between the airport and the airline. All proofs are in the Appendix.

2. THE MODEL

An airport provides aeronautical services to an airline company that provides transportation services to passengers.

There is a continuum of individuals with valuation $\tilde{v}$ for transportation services, where $\tilde{v}$ is drawn from a cumulative distribution $F(\cdot, e)$ on $[0, \overline{v}]$, with a strictly positive density $f(\cdot, e)$. Note that both the cumulative distribution and the density of $\tilde{v}$ depend upon the amount of investment e of the airport, as we will detail below. Hereafter, an individual who decides to buy transportation services from the airline company will be referred to as "a passenger."

We assume that only passengers can consume commercial services. Therefore, once a passenger is in the airport, we suppose that the passenger has a valuation $\tilde{v}_0$ for commercial services, where $\tilde{v}_0$ is drawn from a cumulative distribution $G(\cdot)$ on $[0, \overline{v}_0]$, with a strictly positive density $g(\cdot)$. Put differently, we consider that revenues from commercial activities are conditional upon revenues from aeronautical services. Indeed, passengers may want to consume commercial services once they entered the airport. It seems,

[10] As a result, a positive surplus generated by the consumption of commercial service can compensate for a negative surplus on aeronautical services. Although it may be true for some passengers (business) or when several airports are available for the same aeronautical services, we believe that our assumption better reflects the consumer decision to fly.

however, rather unlikely that a consumer not interested in transportation services has a demand for the airport's commercial activities. Commercial activities are complementary to aeronautical services, but the reverse is not true.

Demands for aeronautical and commercial services. Let p and p_0 denote unit prices of aeronautical and commercial services, respectively. The airport sets p_0 whereas the airline sets p. Following our assumption of unidirectional complementarity between aeronautical and commercial services, the utility of a consumer can be expressed as:

$$\max\{\tilde{v} - p, 0\} + \mathbb{1}_{\{\tilde{v}-p\geq 0\}} \max\{\tilde{v}_0 - p_0, 0\}.$$

The indicator function $\mathbb{1}_{\{\tilde{v}-p\geq 0\}}$ captures the unidirectional complementarity between aeronautical services and commercial activities. This formulation has two implications. First, only passengers (i.e., consumers with $\tilde{v} - p \geq 0$) can benefit from the consumption of commercial services. Second, when choosing whether to fly or not, consumers only take into account the surplus they can derive from consumption of aeronautical services.[11]

The demand for aeronautical services may be expressed as follows:

$$D(p, e) = \Pr\{\tilde{v} \geq p|e\} = 1 - F(p, e).$$

The price elasticity of this demand is denoted by:

$$\varepsilon(p, e) = -\frac{p\frac{\partial D}{\partial p}(p, e)}{D(p, e)} = \frac{pf(p, e)}{1 - F(p, e)}.$$

Although we do not explicitly model competition between airline companies, this feature could be captured through the elasticity of demand. For a given price p and level of investment e, the more competitive the airline industry is, the more elastic demand is.[12]

Demand for commercial activities depends upon both the price of aeronautical services p and the price of commercial activities p_0. For a given p_0, a passenger buys commercial services with probability $1 - G(p_0)$. Demand for commercial activities is obtained by taking the unidirectional complementarity for all customers:

$$D_0(p, p_0, e) = \int_{v\in[0,\overline{v}]} \mathbb{1}_{\{\tilde{v}-p\geq 0\}}(1 - G(p_0))f(v, e)dv = D(p, e)(1 - G(p_0)).$$

The elasticity of this demand with respect to the price of commercial services p_0 can be

[11]By way of comparison, the indirect utility of a consumer in Czerny (2006) can be written as $\mathbb{1}_{\{\tilde{v}-p+\tilde{v}_0-p_0\geq 0\}}(\tilde{v} - p + \max\{\tilde{v}_0 - p_0, 0\})$ in our model. Therefore, it is such that consumers can enjoy commercial services only if they decide to fly. But it also implies that consumers can decide to fly even if they get a negative surplus from aeronautical services as long as it is compensated by a positive surplus from consumption of commercial services.

[12]Competition can be captured by changing the specification of the cumulative distribution function F. Indeed, assume that each consumer has an outside option for aeronautical services whose net valuation is a random variable $\tilde{w}$ drawn from a cumulative distribution $H(\cdot)$, with density $h(\cdot)$. The probability that the consumer is willing to pay p for aeronautical services, or equivalently, the residual demand, is as follows: $\tilde{D}(p, e) = \Pr\{\tilde{v} - p \geq \tilde{w}\} = \int_0^{\overline{v}} H(v - p)f(v, e)dv$. Therefore, the elasticity of demand can be expressed as: $\tilde{\varepsilon}(p, e) = -\frac{p\tilde{D}'(p,e)}{\tilde{D}(p,e)} = \frac{p\int_0^{\overline{v}} h(v-p)f(v,e)dv}{1-\int_0^{\overline{v}} H(v-p)f(v,e)dv}$.

expressed as a function of p_0 only:

$$\zeta(p_0) = -\frac{p_0 \frac{\partial D_0}{\partial p_0}(p, p_0, e)}{D_0(p, p_0, e)} = \frac{p_0 g(p_0)}{1 - G(p_0)}.$$

To ensure the quasi-concavity of the various optimization problems and the monotonicity of the equilibrium prices analyzed later on, we assume that distributions $F(\cdot)$ and $G(\cdot)$ satisfy the usual Monotone Hazard Rate Property: $\frac{\partial}{\partial v}(\frac{1-F(v,e)}{f(v,e)}) \leq 0 \ \forall v \in [0, \overline{v}]$ and $\frac{d}{dv_0}(\frac{1-G(v_0)}{g(v_0)}) \leq 0 \ \forall v_0 \in [0, \overline{v}_0]$. These assumptions guarantee that the elasticities for aeronautical services and commercial activities are both increasing in the price of the service concerned.

Investment in airport infrastructure. The airport can invest an amount $e \geq 0$ to enhance the quality of its infrastructure or to relieve congestion. We assume that investing in airport infrastructure directly leads to an increase in consumer demand for aeronautical services. More specifically, we assume that $F(\cdot, \hat{e})$ first-order stochastically dominates $F(\cdot, e)$ for any $\hat{e} > e$ (i.e., $F(v, \hat{e}) \leq F(v, e)$ for any $v \in [0, \overline{v}]$ and $\hat{e} > e$). This corresponds to the intuition that higher investment levels make higher valuations for aeronautical services more likely. Hence, $D(p, \hat{e}) \geq D(p, e)$ for $\hat{e} > e$.

Commercial activities also benefit from the investment undertaken by the airport. That benefit is indirect, though, and is channeled through the increase in the number of passengers: $D_0(p, p_0, \hat{e}) = (1 - G(p_0))D(p, \hat{e}) \geq D_0(p, p_0, e) = (1 - G(p_0))D(p, e)$ for $\hat{e} > e$.

Last, we assume that the investment increases the demand for aeronautical services, but at a decreasing rate: $\frac{\partial F}{\partial e}(v, e) \leq 0$ and $\frac{\partial^2 F}{\partial e^2}(v, e) \geq 0$, $\forall v \in [0, \overline{v}]$.

Costs. We assume that aeronautical and commercial services are produced at positive constant marginal costs c and c_0, respectively. Hence, the cost structure exhibits neither economies of scope nor economies of scale. However, we can still interpret the investment e as a fixed cost for setting up airport infrastructure. For future reference, let $c_{pr}(p_0) = c - (p_0 - c_0)(1 - G(p_0))$ denote the total private marginal cost of aeronautical services. This cost takes into account the marginal cost of aeronautical services minus the profits generated by commercial activities.

3. Benchmarks

The present section is organized as follows. First, we present the outcome in the absence of regulation. Then, we derive the optimal regulatory policy for prices of aeronautical and commercial services and examine how our results might shed some light on the debate about airport regulation. Finally, we investigate the optimal investment rule.

3.1. The Unregulated and Integrated Airport-Airline Company

Let us first consider the simple case in which the airport and the airline company are integrated and can freely choose both the prices of aeronautical and commercial services and the investment in the infrastructure.

The profit of the integrated firm writes as follows:

$$\Pi_I(p, p_0, e) = (1 - F(p, e))\left(p - c + (p_0 - c_0)(1 - G(p_0))\right) - e. \tag{3.1}$$

This expression contains the airline's profit, $(1-F(p,e))(p-c)$, and the airport's profit net of investment costs, $(1-F(p,e))(p_0-c_0)(1-G(p_0))-e$. In the absence of regulation, the integrated firm chooses (p,p_0,e) to maximize $\Pi_I(p,p_0,e)$. The solution to this problem is as follows.

Proposition 1. *The unregulated and integrated airport-airline company sets prices:*

$$\frac{p^m-c_{pr}(p_0^m)}{p^m}=\frac{1}{\varepsilon(p^m,e^m)}, \tag{3.2}$$

$$\frac{p_0^m-c_0}{p^m}=\frac{1}{\zeta(p_0^m)}, \tag{3.3}$$

and investment decisions solve:

$$-\frac{\partial F}{\partial e}(p^m,e^m)(p^m-c_{pr}(p_0^m))=1. \tag{3.4}$$

Equation (3.2) shows that the price of aeronautical services depends on the private marginal cost of production $c_{pr}(p_0)$. As $c_{pr}(p_0)<c$, it follows that p^m is lower than if no commercial services were carried out at the airport. Intuitively, the integrated firm is willing to decrease the price of aeronautical services since this boosts the demand for commercial services. Equation (3.3) illustrates that the integrated firm sets the standard monopoly price for commercial services since the demand for aeronautical services plays no role in that. Last, Equation (3.4) simply states that the marginal cost of the investment must be equal to its marginal benefit.

3.2. Socially Optimal Regulation

Let us now consider the optimal regulation of prices of aeronautical and commercial services and investment, still assuming that the airport and the airline are vertically integrated. Additionally, we allow the regulator to provide public subsidies T to the integrated structure.

Consumer surplus is given by the sum of the surplus generated by aeronautical services and the surplus generated by commercial services, taking into account the unidirectional complementarity between both activities. Formally, we obtain:

$$CS(p,p_0,e)=\int_{v\geq p}(v-p)f(v,e)dv+(1-F(p,e))\int_{v_0\geq p_0}(v_0-p_0)g(v_0)dv_0.$$

We can now define social welfare as the sum of consumer surplus (CS) and the profit of the integrated structure (Π_I+T), net of the social cost of public subsidies borne by the consumers-taxpayers:

$$W(p,p_0,e,T)=CS(p,p_0,e)-(1+\lambda)T+\Pi_I(p,p_0,e)+T,$$

where the parameter $\lambda>0$ stands for the cost of public funds.[13] The problem faced by the regulator is to set prices (p,p_0), the investment level e and the subsidy T to maximize welfare W subject to the constraint that the integrated firm breaks even ($\Pi_I+T\geq 0$). The solution is given in the next proposition.

[13] In developed countries, this cost is estimated at about 0.3. See Oum et al. (1992).

Proposition 2. *The socially optimal prices of aeronautical and commercial services* (p^{rb}, p_0^{rb}) *and investment level* e^{rb} *are given by:*

$$\frac{p^{rb} - c_s(p_0^{rb})}{p^{rb}} = \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon(p^{rb}, e^{rb})}, \tag{3.5}$$

$$\frac{p_0^{rb} - c_0}{p_0^{rb}} = \frac{\lambda}{1+\lambda}\frac{1}{\zeta(p_0^{rb})}, \tag{3.6}$$

$$-\frac{\partial F}{\partial e}(p^{rb}, e^{rb})\left(p^{rb} - c_s(p_0^{rb})\right) - \frac{1}{1+\lambda}\int_{v \geq p^{rb}} \frac{\partial F}{\partial e}(v, e^{rb})dv = 1, \tag{3.7}$$

where $c_s(p_0) = c_{pr}(p_0) - \frac{s_0(p_0)}{1+\lambda} < c$ *is the social marginal cost of aeronautical services, with* $s_0(p_0) = \int_{v_0 \geq p_0}(v_0 - p_0)g(v_0)dv_0$.

The social marginal cost of aeronautical services $c_s(p_0)$ must take into account not only the profit but also the consumer surplus generated by commercial activities, weighted by the social cost of public funds.[14] Hence, the social marginal cost of aeronautical services is lower than c, the marginal cost of production, but also lower than $c_{pr}(p_0)$, the total marginal cost of these services for the integrated firm.

In light of the above results, we are able to revisit some common wisdom on the debate about airport regulation.

First, the prices of both services must be greater than their associated social marginal cost. For aeronautical services, pricing at marginal cost would ignore the additional profits and surplus that could be derived from an increase in passengers also consuming commercial services. However, it is not optimal to price aeronautical and commercial services exactly at their social marginal cost as the cost of public funds is positive.

Second, the price of aeronautical services does not necessarily cover the marginal cost of production. Formally, Equation (3.5) rewrites as $p^{rb} - c_{pr}(p_0) = \frac{\lambda}{1+\lambda}\frac{p^{rb}}{\varepsilon(p^{rb},e^{rb})} - \frac{s_0(p_0)}{1+\lambda}$. This shows that the margin on aeronautical services may be either positive or negative. Intuitively, the socially optimal price of these services trades off an increase in the profit of the integrated structure motivated by the budget constraint and a decrease in the consumer surplus generated by aeronautical services and commercial activities. When the demand for aeronautical services is very elastic or when the surplus generated by commercial activities is large, it may be that $p^{rb} - c_{pr}(p_0) < 0$. In that case, the integrated firm's profit is negative absent any subsidies. This suggests that, even with a positive cost of public funds, the regulator may want to price aeronautical services below marginal cost and subsidize the integrated firm so as it breaks even. Notably, when commercial services generate a high consumer surplus, the regulator is more likely to set the price of aeronautical services below the marginal cost of production and must, therefore, provide a higher subsidy to ensure that the integrated firm breaks even.

Third, from Proposition 2, the price-cost margins $\frac{p^{rb}-c_s}{p^{rb}}$ and $\frac{p_0^{rb}-c_0}{p_0^{rb}}$ depend upon the inverse of the elasticity of aeronautical services and commercial activities, respectively. Therefore, more competition in the airline industry increases the elasticity of demand for aeronautical services and decreases the price-cost margin of the airline. However, the price-cost margin of commercial activities is not affected by this change in competition

[14] The weighting coefficient $1/(1+\lambda)$ simply expresses the fact that providing more profit to the integrated firm reduces the need to use costly public funds to ensure budget-balance.

in the airline industry. Again, this stems directly from the unidirectional externality between aeronautical services and commercial activities. Once the consumer is in the airport, the airport enjoys monopoly power on commercial services, regardless of the intensity of competition between airlines.

Let us now turn on to the optimal investment level characterized by Equation (3.7). A marginal increase in the level of investment e directly leads to an increase in the demand for aeronautical services. Note that the first term in the left-hand side of Equation (3.7) can be decomposed as:

$$-\frac{\partial F}{\partial e}(p^{rb}, e^{rb})\left(p^{rb} - c\right) - \frac{\partial F}{\partial e}(p^{rb}, e^{rb})\left(c - c_s(p_0^{rb})\right).$$

When e increases, $-\frac{\partial F}{\partial e}(p^{rb}, e^{rb})(p^{rb} - c)$ represents the increase of the airline's profit on the last unit sold whose sign is a priori ambiguous. The term $-\frac{\partial F}{\partial e}(p^{rb}, e^{rb})(c - c_s(p_0^{rb}))$ captures the positive benefit of an increase in e on the consumer surplus generated from commercial activities. Finally, $\frac{1}{1+\lambda}\int_{v \geq p^{rb}} \frac{\partial F}{\partial e}(v, e^{rb})dv$ represents the positive impact on the surplus of supra-marginal consumers, that is, consumers who would still buy aeronautical services even if their price were to increase slightly. When the airport invests, the mass of these supra-marginal consumers increases.

Before going further, let us note that if the regulator cannot use public subsidies to ensure that the firm breaks even, then the optimal regulation is still given by Equations (3.5), (3.6) and (3.7) in which the shadow cost of public funds λ is replaced by the Lagrange multiplier associated to the break-even constraint $\Pi_I \geq 0$. Hence, our previous discussion continues to apply in that case.

4. NON-VERIFIABLE INVESTMENTS

So far, we have assumed that the level of investment e was verifiable and hence contractible. However, the level of investment may not always be fully contractible. This can come from intangible investment opportunities or difficulties in measuring investment returns. In this section, we investigate how prices and investment are affected by the non-verifiability of investments.

The main change is that the airport now chooses e to maximize its profits. This implies that the regulator faces an additional constraint, namely the moral hazard incentive constraint associated to investment:

$$e = \arg\max_{\tilde{e}} \left(1 - F(p, \tilde{e})\right)\left(p - c_{pr}(p_0)\right) - \tilde{e}.$$

In other words, the set of feasible levels of investment is restricted to the set of e that maximize the airport's profit for each value of p and p_0. The first-order condition associated to this problem writes as:

$$-\frac{\partial F}{\partial e}(p, e)\left(p - c_{pr}(p_0)\right) = 1. \tag{4.1}$$

Contrary to the optimal investment rule defined by Equation (3.7) for the case of an observable investment, the airport only perceives the private cost when choosing the investment. This private cost ignores the social benefits on consumer surplus generated by both increased aeronautical services and commercial activities when investment increases.

Let μ be the Lagrange multiplier associated with the incentive constraint (4.1). When prices are set at their Ramsey-Boiteux levels, if the following holds:

$$-\frac{\partial F}{\partial e}(p^{rb}, e^{rb})\big(p^{rb} - c + (p_0^{rb} - c_0^{rb})(1 - G(p_0^{rb}))\big) > 1, \tag{4.2}$$

then Ramsey-Boiteux prices as defined by Proposition 2 do not provide enough incentives to invest in the infrastructure. Put differently, Condition (4.2) ensures that $\mu > 0$ at the optimum of the regulator.

The optimal regulatory policy can be easily characterized following the analysis undertaken in Section 3.

Proposition 3. *Suppose that the level of investment is non-verifiable and that $\mu > 0$ (i.e., Equation (4.2) holds). The social optimum obtained by regulating both prices of aeronautical services and commercial activities has the following properties:*

- *The price of aeronautical services is given by:*

$$\frac{p^{nv} - c_s(p_0^{nv})}{p^{nv}} = \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon(p^{nv}, e^{nv})}\left(1 - \frac{\mu}{\lambda}\left(\frac{\left(\frac{\partial F}{\partial e}\right)^2 - \frac{\partial^2 F}{\partial e \partial v}}{(1-F)\frac{\partial F}{\partial e}}\right)(p^{nv}, e^{nv})\right). \tag{4.3}$$

  The sign of $\left(\frac{\partial F}{\partial e}\right)^2 - \frac{\partial^2 F}{\partial e \partial v}$ is a priori ambiguous, so that the investment can move either upward or downward with respect to the Ramsey-Boiteux level.

- *The price of commercial services moves upward with respect to the Ramsey-Boiteux price:*

$$\frac{p_0^{nv} - c_0}{p_0^{nv}} = \frac{\lambda}{1+\lambda}\frac{1}{\zeta(p_0^{nv})} - \frac{\mu}{1+\lambda}\frac{\frac{\partial F}{\partial e}(p^{nv}, e^{nv})}{1 - F(p^{nv}, e^{nv})}\left(\frac{1}{\zeta(p_0^{nv})} - \frac{p_0^{nv} - c_0}{p_0^{nv}}\right) > \frac{\lambda}{1+\lambda}\frac{1}{\zeta(p_0^{nv})}. \tag{4.4}$$

- *The optimal investment moves downward with respect to the Ramsey-Boiteux level:*

$$-\frac{\partial F}{\partial e}(p^{nv}, e^{nv})\left(p^{nv} - c_s(p_0^{nv})\right) - \frac{1}{1+\lambda}\int_{p^{rb}}^{\overline{v}} \frac{\partial F}{\partial e}(v, e^{rb})dv = 1 - \frac{\mu}{1+\lambda}\frac{\frac{\partial^2 F}{\partial e^2}(p^{nv}, e^{nv})}{\frac{\partial F}{\partial e}(p^{nv}, e^{nv})} > 1. \tag{4.5}$$

When the investment level is non-verifiable, the airport lacks incentives to invest at the Ramsey-Boiteux price levels because, for these prices, the airport's margin is too low and investing to create demand is not interesting enough. Therefore, in order to increase the airport's incentives to invest, the regulator sets a higher price on commercial services so that the airport's margin increases when investment increases. A similar logic applies to aeronautical services, but with a twist: increasing the price of aeronautical services increases the airport's margin and thus reinforces the incentives to invest; however, this also changes the composition of demand (as embodied by the term $\frac{\partial^2 F}{\partial e \partial v}$ in Equation (4.3)) and may decrease incentives to invest if investment changes the demand in an unfavorable way.[15]

5. UNREGULATED MONOPOLY VS RAMSEY-BOITEUX OPTIMUM: DISCUSSION

In our model, welfare is always higher when the airport is regulated than when it is left unregulated. In practice, though, regulation entails some costs and may be justified only when prices are deemed sufficiently excessive or the investment is insufficient. That the unregulated airport charges excessive prices with respect to the social optimum is immediate and results from the sheer monopoly market power of the airport. It is, however, less clear that the unregulated airport always under-invests with respect to the social optimum. Inspecting the two first-order conditions (3.4) and (3.7) shows that, a priori, the unregulated airport may either over- or under-invest with respect to what would be socially desirable. The reason is that the unregulated airport cares about the impact of investment on the marginal passenger; by contrast, the social planner is interested in the impact of investment on the infra-marginal passengers.

To illustrate, consider the following first illustration. First, we consider the case of no shadow cost of public funds: $\lambda = 0$. Second, distributions for the services are given by $F(v, e) = v \exp^{-\alpha e(1-v)}$ and $G(v_0) = v_0/\overline{v}_0$. The valuation for aeronautical services v is thus distributed on $[0, 1]$ and parameter α relates to the impact of the airport's investment on the demand for aeronautical services. Intuitively, as α increases, investment generates more high-valuations passengers. The valuation for commercial services is distributed according to the uniform distribution on $[0, \overline{v}_0]$. In the sequel, $\overline{v}_0$ is interpreted as the relative importance of commercial services relative to aeronautical services.

Let us start by comparing the prices of the services. It comes immediately that $p_0^{rb} = c_0 < p_0^m$ and $p^{rb} = c - s_0(c_0) = c - (\overline{v}_0 - c_0)^2/(2\overline{v}_0) < p^m$. Since the shadow cost of public funds is nil, the regulator prices commercial services at marginal cost. Since aeronautical services create a positive externality on commercial services, the regulator prices aeronautical services below their marginal cost; that price may even become negative as commercial services bring higher surplus to passengers.

As commercial services become more important (that is, as $\overline{v}_0$ increases), the unregulated airport reduces the price of aeronautical services. However, that price decrease is sufficient neither in level nor in structure with respect to the Ramsey optimum. Put differently, although the development of commercial services provides the airport with the incentives to lower the price of aeronautical services, there remains a scope for regulation because such price reduction is insufficient. Moreover, as $\overline{v}_0$ increases, the unregulated airport increases the price of commercial services. Summarizing, the development of commercial services changes the exercise of market power by airports but regulation is still required to curb the unregulated airport's market power.

The next figures compute the prices of aeronautical and commercial services as functions of the development of commercial services.[16]

[15] When $\frac{\partial^2 F}{\partial e \partial v} \leq 0$, increasing e implies that the demand for aeronautical services becomes steeper. This effect has to be sufficiently strong to lead to a lower price of aeronautical services.

[16] The values of parameters we use are: $\lambda = 0$, $\alpha = 15$, $c = .1$, $c_0 = .1$. Simulations are performed using Mathematica. Files are available on the authors' webpages.

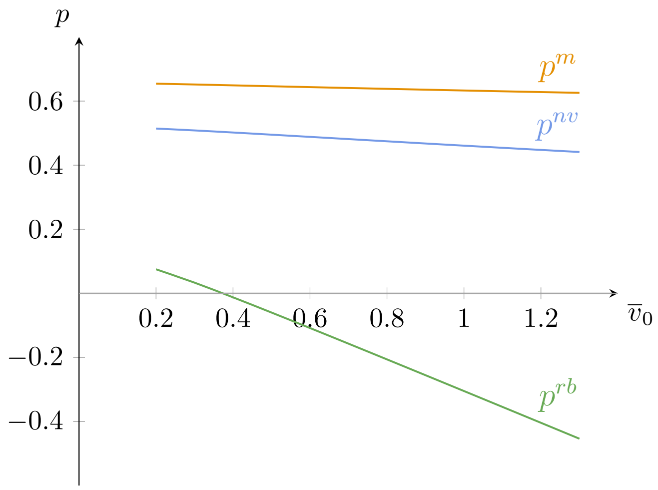

Figure 1: Price of aeronautical services in the Ramsey-Boiteux benchmark (p^{rb}), the unregulated monopoly case (p^m), and when investment is non-verifiable (p^{nv}), as functions of the importance of commercial services ($\overline{v}_0$).

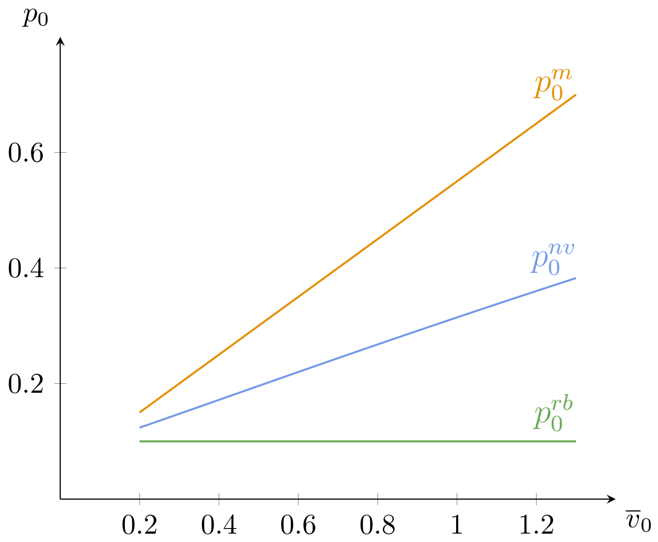

Figure 2: Price of commercial services in the Ramsey-Boiteux benchmark (p_0^{rb}), the unregulated monopoly case (p_0^m), and when investment is non-verifiable (p_0^{nv}), as functions of the importance of commercial services ($\overline{v}_0$).

Next, consider the investment level. The next figure presents a numerical simulation of the investment level in the regulated and the unregulated cases. The unregulated airport does not systematically under-invest with respect to the socially optimal outcome. It turns out that when commercial services are sufficiently important, the unregulated airport over-invests with respect to what would be socially desirable. Intuitively, the unregulated airport tends to over-invest when it has the possibility to exert a high market power on the commercial and aeronautical services. Over-investment and excessive market power go hand-in-hand.

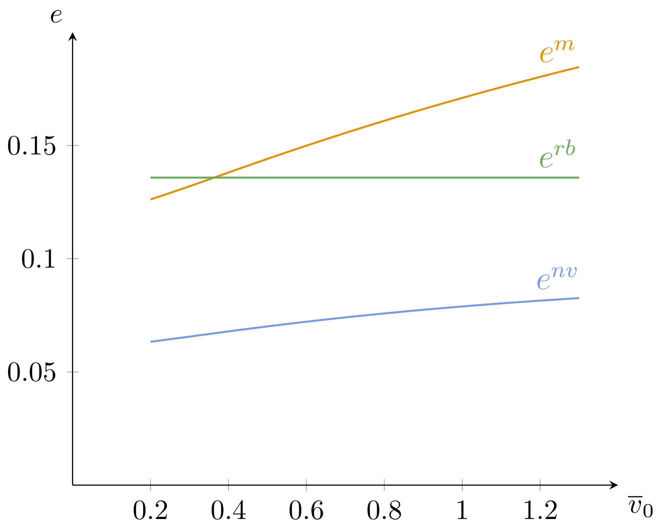

Figure 3: Investment level in the Ramsey-Boiteux benchmark (e^{rb}), the unregulated monopoly case (e^m), and when investment is non-verifiable (e^{nv}), as functions of the importance of commercial services ($\overline{v}_0$).

Another question we want to address is how much welfare is lost by not regulating the airport. In the next figure, we compute welfare in the Ramsey-Boiteux and the unregulated benchmarks, and express the percentage of Ramsey-Boiteux welfare that is reached if the airport is left unregulated. The simulation suggests that as commercial services become more important, the need for regulation is reinforced. Even though the unregulated airport lowers the price of aeronautical services, it also exercises a substantial market power on commercial services and tend to over-invest when commercial services become more important relative to aeronautical services.

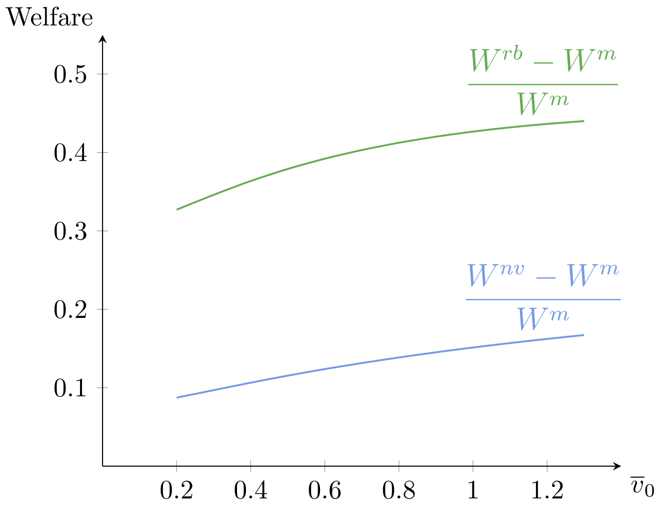

Figure 4: Welfare gain associated to regulation when investment is verifiable and when it is not, as functions of the importance of commercial services ($\overline{v}_0$).

Last, let us briefly consider how the non-verifiability of the investment impacts the comparison between regulation and no regulation. As expected, non-verifiability leads to a lower investment and higher prices with respect to the Ramsey-Boiteux benchmark. Perhaps more strikingly is the fact that the welfare gain associated to regulation becomes much smaller. This shows that the informational cost of regulation may severely impact the efficiency of regulation.

6. Implementation

We now turn to the question of implementing the optimal regulation. We investigate the traditional use of price-cap regulation and show that it fails to provide incentives for implementing the optimal level of investment. We then show that an additional policy must supplement the price-cap regulation. We also discuss the dual-till versus single-till approaches.

6.1. Failures of Price-cap Regulations

In a price-cap regulation, the airport is free to choose any combinations of prices and level of investment (p, p_0, e) as long as the following condition is satisfied:

$$w\,p + w_0\,p_0 \leq \overline{p}, \tag{6.1}$$

where the coefficients (w, w_0) and the cap $\overline{p}$ are chosen by the regulator. Hence, the integrated firm faces the following optimization problem:

$$\begin{aligned} \max_{(p,p_0,e)} \quad & (1 - F(p, e))\,(p - c + (p_0 - c_0)(1 - G(p_0))) - e \\ \text{s.t.} \quad & (6.1). \end{aligned}$$

Observe that the price-cap does not constrain the investment level. Hence, the choice of investment is still guided by the same condition as in the unregulated case, namely Equation (3.4). Therefore, even if the regulation with a price-cap may lead the firm to choose a correct structure of prices, that regulation certainly fails to simultaneously bring the investment to its socially optimal level.[17] Intuitively, a price-cap regulation alone is not constraining-enough when the integrated firm undertakes non-price decision.

6.2. Price-Cap Augmented with a Subsidy Scheme

To implement the optimal regulation of investment, we propose the following policy:

- a price-cap $(w, w_0, \overline{p})$ on aeronautical and commercial services;
- a subsidy scheme for the investment, according to which the firm receives s per unit of investment.

With such regulation, the integrated firm's profit writes as follows:

$$(1 - F(p, e))\,(p - c + (p_0 - c_0)(1 - G(p_0))) - e + s\,e.$$

[17] Observe that a price-cap regulation alone certainly departs from the Ramsey-Boiteux prices, for prices of commercial and aeronautical services impact the firm's incentives to invest.

The integrated firm determines the prices of both services (p, p_0) and the investment level e so as to maximize its profit while satisfying the price-cap constraint:

$$w\,p + w_0\,p_0 \leq \overline{p}.$$

Next proposition shows that with an adequate choice of the weights (w, w_0) and the cap $\overline{p}$ as well as the unit subsidy s, the regulator can indeed implement the socially optimal regulation.

Proposition 4. *The socially optimal regulation can be implemented by combining a price-cap regulation and a subsidy-penalty scheme on investment.*

The price-cap is given by:

$$\begin{aligned} w^* &= 1 - F(p^{rb}, e^{rb}) + s_0(p_0^{rb}) f(p^{rb}, e^{rb}), \\ w_0^* &= \big(1 - F(p^{rb}, e^{rb})\big)\big(1 - G(p_0^{rb})\big), \\ \overline{p}^* &= w^* p^{rb} + w_0^* p_0^{rb}. \end{aligned}$$

The unit subsidy is given by:

$$s^* = -\frac{\partial F}{\partial e}(p^{rb}, e^{rb}) \frac{s_0(p_0^{rb})}{1+\lambda} - \frac{1}{1+\lambda} \int_{p^{rb}}^{\overline{v}} \frac{\partial F}{\partial e}(v, e^{rb}) dv > 0.$$

Intuitively, the regulator has now enough instruments to implement the socially optimal regulatory policy. Indeed, given an investment level, a price-cap allows to implement the corresponding Ramsey-Boiteux prices. Given some prices for aeronautical and commercial services, a subsidy scheme provides the integrated firm with the socially optimal incentives to invest in the infrastructure.

This intuition is made formal in the Appendix. Here, we simply note that the so-regulated integrated firm chooses an investment level such that:

$$-\frac{\partial F}{\partial e}(p, e)\,(p - c + (p_0 - c_0)(1 - G(p_0))) - s = 1.$$

Hence, when the unit subsidy is $s = s^*$, and when prices are at the corresponding Ramsey-Boiteux levels, the integrated firm chooses the socially optimal level of investment. There is a need to subsidize the firm because, when it is regulated via a cap on the prices of its services, the firm tends to under-invest with respect to the social optimum. Hence, any price-cap regulation must go along with a subsidy scheme on invested capital. Omitting one dimension of this policy affects prices and investment and leads to a sub-optimal outcome.

6.3. Single-Till vs. Dual-Till Regulation

Any form of regulation requires non-negativity of the airport's revenues. As revenues from commercial activities are now significant for modern airports, whether these revenues should be included into the price-cap formula has been a hotly debated question. This question is commonly referred to as the single-till versus the dual-till approach. Under a single-till approach, commercial revenues are included into the airport's total revenues to compute the price-cap formula. Under a dual-till approach, they are not. Single-till and dual-till approaches have been discussed in the literature and the conclusions differ from one paper to another. For instance, Beesley (1999) is one of the first to attack the single-till approach but he also recognizes the difficulties to adopt a dual-till approach in practice. By contrast, Starkie (2001) supports the dual-till approach, arguing that it could alleviate distortions on aeronautical prices and on investment incentives induced by the single-till approach.[18]

We now address this question within our framework, assuming no lump-sum transfers from the regulator.[19] We find that both approaches are actually equivalent and the distinction between them is thus irrelevant.

Observe that we have implicitly assumed so far a single-till regime for the price-cap regulation. Let us now assume a dual-till regime wherein revenues generated by commercial activities must cover a fraction α ($\alpha \in [0,1]$) of the investment (e). This leads to a first budget constraint on commercial activities:

$$(1 - F(p,e))(1 - G(p_0))(p_0 - c_0) - \alpha e \geq 0. \tag{6.2}$$

Likewise, revenues generated by aeronautical services must cover the remaining investment cost $(1-\alpha)e$, which leads to a second budget constraint:

$$(1 - F(p,e))(p - c) - (1-\alpha)e \geq 0. \tag{6.3}$$

The problem of the regulator is then to maximize social welfare subject to the two budget constraints (6.2) and (6.3).[20] In the dual-till approach, the regulator is able to choose how to allocate the investment cost on each budget constraint. We obtain the following result.

Proposition 5. *The optimal regulation of aeronautical services, commercial activities and investment under a dual-till approach is identical to the one obtained in Proposition 2.*[21]

Intuitively, the allocation of the investment cost will depend upon which constraint is "more likely" to bind, i.e., the constraint that is the hardest to satisfy. At the optimum, the allocation of the investment cost must be such that the opportunity cost of allocating one additional unit of investment is the same for the two budget constraints. But when both constraints have the same opportunity cost (i.e., the same value for the associated Lagrange multiplier), then (6.2) and (6.3) are equivalent to the integrated firm's break-even constraint. Intuitively, the optimal regulation does not depend upon the choice of a single-till regime or a dual-till regime.

It is however possible that there exists no interior value of α that allows to equalize the shadow cost of the two budget constraints in a dual-till regime. This arises for instance

[18] Oum et al. (2004) are in line with Starkie (2001), while Lu and Pagliari (2004) and Czerny (2006) argue that the single-till approach dominates the dual-till one. See Czerny (2006) for a more detailed discussion.

[19] If the regulator could use transfers, then it is immediate to show that dual-till and single-till would always be equivalent, whatever the sharing of the financing of the investment cost.

[20] Constraints (6.2) and (6.3) ensure that the integrated firm earns a nonnegative profit.

[21] As explained in Section 3, with no transfers, the Ramsey-Boiteux outcome is similar to the one detailed in Proposition 2, except that the exogenous shadow cost of public funds is replaced by the endogenous Lagrange multiplier associated to the industry's break even constraint.

when the margin on one of the services is so low that all the burden of investment financing has to be put on the other more profitable service. In that case, a dual-till regime leads to additional distortions and is dominated by a single till regime.

7. Vertical separation

We now relax the assumption that the airport and the airline are vertically integrated. This airport-airline relationship is now run by a contract between the two entities. The airport provides aeronautical services to the airline (landing rights, aircraft parking areas, airport taxiways, passenger facilities) and the airline is responsible for setting prices charged to consumers for transportation services. Investment decisions, however, are still carried out by the airport. We assume that the aeronautical services supplied by the airport and those supplied by the airline company are one-to-one complements.

We investigate how the optimal regulation is modified for two types of contracts between the airport and the airline. In both cases, the airport offers a unit price for aeronautical services. But the airport may or may not be able to also use a fixed fee for the services supplied to the airline company. For simplicity, we also assume that the airport has all the bargaining power in the relationship, i.e., the airport makes a take-it-or-leave-it offer to the airline company.[22]

7.1. Fixed Access Charge

First, we consider that the airport can set both a fixed access charge A and a unit price w for aeronautical services. When the airline sets p, demand for aeronautical services is $1-F(p,e)$ so that it has to buy the same quantity of aeronautical services to the airport at unit price w. Formally, the airline solves:

$$\max_p \,(p-w-c)(1-F(p,e))-A.$$

Notice that the price p set by the airline depends upon the level of investment e chosen by the airport. The first-order condition of this problem writes as follows:

$$p = w + c + \frac{1-F(p,e)}{f(p,e)}. \tag{7.1}$$

Under our assumptions on distribution F, there is a one-to-one correspondence between the airport's unit price w and the airline company's price for aeronautical services p. It follows that choosing the level of investment e and the unit price w uniquely determines the price to passengers p set by the airline for aeronautical services. Let $P(w,e)$ denote the solution to the airline's first-order condition (7.1).

Once the unit price w has been set, the airport must decide the level of the fixed access charge A. As the airport has all the bargaining power, the fixed access charge is

[22] The assumption that the airport has all the bargaining power can be justified in environments where airlines are engaged in fierce competition to access to the airport facilities. Moreover, airlines may have limited access to close substitutes, although this idea may not hold for low-cost carriers. Major airports may also have significant market power over dominant carriers due to the non-substitutability and to the cost of moving away from major hubs. See Gillen et al. (1988) and Oum and Fu (2009) for detailed discussions.

chosen so as to extract all the profit of the airline, that is:

$$A = (P(w,e) - w - c)(1 - F(P(w,e),e)) = \frac{(1 - F(P(w,e),e))^2}{f(P(w,e),e)}. \tag{7.2}$$

From Equation (7.2), and assuming that the airport can receive a lump-sum subsidy T from the regulator, the airport's profit writes as:

$$\big(1 - F(P(w,e),e)\big)\big(P(w,e) - c + (p_0 - c_0)(1 - G(p_0))\big) - e + T.$$

This profit is equivalent to the integrated structure's profits $\Pi_I(P(w,e), p_0, e) + T$ (see Equation (3.1)). The only difference is that p is replaced by $P(w,e)$, the price chosen by the airline for a given unit price w and a level of investment e.

As in Section 3, assume that the regulator can choose the level of investment e and the price of commercial activities p_0. It is not anymore possible to directly choose the final price of aeronautical service p, but if we assume that the regulator can choose the unit price w charged by the airport, then the following holds.

Proposition 6. *Assume the airport and the airline company are separated. Assume the airport can charge the airline both a fixed charge A and a unit price w for the its aeronautical services. Then, optimal regulation leads to the same outcome as in Proposition 2.*

Therefore, the optimal regulation is unchanged when contracts between the airport and the airline allow for both a unit price and a fixed access charge. As in the two-part tariff literature, a contract of the type (A, w) allows the airport to extract all the profit of the airline with A and w is set to maximize the profit of the replicated integrated structure. As we will see below, the fixed access charge is crucial for the result of Proposition 6.

7.2. No Fixed Access Charge

Assume now that the airport cannot use a fixed access charge A. In that case, the unit price w plays two roles: (i) it collects profit on the airline for each unit of aeronautical services provided and (ii) it determines the final price p and therefore how many units are eventually sold. Unfortunately, this distorts the prices of both services as well as the investment level.

The objective of the airline is the same as in the case with a fixed access charge and $P(w,e)$ is still set according to Equation (7.1). The airport, however, cannot extract the profit of the airline through a fixed charge and must at least break even, that is:

$$\big(1 - F(P(w,e),e)\big)\big(w + (p_0 - c_0)(1 - G(p_0))\big) - e + T \geq 0. \tag{7.3}$$

Due to the absence of fixed access charge, the only available tools to satisfy the previous break-even condition are the unit price w and the level of investment e. We then obtain the following result.

Proposition 7. *Assume the airport and the airline company are separated. Assume the airport can only charge the airline a unit price w for the its aeronautical services. Then, the optimal regulation of aeronautical services and commercial activities leads to the following prices (p^o, p_0^o) and level of investment e^o:*

- *The price of aeronautical services moves upward with respect to the Ramsey-Boiteux price:*

$$\text{(7.4)}\qquad \frac{p^o - c_s(p_0^o)}{p^o} = \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon(p^o,e^o)}\left(1 + \frac{1}{\frac{\partial P}{\partial w}(w^o,e^o)}\right) > \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon(p^o,e^o)},$$

- *The price of commercial services coincides with the Ramsey-Boiteux price:*

$$\text{(7.5)}\qquad \frac{p_0^o - c_0}{p_0^o} = \frac{\lambda}{1+\lambda}\frac{1}{\zeta(p_0^o)} > 0.$$

- *The optimal level of investment e^o moves downward with respect to the Ramsey-Boiteux level:*

$$\text{(7.6)}\qquad -\left(\frac{\partial P}{\partial e}(w^o,e^o)f(p^o,e^o) + \frac{\partial F}{\partial e}(p^o,e^o)\right)\left(p^o - c_s(p_0^o) - \frac{\lambda}{1+\lambda}\frac{1-F(p^o,e^o)}{f(p^o,e^o)}\right) - \frac{1}{1+\lambda}\int_{p^o}^{\overline{v}}\frac{\partial F}{\partial e}(v,e^o)dv = 1$$

The airport cannot extract the airline company's profit through a fixed access charge. The airport must therefore use the unit price w as an instrument to satisfy the break-even condition (7.3). The unit price is distorted upward and the price of aeronautical services $P(w,e)$ set by the airline increases above its previous level. This effect is the standard double marginalization problem. In the absence of a fixed access charge, the vertical relationship between the airport and the airline raises the cost payed by the airline to access the airport facilities. The airline passes through this increase to the price of aeronautical services to consumers.

The optimal regulation rule for the investment also differs from the integrated structure case. Intuitively, reducing the investment level allows to lower the price charged by the airline company and somewhat alleviates the double marginalization issue illustrated above. Moreover, under vertical separation without access charge, the airline's profits do not contribute to the balancing of the budget of the airport; hence, they have a smaller social value, which also calls for reducing the airport's investment level.

Last, the price of commercial activities p_0 is unchanged and stays at the Ramsey-Boiteux price level ($p_0^o = p_r^{rb}$).

Overall, that the airport cannot use a fixed charge in its relationship with the airline company leads to socially costly distortions. Airports should thus be allowed to use a sufficiently rich set of pricing instruments in their contractual relationships with airlines.

8. CONCLUDING REMARKS

Modern airports are often privately-owned entities in charge of several activities. Besides their core business, aeronautical services provided to airline companies, airports also offer commercial services to passengers. The magnitude of revenues generated by commercial services and the captivity of passengers once they are at the airport has raised the question of extending the regulation to these activities in addition to that of aeronautical services.

The optimal regulation encompasses the prices of aeronautical and commercial services as well as investment decisions. Optimal prices follow a Ramsey-Boiteux pricing rule and, therefore, can be implemented with a price-cap that applies on both services. However, that price-cap must be augmented with a specific regulation that controls the airport's incentives to under-invest. This is the role of the subsidy-penalty scheme, which prevents any under- or over-investment in the infrastructure. We also show that the optimal regulation is unchanged in a dual-till regime in which the regulator can choose the fraction of investments that must be covered by the different sources of revenues. Last, we investigate the role of two frictions: a friction in the vertical relationship between the airport and the airline, which leads to a double marginalization phenomenon; an informational friction in the relationship between the regulator and the airport, when the former does not perfectly observe the investment undertaken by the latter.

Our analysis could be extended in various directions. Although competition between airlines could be modeled in reduced form as a change in the elasticity of the demand for transport services,[23] it would be interesting to consider imperfect competition with strategic interactions between airline companies. Additional distortions may then emerge in the optimal regulation. In a similar vein, not all airports have a monopoly market power. Whether competition between airports is a substitute for regulation remains an open question, especially in contexts where airports are multi-product firms. All these extensions are left for future research.

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[23]See the discussion in footnote 12.

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Appendix

Proof of Proposition 1. The unregulated airport chooses prices and the investment level to maximize its profit. Formally, the airport solves:

$$\max_{(p,p_0,e)} \Pi_I(p,p_0,e) = (1-F(p,e))\,(p-c+(p_0-c_0)(1-G(p_0)))-e.$$

First-order conditions of this problem write as:

$$\begin{aligned}
-f(p,e)\big(p-c+(p_0-c_0)(1-G(p_0))\big)+1-F(p,e)&=0,\\
(1-F(p,e))\big(1-G(p_0)-(p_0-c_0)g(p_0)\big)&=0,\\
-\frac{\partial F}{\partial e}(p,e)\big(p-c+(p_0-c_0)(1-G(p_0))\big)-1&=0.
\end{aligned}$$

Rearranging each equation and using $c_{pr}(p_0)=c-(p_0-c_0)(1-G(p_0))$ in the first and third equations, we obtain:

$$\begin{aligned}
p-c_{pr}(p_0)&=\frac{1-F(p,e)}{f(p,e)},\\
p_0-c_0&=\frac{1-G(p_0)}{g(p_0)},\\
-\frac{\partial F}{\partial e}(p,e)\big(p-c_{pr}(p_0)\big)&=1.
\end{aligned}$$

Dividing the first two equations by p and p_0, respectively, gives Equations (3.2) and (3.3). The last equation already corresponds to Equation (3.4). ■

Proof of Proposition 2. The regulator aims to maximize the social welfare subject to the nonnegativity of the integrated structure profit. This problem formally writes as:

$$\begin{aligned}
\max_{(p,p_0,e,T)} \quad & W(p,p_0,e,T)=CS(p,p_0,e)-(1+\lambda)T+\Pi_I(p,p_0,e)+T\\
\text{s.t.} \quad & \Pi_I(p,p_0,e)+T\geq 0.
\end{aligned}$$

Notice that the public subsidy T enters the problem linearly and negatively affects the regulator's objective function. The regulator therefore chooses T as low as possible until the nonnegativity constraint binds, i.e., $T=-\Pi_I(p,p_0,e)$. The problem now rewrites as:

$$\max_{(p,p_0,e)} \quad CS(p,p_0,e)+(1+\lambda)\Pi_I(p,p_0,e).$$

First-order conditions with respect to p and p_0 write:

$$-(1-F(p,e)) - f(p,e)s_0(p_0) + (1+\lambda)(-f(p,e)(p-c_{pr}(p_0)) + 1 - F(p,e)) = 0,$$
$$-(1-F(p,e))(1-G(p_0)) + (1+\lambda)(1-F(p,e))(1-G(p_0) - g(p_0)(p_0-c_0)) = 0,$$

where recall that $s_0(p_0) = \int_{v_0 \geq p_0}(v_0 - p_0)dG(v_0)$ and $c_{pr}(p_0) = c - (p_0 - c_0)(1-G(p_0))$. Rearranging and using the definition of the social marginal cost, $c_s(p_0) = c_{pr}(p_0) - \frac{s_0(p_0)}{1+\lambda}$, we obtain:

$$p - c_s(p_0) = \frac{\lambda}{1+\lambda}\frac{1-F(p,e)}{f(p,e)},$$
$$p_0 - c_0 = \frac{\lambda}{1+\lambda}\frac{1-G(p_0)}{g(p_0)}.$$

Dividing the first equation by p and the second one by p_0 yields Equations (3.5) and (3.6), respectively.

Consider now the optimal choice of investment. The first-order condition of the regulator's problem with respect to e writes as:

$$\int_p^{\overline{v}} (v-p)\frac{\partial f}{\partial e}(v,e)dv - \frac{\partial F}{\partial e}(v,e)s_0(p_0) + (1+\lambda)\Big(-\frac{\partial F}{\partial e}(v,e)(p-c_{pr}(p_0)) - 1\Big) = 0.$$

Integrating by part the first term of this equation yields:

$$\int_p^{\overline{v}} (v-p)\frac{\partial f}{\partial e}(v,e)dv = \Big[(v-p)\frac{\partial F}{\partial e}(v,e)\Big]_p^{\overline{v}} - \int_p^{\overline{v}} \frac{\partial F}{\partial e}(v,e)dv.$$

Notice that for $F(v,e)$ to be a well-defined cumulative distribution function with bounded support on $[0,\overline{v}]$, we must have that $\frac{\partial F}{\partial e}(\overline{v},e) = 0$ since $F(\overline{v},e) = 1$ for all e. Hence, we obtain:

$$\int_p^{\overline{v}} (v-p)\frac{\partial f}{\partial e}(v,e)dv = -\int_p^{\overline{v}} \frac{\partial F}{\partial e}(v,e)dv.$$

Plugging this result in the first-order condition with respect to e, dividing both sides by $(1+\lambda)$, and rearranging yields:

$$-\frac{\partial F}{\partial e}(v,e)\Big(p - c_{pr}(p_0) + \frac{1}{1+\lambda}s_0(p_0)\Big) - \frac{1}{1+\lambda}\int_p^{\overline{v}} \frac{\partial F}{\partial e}(v,e)dv = 1.$$

Finally, using the definition of the social marginal cost, $c_s(p_0) = c_{pr}(p_0) - \frac{s_0(p_0)}{1+\lambda}$, we obtain Equation (3.7). ■

Proof of Proposition 3. The regulator's problem writes as follows:

$$\begin{aligned}
\max_{(p,p_0,e,T)} \quad & W(p,p_0,e,T) = CS(p,p_0,e) - (1+\lambda)T + \Pi_I(p,p_0,e) + T \\
\text{s.t.} \quad & \Pi_I(p,p_0,e) + T \geq 0 \\
& -\frac{\partial F}{\partial e}(p,e)\big(p - c + (p_0 - c_0)(1-G(p_0))\big) = 1,
\end{aligned}$$

where the second constraint is Equation (4.1), the airport's incentive constraint. The first constraint is binding, i.e., $T = -\Pi_I(p, p_0, e)$ and the problem rewrites as follows:

$$\begin{aligned}\max_{(p,p_0,e)} \quad & W(p,p_0,e,T) = CS(p,p_0,e) + (1+\lambda)\Pi_I(p,p_0,e)\\ \text{s.t.} \quad & -\frac{\partial F}{\partial e}(p,e)\big(p-c+(p_0-c_0)(1-G(p_0))\big) = 1.\end{aligned}$$

Let $\mu \geq 0$ denote the Kuhn-Tucker multiplier associated with the incentive constraint. The first-order condition with respect to p writes as follows:

$$\begin{aligned}&-(1+\lambda)f(p,e)(p-c_s(p_0)) + \lambda(1-F(p,e))\\ &\qquad\qquad + \mu\Big(-\frac{\partial F}{\partial e}(p,e) - \frac{\partial^2 F}{\partial e\partial p}(p,e)(p-c_{pr}(p_0))\Big) = 0.\end{aligned}$$

Using the incentive constraint, we have $p - c_{pr}(p_0) = -1/\frac{\partial F}{\partial e}(p,e)$. Plugging this last equality into the above first-order condition, rearranging and dividing both sides by p gives Equation (4.3).

The first-order condition with respect to p_0 is given by:

$$\begin{aligned}&-(1+\lambda)g(p_0)(p_0-c_0)(1-F(p,e)) + \lambda(1-F(p,e))(1-G(p_0))\\ &\qquad\qquad + \mu\Big(-\frac{\partial F}{\partial e}(p,e)(1-G(p_0)-g(p_0)(p_0-c_0))\Big) = 0.\end{aligned}$$

Solving the above equation for $p_0 - c_0$ and diving both sides by p_0 immediately gives Equation (4.4).

Finally, the first-order condition with respect to e writes as follows:

$$-\int_p^{\overline{v}} \frac{\partial F}{\partial e}(v,e)dv - (1+\lambda)\frac{\partial F}{\partial e}(p,e)(p-c_s(p_0)) + \mu\Big(-\frac{\partial^2 F}{\partial e^2}(p,e)(p-c_{pr}(p_0))\Big) = 1+\lambda,$$

where the first term is obtained by integration by parts as in the proof of Proposition 2. Using once again the incentive constraint, we have that $p - c_{pr}(p_0) = -1/\frac{\partial F}{\partial e}(p,e)$. Plugging this expression into the first-order condition with respect to e and rearranging gives Equation (4.5). ∎

Proof of Proposition 4. Suppose that the regulator chooses w^*, w_0^*, $\overline{p}^*$, $\overline{e}^*$ and s^* as specified in Proposition 4. Then, the airport chooses p, p_0 and e to solve:

$$\begin{aligned}\max_{(p,p_0,e)} \quad & \Pi_I(p,p_0,e) = (1-F(p,e))\,(p-c+(p_0-c_0)(1-G(p_0))) - e + s^*(\overline{e}^* - e)\\ \text{s.t.} \quad & w^*p + w_0^*p_0 \leq \overline{p}^*.\end{aligned}$$

Let $\mu \geq 0$ denote the Kuhn-Tucker multiplier associated with the price-cap constraint. First-order conditions with respect to p, p_0 and e write as follows:

$$\begin{aligned}-f(p,e)(p-c+(p_0-c_0)(1-G(p_0))) + 1 - F(p,e) - \mu w^* &= 0,\\ (1-F(p,e))(1-G(p_0)-(p_0-c_0)g(p_0)) - \mu w_0^* &= 0,\\ -\frac{\partial F}{\partial e}(p,e)\,(p-c+(p_0-c_0)(1-G(p_0))) - 1 - s^* &= 0.\end{aligned}$$

Using $c_{pr}(p_0) = c - (p_0 - c_0)(1 - G(p_0))$ and rearranging, those equations rewrite as:

$$\frac{p - c_{pr}(p_0)}{p} = \frac{1}{\varepsilon(p,e)} - \frac{\mu w^*}{pf(p,e)}, \tag{8.1}$$

$$\frac{p_0 - c_0}{p_0} = \frac{1}{\zeta(p_0)} - \frac{\mu w_0^*}{(1 - F(p,e))g(p_0)p_0}, \tag{8.2}$$

$$-\frac{\partial F}{\partial e}(p,e)(p - c_{pr}(p_0)) - s^* = 1. \tag{8.3}$$

We now prove that $(p^{rb}, p_0^{rb}, e^{rb})$ as defined in Proposition 2 is a solution to the maximization problem of the airport, that is, it satisfies Equations (8.1), (8.2) and (8.3) together with the price-cap constraint.

Therefore, assume that $(p, p_0, e) = (p^{rb}, p_0^{rb}, e^{rb})$. First, it is immediate that the price-cap constraint is satisfied and is binding as by definition $\overline{p}^* = w^* p^{rb} + w_0^* p_0^{rb}$. Second, evaluating (8.2) at $(p^{rb}, p_0^{rb}, e^{rb})$ yields:

$$\frac{p_0^{rb} - c_0}{p_0^{rb}} = \frac{1}{\zeta(p_0^{rb})} - \frac{\mu w_0^*}{(1 - F(p^{rb}, e^{rb}))g(p_0^{rb})p_0^{rb}} = \frac{\lambda}{1+\lambda}\frac{1}{\zeta(p_0^{rb})},$$

where the second equality directly stems from the Ramsey-Boiteux price of commercial activities defined in Equation (3.6). Solving this Equation for μ and using $w_0^* = \big(1 - F(p^{rb}, e^{rb})\big)\big(1 - G(p_0^{rb})\big)$ gives:

$$\begin{aligned}
\mu &= \frac{1}{1+\lambda}\frac{1}{\zeta(p_0^{rb})}\frac{(1 - F(p^{rb}, e^{rb}))g(p_0^{rb})p_0^{rb}}{w_0^*} \\
&= \frac{1}{1+\lambda}\frac{1 - G(p_0^{rb})}{g(p_0^{rb})p_0^{rb}}\frac{(1 - F(p^{rb}, e^{rb}))g(p_0^{rb})p_0^{rb}}{(1 - F(p^{rb}, e^{rb})(1 - G(p_0^{rb}))} \\
&= \frac{1}{1+\lambda}.
\end{aligned}$$

The Kuhn-Tucker multiplier $\mu = 1/(1+\lambda) > 0$ is well-defined and strictly positive, i.e., the constraint must indeed be binding. Replacing μ and w^* by their value in Equation (8.1) evaluated at $(p^{rb}, p_0^{rb}, e^{rb})$ yields:

$$\frac{p^{rb} - c_{pr}(p_0^{rb})}{p^{rb}} = \frac{1}{\varepsilon(p^{rb}, e^{rb})} - \frac{1}{1+\lambda}\frac{1 - F(p^{rb}, e^{rb}) + s_0(p_0^{rb})f(p^{rb}, e^{rb})}{p^{rb} f(p^{rb}, e^{rb})},$$

or, equivalently:

$$\frac{p^{rb} - \left(c_{pr}(p_0^{rb}) - \frac{s_0(p_0^{rb})}{1+\lambda}\right)}{p^{rb}} = \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon(p^{rb}, e^{rb})}.$$

Using the definition of the social marginal cost, $c_s(p_0^{rb}) = c_{pr}(p_0^{rb}) - \frac{s_0(p_0^{rb})}{1+\lambda}$, the above equation directly corresponds to Equation (3.5).

Finally, evaluating Equation (8.3) at $(p^{rb}, p_0^{rb}, e^{rb})$ and replacing s^* by its value gives:

$$-\frac{\partial F}{\partial e}(p^{rb}, e^{rb})(p^{rb} - c_{pr}(p_0^{rb})) - \frac{\partial F}{\partial e}(p^{rb}, e^{rb})\frac{s_0(p_0)}{1+\lambda} - \frac{1}{1+\lambda}\int_{p^{rb}}^{\overline{v}} \frac{\partial F}{\partial e}(v, e^{rb})dv = 1,$$

which is equivalent to:

$$-\frac{\partial F}{\partial e}(p^{rb}, e^{rb})(p^{rb} - c_s(p_0^{rb})) - \frac{1}{1+\lambda}\int_{p^{rb}}^{\overline{v}} \frac{\partial F}{\partial e}(v, e^{rb})dv = 1.$$

This last equation exactly corresponds to Equation (8.3).

Hence, the vector $(p^{rb}, p_0^{rb}, e^{rb})$ satisfies the first-order conditions of the airport problem – Equations (8.1), (8.2) and (8.3) – as well as the price-cap constraint. We can conclude that the choice of w^*, w_0^*, $\overline{p}^*$, $\overline{e}^*$ and s^* as specified in Proposition 4 successfully implements the optimal regulation scheme $(p^{rb}, p_0^{rb}, e^{rb})$. ■

Proof of Proposition 5. The regulator maximizes the sum of consumer surplus and and the profit of the integrated structure subject to the nonnegativity constraints on revenues generated by aeronautical and commercial services, respectively. The regulator must now choose how to allocate total investment costs between the two sources of revenue. Formally, the regulator solves:

$$\begin{aligned} \max_{(p,p_0,e,\alpha)} \quad & CS(p,p_0,e) + \Pi_I(p,p_0,e) \\ \text{s.t.} \quad & (1-F(p,e))(1-G(p_0))(p_0-c_0) - \alpha e \geq 0 \\ & (1-F(p,e))(p-c) - (1-\alpha)e \geq 0. \end{aligned}$$

Let λ_1 and λ_2 denote the Lagrange multipliers associated to the first and the second constraints respectively. Optimizing with respect to α leads to $\lambda_1 = \lambda_2 \equiv \lambda$.

The regulator's problem can thus be rewritten as:

$$\max_{(p,p_0,e)} \quad CS(p,p_0,e) + (1+\lambda)\Pi_I(p,p_0,e).$$

This last optimization problem exactly corresponds to the regulator's problem to derive the socially optimal regulation in Proposition 2 (with no transfers). The solution is therefore the same as in Proposition 2.

The previous reasoning requires that there exists $\alpha^* \in [0,1]$ such that both constraints are binding simultaneously at the Ramsey-Boiteux outcome, or

$$(1-F(p^{rb}, e^{rb}))\left((1-G(p_0^{rb})(p_0^{rb}-c_0) - (p^{rb}-c))\right) = e^{rb}(2\alpha^* - 1).$$

When this is not the case, all the burden of the financing of the investment is put on either the aeronautical service ($\alpha^* = 0$) or on the commercial service ($\alpha^* = 1$). The outcome in a dual-till regime does no longer coincide with the Ramsey-Boiteux outcome and a dual-till regime is dominated by a single-till one. ■

Proof of Proposition 6. The regulator's problem still consists in maximizing the sum of consumer surplus and the profit of the airport subject to nonnegativity of the latter. However, the profit of the airport is now given by:

$$\Pi_A(P(w,e), p_0, e, T) = \big(1 - F(P(w,e), e)\big)\big(P(w,e) - c + (p_0 - c_0)(1 - G(p_0))\big) - e + T,$$

where $P(w,e)$ is chosen by the airline according to Equation (7.1).

Therefore, the regulator cannot directly determine the price of aeronautical services

$P(w,e)$ and instead solves:

$$\max_{(w,p_0,e,T)} \quad W(P(w,e),p_0,e,T) = CS(P(w,e),p_0,e) - (1+\lambda)T + \Pi_A(P(w,e),p_0,e) + T$$
$$\text{s.t.} \quad \Pi_A(P(w,e),p_0,e) + T \geq 0.$$

It is immediate that the constraint is binding, i.e., $T = -\Pi_A(P(w,e),p_0,e)$ such that the regulator's problem rewrites as:

$$\max_{(w,p_0,e)} \quad CS(P(w,e),p_0,e) + (1+\lambda)\Pi_A(P(w,e),p_0,e)$$

From Proposition 2, we know that a solution to this problem is $P(\cdot) = p^{rb}$, $p_0 = p_0^{rb}$ and $e = e^{rb}$. To prove our result, we must show that when the regulator sets $p_0 = p_0^{rb}$ and $e = e^{rb}$ there exists a w^{rb} such that the airline chooses the aeronautical price $P(w^{rb},e^{rb}) = p^{rb}$ at its socially optimal value.

To this end, suppose that the regulator sets the price of commercial services and the investment level at their Ramsey-Boiteux value, that is, $p_0 = p_0^{rb}$, $e = e^{rb}$. Now assume that the regulator also chooses the unit price as follows:

$$w^{rb} = c_s(p_0^{rb}) - c - \frac{1}{1+\lambda}\frac{1-F(p^{rb},e^{rb})}{f(p^{rb},e^{rb})}.$$

As the airline chooses the price of aeronautical services according to Equation (7.1), it must solve:

$$\begin{aligned} P(w^{rb},e^{rb}) &= w^{rb} + c + \frac{1-F(P(w^{rb},e^{rb}),e)}{f(P(w^{rb},e^{rb}),e)} \\ &= \left(c_s(p_0^{rb}) - c - \frac{1}{1+\lambda}\frac{1-F(p^{rb},e^{rb})}{f(p^{rb},e^{rb})}\right) + c + \frac{1-F(P(w^{rb},e^{rb}),e^{rb})}{f(P(w^{rb},e^{rb}),e^{rb})}. \end{aligned}$$

Rearranging gives:

$$\frac{P(w^{rb},e^{rb}) - c_s(p_0^{rb})}{P(w^{rb},e^{rb})} = \frac{1-F(P(w^{rb},e^{rb}),e^{rb})}{P(w^{rb},e^{rb})f(P(w^{rb},e^{rb}),e^{rb})} - \frac{1}{1+\lambda}\frac{1-F(p^{rb},e^{rb})}{P(w^{rb},e^{rb})f(p^{rb},e^{rb})}.$$

Finally, notice that if the airline indeed chooses $P(w^{rb},e^{rb}) = p^{rb}$ then the above equation rewrites as:

$$\begin{aligned} \frac{p^{rb} - c_s(p_0^{rb})}{p^{rb}} &= \frac{1-F(p^{rb},e^{rb})}{p^{rb}f(p^{rb},e^{rb})} - \frac{1}{1+\lambda}\frac{1-F(p^{rb},e^{rb})}{p^{rb}f(p^{rb},e^{rb})} \\ &= \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon(p^{rb},e^{rb})}, \end{aligned}$$

which is exactly Equation (3.5) that determines the socially optimal price of aeronautical services. We can therefore conclude that choosing $P(w^{rb},e^{rb}) = p^{rb}$ is a solution to the airline maximization problem. Under our assumptions on $F(\cdot)$, this solution is also unique. ■

Proof of Proposition 7. In the absence of a fixed access charge, the airport's profits is given by:

$$\tilde{\Pi}_A(w, P(w,e), p_0, e) = \big(1 - F(P(w,e),e)\big)\big(w + (p_0 - c_0)(1 - G(p_0))\big) - e,$$

which corresponds to Equation (7.3) without the subsidy. The regulator's problem writes as follows:

$$\max_{(w,p_0,e,T)} \; CS(P(w,e),p_0,e) - (1+\lambda)T + \Pi_I(P(w,e),p_0,e) + T$$
$$\text{s.t. } \tilde{\Pi}_A(w, P(w,e), p_0, e) + T \geq 0,$$

where $\Pi_I(P(w,e),p_0,e)$ is the sum of profits of the airport and the airline when the airline chooses the price of aeronautical services $P(w,e)$ as defined by Equation (7.3). The constraint ensures that the airport makes nonnegative profits.

At the optimum, the constraint must be binding, that is, $T = -\tilde{\Pi}_A(w, P(w,e), p_0, e)$. The problem therefore rewrites as follows:

$$\max_{(w,p_0,e)} \; CS(P(w,e),p_0,e) + \Pi_I(P(w,e),p_0,e) + \lambda\tilde{\Pi}_A(w, P(w,e), p_0, e)$$

After some simplifications, the first-order condition with respect to w writes as follows:

$$-\frac{\partial P}{\partial w}(w,e) f(P(w,e),e)\Big(P(w,e) - c_{pr}(p_0) + s_0(p_0)\Big)$$
$$+ \lambda\Big(- \frac{\partial P}{\partial w}(w,e) f(P(w,e),e)[w + (p_0 - c_0)(1 - G(p_0))] + 1 - F(P(w,e),e)\Big) = 0.$$

Using Equation (7.1) and rearranging gives Equation (7.4). Taking the first-order condition with respect to p_0 and simplifying gives:

$$-(1 - G(p_0)) + (1+\lambda)(1 - G(p_0) - (p_0 - c_0)g(p_0)) = 0.$$

Solving this equation for $p_0 - c_0$ and dividing by p_0 on both sides immediately yields (7.5). Finally, the first-order condition with respect to e writes as follows:

$$-\frac{\partial P}{\partial e}(w,e)\int_{P(w,e)}^{\overline{v}} f(v,e)dv + \int_{P(w,e)}^{\overline{v}} (v - P(w,e))\frac{\partial f}{\partial e}(v,e)dv$$
$$- \left(\frac{\partial P}{\partial e}(w,e) f(P(w,e),e) + \frac{\partial F}{\partial e}(P(w,e),e)\right)\Big(s_0(p_0) + P(w,e) - c_{pr}(p_0)$$
$$+ \lambda(w + (p_0 - c_0)(1 - G(p_0)))\Big) + (1 - F(P(w,e),e))\frac{\partial P}{\partial e}(w,e) = 1 + \lambda.$$

Integrating by parts the second term gives:

$$\int_{P(w,e)}^{\overline{v}} (v - P(w,e))\frac{\partial f}{\partial e}(v,e)dv = \Big[(v - P(w,e))\frac{\partial F}{\partial e}(v,e)\Big]_{P(w,e)}^{\overline{v}} - \int_{P(w,e)}^{\overline{v}} \frac{\partial F}{\partial e}(v,e)dv$$
$$= -\int_{P(w,e)}^{\overline{v}} \frac{\partial F}{\partial e}(v,e)dv,$$

where the second equality stems from $\frac{\partial F}{\partial e}(\overline{v},e) = 0$ (see the proof of Proposition 2). Using this last equality, Equation (7.1), and simplifying, the first-order condition with respect to e rewrites as follows:

$$-\int_{P(w,e)}^{\overline{v}} \frac{\partial F}{\partial e}(v,e)dv \\ - \left(\frac{\partial P}{\partial e}(w,e)f(P,e) + \frac{\partial F}{\partial e}(P,e)\right)\left((1+\lambda)(P - c_s(p_0)) - \lambda\frac{1-F(P,e)}{f(P,e)}\right) = 1+\lambda,$$

where we use $P = P(w,e)$ to lighten the notation. Rearranging immediately yields Equation (7.6).

Last, we immediately obtain that $\frac{\partial P}{\partial e} > 0$ under the assumption that the airline's profit is concave in its price p. ■