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Optimal Regulation Design of Airports: Investment Incentives and Impact of Commercial Services*

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Abstract

Modern airports provide commercial services to passengers in addition to aeronautical services to airlines. We analyze the optimal regulation design of the airport when the airport also invests in the quality of its infrastructure. The optimal regulation can be implemented with a price-cap and a subsidy scheme targeted to the investment. We compare that optimal regulation with more constrained scenarios and discuss how commercial services change the need for regulation. We also investigate the consequences of the non-observability of the airport's 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

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

²See [Bel and Fageda \(2010\)](#) and [Iossa and Martimort \(2011\)](#).

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 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 transportation and commercial services, we make two assumptions. First, only passengers may buy commercial services at the airport. Second, the decision whether to fly is solely based on the passenger's valuation for transportation services. The airport also invests in its infrastructure, which boosts the demand for transportation services.

Before describing our results, let us clarify the scope of our analysis. First, we focus on big hub platforms or big regional airports that have enough traffic to cover the costs of providing the services. Second, a condition for regulation to be relevant is that the airport must have sufficient market power due to its natural monopoly position. Third, the debate about whether and how to regulate an airport is independent to the nature of its ownership (public vs. private). In both cases, the issue is how to best deal with the delegated management of such a multi-product essential facility.¹⁰

Our results are as follows. First, we characterize the optimal regulatory policy, assuming that investment is observable and hence contractible. Socially optimal prices for transportation and commercial services obey a Ramsey-Boiteux pricing rule. In particular, both prices are above the corresponding social marginal cost to limit the use of costly

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

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

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

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

⁷See Reynolds et al. (2018).

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

⁹This is generally referred to as “single-till” versus “dual-till” question.

¹⁰According to Forsyth et al. (2020) the main consequence of Covid-19 is the collapse in passenger demand which could be accounted for in our framework as we do not make any particular assumption on the size of the demand for transportation services. Furthermore, Forsyth et al. (2020) argue that allowing for temporary deficits or government financial assistance while keeping airport charges low during the pandemic would be a sufficient policy to face the crisis. We believe that our framework can provide further guidance on how to design such regulation.

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).

When investment is not observable by the regulator, prices of transportation and commercial services have to be further distorted in order to provide the airport with incentives to invest. We 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 implements the optimal regulation. It consists in a price-cap that encompasses the aeronautical and commercial services supplied by the airport and a subsidy scheme that provides the airport with the socially 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 requires that each service has to cover a given share of the investment cost. By contrast, in a single-till regulation all the airport's sources of profits 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 than one. At the optimum, it must be that the opportunity cost of allocating one additional dollar of investment cost is the same for both budget constraints. And when this holds, the two budget constraints in a dual-till regime actually coincide with the unique budget constraint in a single-till regime; hence, a dual-till approach is actually equivalent to a single-till one. This result holds in different environments but requires that the profits earned by the airport from aeronautical and commercial services are not too different; otherwise, a single-till regime dominates.

We then analyze the situation in which the vertical relationship between the airport and the airline company is plagued with some inefficiencies. More precisely, when the

airport has a limited set of pricing instruments in its contractual relationship with the airlines, a phenomenon of double marginalization occurs within the vertical chain. This tends to lead to excessive prices as well as under-investment.

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 profits 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 any abuse of market power by airports 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.¹¹ 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 profits 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. \(2011\)](#), [Yang et al. \(2015\)](#) and [Bottasso et al. \(2017\)](#).

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 the investment undertaken by the airport is 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 scheme targeted to the airport's investment. Section 7 investigates the consequences of inefficiencies within the vertical relationship between the airport and the airline. All proofs are in the Appendix.

¹¹As 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's decision to fly.

2. THE MODEL

An airport provides aeronautical services to an airline company that sells transportation services to passengers. For the airline, one unit of aeronautical service is required to produce one unit of transportation service 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 $[0, \bar{v}]$, 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 undertaken by the airport, as we will detail below. Hereafter, an individual who decides to buy transportation services from the airline company is referred to as “a passenger.”

We assume that only passengers can consume commercial services offered by the airport. Therefore, we assume that, once in the airport, the passenger has a valuation $\tilde{v}_0$ for commercial services, where $\tilde{v}_0$ is drawn from a cumulative distribution $G(\cdot)$ on $[0, \bar{v}_0]$, with a strictly positive density $g(\cdot)$. Put differently, we consider that the demand for commercial activities is conditional upon the demand for transportation services. It seems, indeed, rather unlikely that a consumer not interested in transportation services has a demand for the airport’s commercial activities. Commercial activities are complementary to transportation services, but the reverse is not true.

Demands for transportation and commercial services. Let p and p_0 denote unit prices of transportation and commercial services, respectively. The airport sets p_0 whereas the airline sets p . Following our assumption of unidirectional complementarity between transportation 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 transportation services and commercial activities. This formulation has two implications. First, only passengers (i.e., consumers with valuation $\tilde{v} - p \geq 0$) 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 transportation services.¹²

The demand for transportation 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:

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

Although we do not explicitly model competition between airline companies, this feature could be captured in reduced form through the elasticity of demand. For a given price p

¹²By 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 transportation services as long as it is compensated by a positive surplus from consumption of commercial services.

and level of investment e , the more competitive the airline market is, the more elastic is the demand for transportation services. We shall use this later on in our simulations to discuss the impact of competition between airlines.

Demand for commercial activities depends upon both the price of transportation 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 into account:

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

The elasticity of this demand with respect to the price of commercial services p_0 can be 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 $F(\cdot, e)$ and $G(\cdot)$ satisfy the usual Monotone Hazard Rate Property: $\frac{\partial}{\partial v} \left(\frac{1 - F(v, e)}{f(v, e)} \right) \leq 0 \ \forall v \in [0, \bar{v}]$ and $\frac{d}{dv_0} \left(\frac{1 - G(v_0)}{g(v_0)} \right) \leq 0 \ \forall v_0 \in [0, \bar{v}_0]$. These assumptions guarantee that the elasticities for transportation 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. Investing in airport infrastructure directly leads to an increase in consumer demand for transportation 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 $v \in [0, \bar{v}]$ and $\hat{e} > e$). This corresponds to the intuition that higher investment levels make higher valuations for transportation services more likely. Hence, $D(p, \hat{e}) \geq D(p, e)$ for $\hat{e} > e$. Last, investment increases the demand for transportation services at a decreasing rate: $\frac{\partial^2 F}{\partial e^2}(v, e) \geq 0, \forall v \in [0, \bar{v}]$.

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 $\hat{e} > e$.

Costs. From the perspective of the airport, 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 c minus the profits generated by commercial activities $(p_0 - c_0)(1 - G(p_0))$. For the airline, the marginal cost of transportation services is normalized to nil without loss of generality.

Vertical organization of the industry. Throughout the paper, we consider that the airport and the airline are vertically separated; an assumption which fits most real-world market

structures. Hence, the airline is responsible for setting the price p charged to passengers. The investment decision e and the pricing of commercial services p_0 are decided by the airport. The airport-airline relationship is 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 charges the airline a two-part tariff (w, A) for these services, where w is a unit price and A a fixed fee. 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.¹³

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 transportation 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 can freely choose the prices of aeronautical and commercial services as well as the level of investment in its infrastructure.

When the airline sets a price 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:

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

Notice that the price 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:

$$(3.1) \quad p = w + \frac{1 - F(p, e)}{f(p, e)}.$$

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, given the level of investment e , the unit price w uniquely determines the price p charged by the airline to passengers for transportation services. Let $P(w, e)$ denote the solution to the airline's first-order condition (3.1).

As the airport has all the bargaining power, the fixed access charge A is chosen so as to extract all the profit of the airline, that is:

$$(3.2) \quad A = (P(w, e) - w)(1 - F(P(w, e), e)) = \frac{(1 - F(P(w, e), e))^2}{f(P(w, e), e)}.$$

¹³The 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.

From Equation (3.2), the airport's profit rewrites as:

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

This expression contains the airline's profit, $(P(w, e) - w)(1 - F(P(w, e), e))$, and the airport's profit net of investment costs, $(1 - F(P(w, e), e))(w - c + (p_0 - c_0)(1 - G(p_0))) - e$.

Since the airport can fully appropriate the airline's profit through the fixed fee A and controls the airline's price p through the unit price for aeronautical services w , everything happens as if the airport directly chooses the price of transportation services p (through the choice of w) on top of (p_0, e) to maximize:¹⁴

$$(3.3) \quad \Pi_I(p, p_0, e) = (1 - F(p, e))(p - c + (p_0 - c_0)(1 - G(p_0))) - e.$$

The solution to this problem is as follows.¹⁵

Proposition 1. *In the absence of airport regulation, the prices and the investment level are given by:*

$$(3.4) \quad \frac{p^m - c_{pr}(p_0^m)}{p^m} = \frac{1}{\varepsilon(p^m, e^m)},$$

$$(3.5) \quad \frac{p_0^m - c_0}{p_0^m} = \frac{1}{\zeta(p_0^m)},$$

$$(3.6) \quad -\frac{\partial F}{\partial e}(p^m, e^m)(p^m - c_{pr}(p_0^m)) = 1.$$

Equation (3.4) shows that the price of transportation 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, from the perspective of the industry profit, it is optimal to decrease the price of transportation services below the marginal cost since it boosts the demand for commercial services. Equation (3.5) is a usual monopoly pricing formula for commercial services since the demand for transportation services plays no role in that. Last, Equation (3.6) simply states that the marginal cost of the investment must be equal to its marginal benefit in terms on increased profits for both transportation and commercial services.

3.2. Optimal Regulation

Let us now consider the optimal regulation of the airport. That regulation consists in setting the tariff (w, A) charged by the airport to the airline for aeronautical services, the price of commercial services p_0 and the investment level e . Again, this amounts to the regulator controlling prices p and p_0 and investment level e while facing an airport whose profit is given by Π_I . Additionally, we allow the regulator to provide public subsidies T to the airport.

Consumer surplus is given by the sum of the surplus generated by transportation services and the surplus generated by commercial services, taking into account the uni-

¹⁴ Π_I coincides with the industry profit.

¹⁵Throughout our analysis, we will focus mainly on the prices of transportation and commercial services as well as the investment level. The optimal prices for aeronautical services (w, A) can be recovered from (p, p_0, e) using Equations (3.1) and (3.2).

directional 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 $\Pi_I + T$, net of the social cost of public subsidies borne by the consumers-taxpayers:

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

where parameter $\lambda > 0$ stands for the cost of public funds.¹⁶ 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 airport breaks even ($\Pi_I + T \geq 0$). The solution is given in the next proposition.

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

$$(3.7) \quad \frac{p^{rb} - c_s(p_0^{rb})}{p^{rb}} = \frac{\lambda}{1 + \lambda} \frac{1}{\varepsilon(p^{rb}, e^{rb})},$$

$$(3.8) \quad \frac{p_0^{rb} - c_0}{p_0^{rb}} = \frac{\lambda}{1 + \lambda} \frac{1}{\zeta(p_0^{rb})},$$

$$(3.9) \quad -\frac{\partial F}{\partial e}(p^{rb}, e^{rb}) (p^{rb} - c_s(p_0^{rb})) - \frac{1}{1 + \lambda} \int_{v \geq p^{rb}} \frac{\partial F}{\partial e}(v, e^{rb})dv = 1,$$

where $c_s(p_0) = c_{pr}(p_0) - \frac{s_0(p_0)}{1 + \lambda} < c$ is the social marginal cost of transportation 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 transportation 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.¹⁷ Hence, the social marginal cost of transportation services is lower than c , the marginal cost of production which coincides with the marginal cost of aeronautical services, but also lower than $c_{pr}(p_0)$, the perceived marginal cost of these services for the airport.

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 transportation 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 transportation and commercial services exactly at their social marginal cost as the cost of public funds is positive.

Second, the price of transportation services does not necessarily cover the marginal cost of production. Indeed, Equation (3.7) could be rewritten as $p^{rb} - c_{pr}(p_0) = \frac{\lambda}{1 + \lambda} \frac{p^{rb}}{\varepsilon(p^{rb}, e^{rb})} -$

¹⁶In developed countries, this cost is estimated at about 0.3. See [Oum et al. \(1992\)](#).

¹⁷The weighting coefficient $1/(1 + \lambda)$ simply expresses the fact that providing more profit to the airport reduces the need to use costly public funds to ensure budget-balance.

$\frac{s_0(p_0)}{1+\lambda}$. This shows that the margin on transportation services may be either positive or negative. Intuitively, the socially optimal price of these services trades off an increase in the profit of the airport motivated by the budget constraint and a decrease in the consumer surplus generated by transportation services and commercial activities. When the demand for transportation 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 airport's profit is negative absent any subsidies. It suggests that, even with a positive cost of public funds, the regulator may want to price transportation services below marginal cost and subsidize the airport so that it breaks even. Notably, when commercial services generate a high consumer surplus, the regulator is more likely to set the price of transportation services below the marginal cost of production and must, therefore, provide a higher subsidy to ensure that the airport 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 transportation services and commercial activities, respectively. Therefore, more competition in the airline industry increases the elasticity of demand for transportation services and decreases the price-cost margin of these services. However, the price-cost margin of commercial activities is not affected by this change in competition in the airline industry. Again, this stems from the unidirectional externality between transportation services and commercial activities. Once the passenger 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 (3.9). A marginal increase in the level of investment e directly leads to an increase in the demand for transportation services. Note that the first term in the left-hand side of Equation (3.9) can be decomposed as:

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

When e increases, $-\frac{\partial F}{\partial e}(p^{rb}, e^{rb})(p^{rb} - c)$ represents the increase of the industry 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 transportation 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 (3.7), (3.8) and (3.9) in which the (exogenous) shadow cost of public funds λ is replaced by the (endogenous) Lagrange multiplier associated to the break-even constraint $\Pi_I \geq 0$. Hence, our previous discussion continues to apply in that case.

3.3. Partial Regulation of Aeronautical Services Only

In many real-world situations, airport regulation does not directly include commercial services. Put differently, while some constraints might be put on the pricing of aeronautical services provided by the airport and on its investments, commercial activities tend to

remain unregulated. The purpose of this section is to analyze how the optimal regulation changes in such a scenario of partial regulation.

Clearly, the airport can now exert an unfettered monopoly market power on commercial services, whose price is now given by p_0^m characterized by Equation (3.5). Thanks to the unidirectional complementarity between aeronautical and commercial services, that price is independent from the price of transportation services and from the investment level. Hence, it immediately comes that $p_0^m > p_0^{rb}$. The problem faced by the regulator is now to maximize $W(p, p_0^m, e, T)$ subject to the break-even constraint $\Pi_I(p, p_0^m, e) + T \geq 0$. Therefore, the optimal partial regulation is such that the price charged to passengers and the investment level are still given by (3.7) and (3.9), in which the social marginal cost of transportation services is now $c_s(p_0^m)$ instead of $c_s(p_0^{rb})$, with $c_s(p_0^m) > c_s(p_0^{rb})$. Hence, the price of transportation services increases and the investment level decreases with respect to the Ramsey-Boiteux benchmark.

To summarize, when commercial services are not included in the regulation, the structure of the optimal partial regulation is similar to the Ramsey-Boiteux one; levels differ, however.

4. NON-VERIFIABLE INVESTMENTS

So far, we have assumed that the level of investment e was verifiable and hence contractible. However, 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 such a non-verifiability assumption.

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:

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

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:

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

Contrary to the optimal investment rule defined by Equation (3.9) 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 condition holds:

$$(4.2) \quad -\frac{\partial F}{\partial e}(p^{rb}, e^{rb})(p^{rb} - c_{pr}(p_0^{rb})) > 1,$$

then Ramsey-Boiteux prices as defined in 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. In the Appendix, we show that the prices and the investment level $(p^{nv}, p_0^{nv}, e^{nv})$ are characterized by the following system:

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

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

$$(4.5) \quad -\frac{\partial F}{\partial e}(p^{nv}, e^{nv}) (p^{nv} - c_s(p_0^{nv})) - \frac{1}{1 + \lambda} \int_{v \geq p^{nv}} \frac{\partial F}{\partial e}(v, e^{nv}) dv = 1 - \frac{\mu}{1 + \lambda} \frac{\frac{\partial^2 F}{\partial e^2}(p^{nv}, e^{nv})}{\frac{\partial F}{\partial e}(p^{nv}, e^{nv})}.$$

First, the sign of $\left(\frac{\partial F}{\partial e} \right)^2 - \frac{\partial^2 F}{\partial e \partial v}$ is a priori ambiguous; the price of transportation services can move either upward or downward with respect to the Ramsey-Boiteux level. Second, it comes immediately from Equation (4.4) that the price of commercial services increases with respect to the Ramsey-Boiteux benchmark. Third, under our assumption on the impact of the investment on the demand for transportation services, the right-hand side in Equation (4.5) is strictly larger than the marginal cost of investment (that is, 1) because it is now costly to provide the airport with the socially optimal incentives to invest; which tends to lower the investment. Next proposition summarizes these findings.

Proposition 3. *Suppose that the level of investment is non-verifiable and that Condition (4.2) holds. With respect to the Ramsey-Boiteux benchmark, the optimal regulation is such that: (i) the price of transportation services can either increase or decrease; (ii) the price of commercial services moves upwards; (iii) the investment level moves downwards.*

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 transportation services, but with a twist: Increasing the price of transportation services increases the airport's margin and thus reinforces the incentives to invest. However, it 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.¹⁸

It is now straightforward to analyze the case where commercial services are left unregulated. The price of commercial services is now given by p_0^m characterized by Equation (3.5) (instead of Equation (4.4)). Since the externality is unidirectional, the monopoly price p_0^m does not depend on the airport's investment e . Therefore, the price of transportation services and the investment level under the optimal partial regulation are still

¹⁸When $\frac{\partial^2 F}{\partial e \partial v} \leq 0$, increasing e implies that the demand for transportation services becomes steeper. This effect has to be sufficiently strong to lead to a lower price of transportation services.

characterized by Equations (4.3) and (4.5) but with $p_0 = p_0^m$. With non-verifiable investments, the optimal partial regulation is quite similar in structure to the optimal regulation, but differs in levels.

5. UNREGULATED MONOPOLY VS RAMSEY-BOITEUX OPTIMUM: SIMULATIONS

In this section, we provide an illustration of some of our theoretical results by means of a numerical simulation of our framework. We focus on two applications of interest. First, we investigate how prices, investment levels and welfare change in the different scenarios following an increase in the importance of commercial services. Second, we perform a similar analysis in the case of an increase of competition on the transportation services side.

Consider the following specification. First, suppose that there is no shadow cost of public funds: $\lambda = 0$. Second, distributions for services are given by $F(v, e) = v \exp^{-e(1-v)/\gamma}$ and $G(v_0) = v_0/\bar{v}_0$, respectively. The valuation for transportation services v is thus distributed on $[0, 1]$ and that for commercial services is distributed according to the uniform distribution on $[0, \bar{v}_0]$. The parameter γ relates to the impact of competition on the shape of the demand for transportation services through an increase in the elasticity.

5.1. Impact of Commercial Services

The benefits of airport regulation has often been questioned by scholars and practitioners claiming that the increasing presence of commercial services would temper the airport market power on aeronautical services due to the interdependency between those services.

Our previous results show that this effect is likely to be insufficient to mitigate the market power of the unregulated airport. By construction 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 excessive or the investment 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 (3.6) and (3.9) 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.

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

As commercial services become more important (that is, as $\bar{v}_0$ increases), the unregulated airport reduces the price of transportation services.¹⁹ However, that price decrease

¹⁹Or equivalently, the airport reduces the variable price of aeronautical services.

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 transportation services, a scope for regulation remains because such price reduction is insufficient. Moreover, as $\bar{v}_0$ 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.

We now compare prices, investment levels and welfare between the unregulated airport and three regulation scenarios: the optimal Ramsey-Boiteux regulation (Section 3.2); the optimal partial regulation in which commercial services are not regulated (Section 3.3); and the optimal regulation under a non-verifiable investment (Section 4). For each scenario, $\bar{v}_0$ is interpreted as a measure of the importance of commercial services.

The next three figures (1, 2 and 3) show the prices of transportation and commercial services and the investment level as functions of the development of commercial services.²⁰

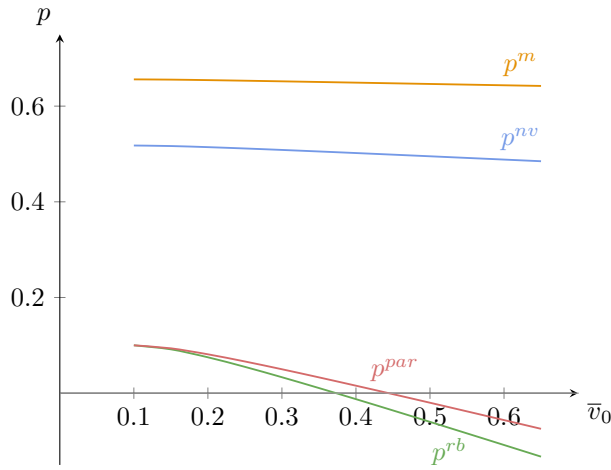


Figure 1: Prices of transportation services in the unregulated monopoly case p^m , the Ramsey-Boiteux benchmark p^{rb} , the partial regulation case p^{par} , and when investment is non-verifiable p^{nv} , as functions of the importance of commercial services $\bar{v}_0$.

²⁰The values of parameters we use are: $\lambda = 0$, $\gamma = 15$, $c = .1$, $c_0 = .1$. Simulations are performed using Mathematica. Files are available on the authors' webpages.

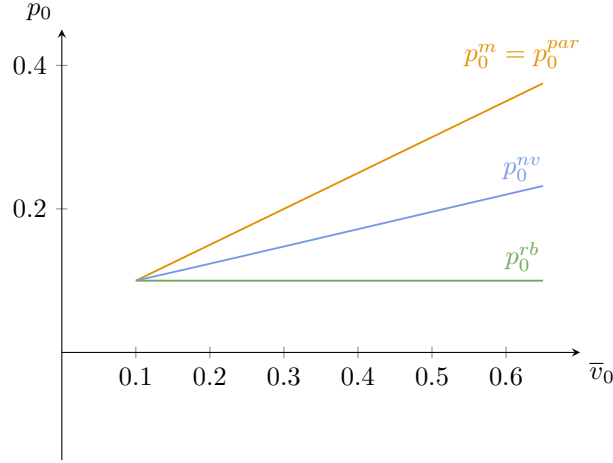


Figure 2: Prices of commercial services in the unregulated monopoly case p_0^m , the Ramsey-Boiteux benchmark p_0^{rb} , the partial regulation case p_0^{par} , and when investment is non-verifiable p_0^{nv} , as functions of the importance of commercial services $\bar{v}_0$.

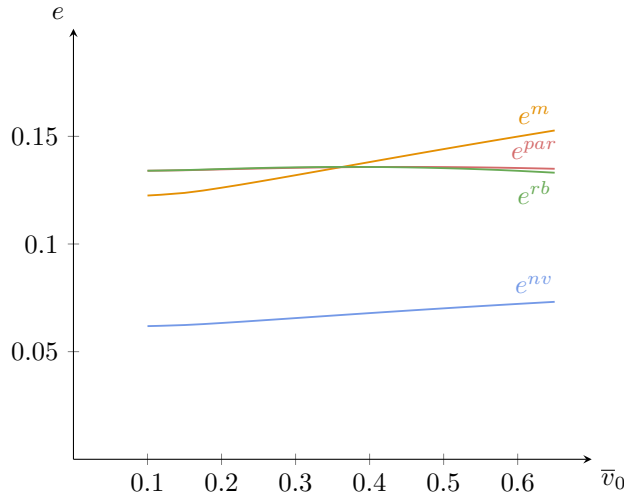


Figure 3: Investment level in the unregulated monopoly case e^m , the Ramsey-Boiteux benchmark e^{rb} , the partial regulation case e^{par} , and when investment is non-verifiable e^{nv} , as functions of the importance of commercial services $\bar{v}_0$.

First, notice that the price of transportation services is much lower in the Ramsey-Boiteux benchmark and in the partial regulation case than the one chosen by the unregulated airport. When commercial services become more important, all prices of transportation services decrease but it is clear that the unregulated price p^m is far from converging to the Ramsey-Boiteux benchmark price. This illustrates the idea that the presence of commercial services seems to be rather insufficient to curb the airport's market power. Interestingly, in the non-verifiable investment case, the price of transportation services is maintained at a very high level, quite close to that of the unregulated airport. This is due to the necessity to provide incentives to invest to the airport in a context with asymmetric information.

Regarding commercial services, the unregulated price and the partial regulation price coincide. Both of these prices naturally increase in $\bar{v}_0$ as the airport takes advantage of an increasing demand on commercial services. By contrast, the Ramsey-Boiteux benchmark price is constant and equal the marginal cost of providing commercial services because the social cost of public funds is nil in the simulations. Not surprisingly, in the non-verifiable investment case, the price of commercial services is higher than the Ramsey-Boiteux benchmark in order to provide incentives to invest, but is still lower than the unregulated one. Finally, it is worth noticing that all prices are quite similar when commercial services are not very important (i.e., $\bar{v}_0$ low) but appear to be far apart when commercial services grow in importance. This suggests that the absence of the price of commercial services in the perimeter of past regulations might have been justified given the small impact of doing so. Alternatively, it suggests that the growth of commercial services calls for considering the price of commercial services as an important instrument of the optimal regulation.

Consider now the investment level. 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 both commercial and transportation services. Over-investment and excessive market power go hand-in-hand. This last feature will be further explored in Section 5.2 when we investigate the role of competition in our model. It is also interesting to notice that investment levels in the Ramsey-Boiteux benchmark and in the partial regulation case are almost equivalent. This suggests that the choice of the optimal investment level is mainly driven by transportation services and that leaving commercial services unregulated seems to have a limited impact.

Figure 4 presents the welfare gain from the Ramsey-Boiteux benchmark, the partial regulation and the non-verifiable investment regulation with respect to the unregulated airport.

As expected, there are positive welfare gains in each scenario we consider compared to the unregulated case. Naturally, those gains are the highest in the Ramsey-Boiteux benchmark. Furthermore, those gains are increasing in the importance of commercial services in both the Ramsey-Boiteux benchmark and the non-verifiable investment case. On the contrary, the welfare gains of the partial regulation are decreasing in $\bar{v}_0$ as this regulation precisely excludes commercial services from the perimeter of regulated prices. In light with the current rise in the importance of commercial services at airports, the simulation suggests that as commercial services become more important, the need for regulation is reinforced, provided that prices of commercial services are also part of it. Even though the unregulated airport lowers the price of aeronautical services, it also exercises a substantial market power on commercial services and tends to over-invest when commercial services become more important relative to transportation services.

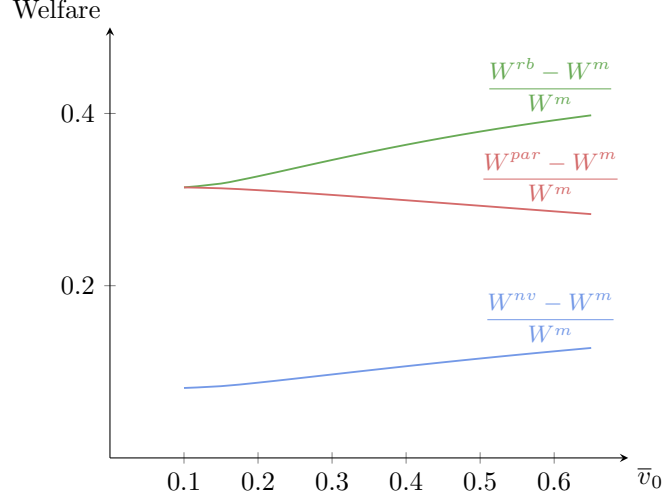


Figure 4: Welfare gain associated with Ramsey-Boiteux regulation, partial regulation and when investment is not verifiable, as function of the importance of commercial services $\bar{v}_0$.

5.2. Impact of Competition on the Airline Market

We now investigate the behavior of the prices, the investment level and the welfare gains in the unregulated case, the Ramsey-Boiteux benchmark and the non-verifiable investment case when there is an increase in competition on the airline market. To capture the intensity of competition in a shortcut, we use the parameter γ in the specification of the cumulative distribution function of consumers' valuations for transportation services. An increase in γ leads to a higher elasticity of the demand for transportation services, which can be interpreted as a reduced-form approach to model competition.

Figures 5 and 6 show the price of transportation services and the investment level in the different scenarios of interests as functions of the intensity of competition γ .^{21, 22}

²¹The values of parameters we use are: $\lambda = 0$, $\bar{v}_0 = .5$, $c = .1$, $c_0 = .1$.

²²We voluntarily omit the plot for the price of commercial services. Let us briefly mention that this price is unaffected by the intensity of competition both in the unregulated case (p_0^m) and in the Ramsey-Boiteux benchmark (p_0^{rb}) as an immediate consequence of Equations (3.5) and (3.8) respectively.

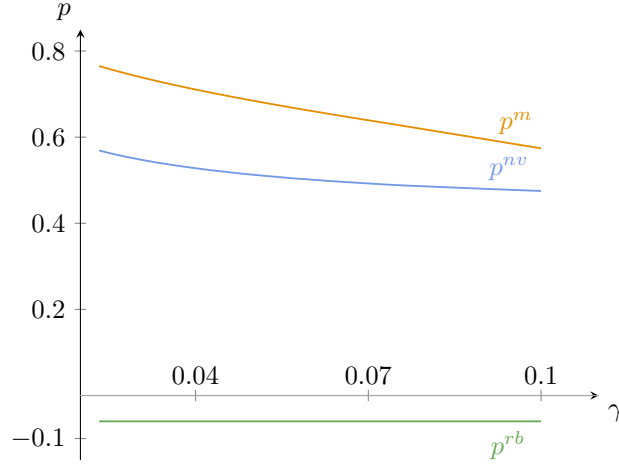


Figure 5: Prices of transportation services in the unregulated monopoly case p^m , the Ramsey-Boiteux benchmark p^{rb} , and when investment is non-verifiable p^{nv} , as functions of the intensity of competition γ .

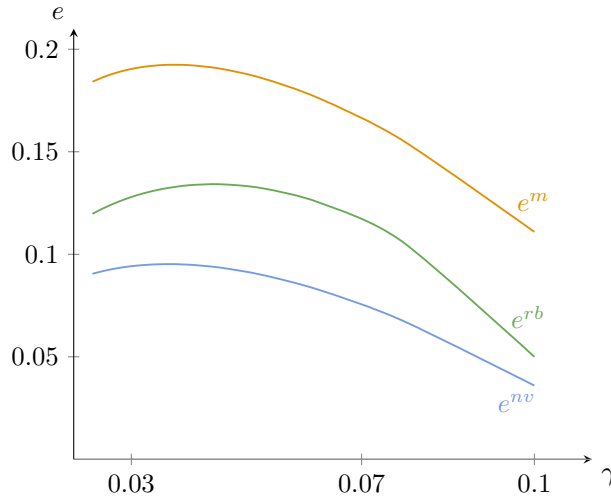


Figure 6: Investment level in the unregulated monopoly case e^m , the Ramsey-Boiteux benchmark e^{rb} , and when investment is non-verifiable e^{nv} , as functions of the intensity of competition γ .

As expected, the price of transportation services chosen by the unregulated airport p^m decreases as the intensity of competition increases. It is worth noticing that this effect is quite mild – the unregulated price remains at a rather high level in comparison with the price in the Ramsey-Boiteux benchmark p^{rb} . Non-verifiability of the investment calls for a significantly higher regulated price of transportation services p^{nv} than in the Ramsey-Boiteux benchmark. Once again, it is due to the necessity to provide the airport with appropriate incentives to invest.

Regarding the level of investment, all three investment levels are increasing then decreasing with parameter γ . Intuitively, tougher competition reduces the benefit of

investment as it becomes more difficult to extract surplus from passengers when the elasticity of their demand for transportation services increases.

Finally, Figure 7 shows the welfare gains from the Ramsey-Boiteux benchmark and the non-verifiable investment case with respect to the unregulated airport outcome.

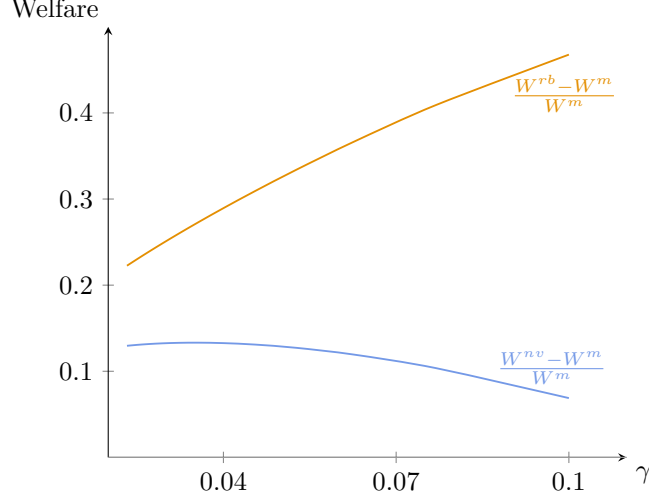


Figure 7: Welfare gain associated with Ramsey-Boiteux regulation and when investment is non-verifiable, as function of the intensity of competition γ .

The welfare gain of regulation in the Ramsey-Boiteux benchmark appears to be increasing in the intensity of competition. This result is noticeable as it seems to contradict the intuition that regulation is needed and desirable mostly when competition is low. Our simulations suggest that more competition generates greater inefficiencies in the unregulated scenario notably through a tendency towards over-investment of the unregulated airport. On the contrary, regulation yields little benefits and those benefits decrease in the intensity of competition in the non-verifiable investment scenario. This last observation reinforces the argument made in the Ramsey-Boiteux benchmark. Most of the benefits of regulation goes through correcting inefficiencies on the investment level. In other words, the benefits of regulation largely depend on whether the investment level can be easily regulated or not.

6. IMPLEMENTATION

We now turn to the question of implementing the optimal regulation. We analyze 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 instrument 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:

$$(6.1) \quad \beta p + \beta_0 p_0 \leq \bar{P},$$

where the coefficients (β, β_0) and the cap $\bar{P}$ are chosen by the regulator. Hence, the airport 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 (3.6). Therefore, even if the regulation with a price-cap may lead the airport to choose a correct structure of prices, that regulation certainly fails to simultaneously bring the investment to its socially optimal level.²³ Intuitively, a price-cap regulation alone is not constraining-enough when the airport 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 $(\beta, \beta_0, \bar{P})$ on transportation and commercial services;
- a subsidy scheme for the investment, according to which the firm receives s per unit of investment.

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

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

The airport 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:

$$\beta p + \beta_0 p_0 \leq \bar{P}.$$

Next proposition shows that with an adequate choice of the weights (β, β_0) and the cap $\bar{P}$ as well as the unit subsidy s , the regulator can indeed implement the socially optimal regulation.

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

The price-cap is given by:

$$\begin{aligned} \beta^* &= 1 - F(p^{rb}, e^{rb}) + s_0(p_0^{rb})f(p^{rb}, e^{rb}), \\ \beta_0^* &= (1 - F(p^{rb}, e^{rb}))(1 - G(p_0^{rb})), \\ \bar{P}^* &= \beta^* p^{rb} + \beta_0^* p_0^{rb}. \end{aligned}$$

The unit subsidy is given by:

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

²³Observe that a price-cap regulation alone certainly departs from the Ramsey-Boiteux prices, for prices of commercial and transportation services impact the airport's incentives to invest.

Intuitively, the regulator has now enough instruments to implement the socially optimal regulatory policy. Indeed, for a given investment level, a price-cap allows to implement the corresponding Ramsey-Boiteux prices. Given some prices for transportation and commercial services, a subsidy scheme provides the airport 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 airport 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 set at s^* and when prices are at the Ramsey-Boiteux levels, the airport 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 airport 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.

When commercial services are not regulated, we have shown in Section 3.3 that the optimal partial regulation is similar to the Ramsey-Boiteux regulation in structure, but differs in levels. Therefore, a possible implementation of the optimal partial regulation relies again on a price-cap on aeronautical services augmented with a subsidy scheme on the investment level.

Before going further, let us emphasize that the proposed implementation requires complete information on the regulator's side. In practice, allocating the costs between aeronautical and commercial services is far from an easy accounting task. Costs may also be subject to strategic manipulations by the regulated airport. The new economics of regulation has shown that pricing decisions may be decoupled from incentive corrections.²⁴ Put differently, under asymmetric information, regulated prices still have a Ramsey-Boiteux structure, but the optimal regulation has to be augmented with a cost-sharing rule that prevents any manipulation of its cost by the regulated airport.

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 regulation, in one way or another, 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 profits to determine the regulation. 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. In contrast, Starkie (2001) supports the dual-till approach, arguing that it could alleviate the distortions on transportation prices and on investment

²⁴This so-called 'dichotomy property' holds under certain conditions on the cost function of the regulated firm; see Laffont and Tirole (1993) for a complete analysis and an extensive account of the modern theory of regulation.

incentives that are induced by the single-till approach.²⁵

We now address this question within our framework, assuming no lump-sum transfers from the regulator.²⁶ We find that, under some conditions, both approaches are actually equivalent and the distinction between them is thus irrelevant.

Observe that our analysis has implicitly assumed so far a single-till regime. The airport's budget constraint includes both the profits earned from commercial activities and those derived from transportation services. Let us now assume a dual-till regime wherein profits 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:

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

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

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

The problem of the regulator is then to maximize social welfare subject to the two budget constraints (6.2) and (6.3).²⁷ In the dual-till approach, the regulator is able to choose how to allocate the investment cost on each budget constraint. If we denote by λ_1 and λ_2 the multipliers associated to budget constraints (6.2) and (6.3) respectively, then, at the optimum, the regulator chooses the parameter α so that $\lambda_1 = \lambda_2$. 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 the binding constraints (6.2) and (6.3) are equivalent to the binding break-even constraint in a single-till regime:

$$(6.4) \quad (1 - F(p, e))(1 - G(p_0))(p_0 - c_0) + (1 - F(p, e))(p - c) - e = 0.$$

It should come at no surprise that the optimal regulation in a dual-till regime is then actually equivalent to that obtained in a single-till regime.

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.*²⁸

²⁵Oum 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.

²⁶If 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.

²⁷Constraints (6.2) and (6.3) ensure that the airport earns a nonnegative profit.

²⁸As 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 both constraints are binding, the optimal burden sharing parameter α satisfies:

$$(6.5) \quad \underbrace{(1 - F(p^{rb}, e^{rb}))(1 - G(p_0^{rb}))(p_0^{rb} - c_0))}_{\text{Profit from commercial services}} - \underbrace{(1 - F(p^{rb}, e^{rb}))(p^{rb} - c)}_{\text{Profit from aeronautical services}} = e^{rb}(2\alpha - 1).$$

Equation (6.5) illustrates a simple intuition. When commercial services yield higher profits than aeronautical services, they must contribute more to the financing of the airport's investment (i.e., $\alpha \geq 1/2$). Observe that it is 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 when the profit made 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.

The main argument underlying Proposition 5 is quite robust. For instance, if competition between airlines would be considered, the same logic would apply. At the optimal regulation, the regulator should always allocate the burden of investment across profit lines so as to equalize the shadow costs of the two budget constraints. Proposition 5 continues to hold when regulation is partial. When commercial services are unregulated, the airport prices these services at the monopoly price p_0^m . But the regulator still wants to equalize the shadow costs of the budget constraints under a dual-till regime and, when this happens, the two budget constraints in a dual-till regime again coincide with the unique break-even constraint in a single-till regime.

Last, we acknowledge that Proposition 5 may be of limited use in practice. It heavily relies on the assumption that the regulator is able to observe investment and even more that the airport sticks to the requested allocation of the investment cost across profit lines. Even though we have not formulated our argument in a framework with asymmetric information, we believe that such extension would somehow mitigate the scope of our results.

7. VERTICAL INEFFICIENCIES BETWEEN THE AIRPORT AND THE AIRLINE

As far as the relationship between the airport and the airline is concerned, we have consistently assumed throughout the analysis that the airport can use a two-part tariff to contract with the airline. As a result, the airport can fully appropriate the airline's profit and everything happens as if the regulator were facing a vertically-integrated structure. We now discuss how our analysis is modified when there are frictions in the contractual relationship between the airport and the airline.

To do so, 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 the number of passengers and the volume of aeronautical services required by the airline. Because the airport has only one pricing instrument to reach two competing objectives, there will be distortions on the prices of both services as well as on the investment. This is the issue of 'double marginalization' along a vertical chain, which we now detail more formally.

The objective of the airline is to choose the price of transportation services so as to maximize its profit given by $(1 - F(p, e))(p - w)$. Let us assume that the price $P(w, e)$ chosen by the airline is given by the following condition:

$$(7.1) \quad p = w + \theta \frac{1 - F(p, e)}{f(p, e)},$$

where $\theta \in [0, 1]$. Parameter θ is a ‘conjectural variations’ parameter that could be related to the intensity of competition on the market for transportation services. When $\theta = 1$, everything happens as if the airline has a monopoly position on the downstream market (and $P(w, e)$ coincides with the solution Equation (3.1)). When $\theta = 0$, everything happens as if the airline is perfectly competitive and prices at its perceived marginal cost (i.e., $P(w, e) = w$ and thus makes no profit). To focus on the relevant cases, let us assume that a higher investment, which generates a higher demand for transportation services, leads the airport to charge a higher price, i.e., $\frac{\partial}{\partial e} P(w, e) > 0$, which holds when $\frac{\partial}{\partial e} \frac{1 - F(p, e)}{f(p, e)} > 0$.

Since the airport cannot extract the profit of the airline through a fixed charge, the break-even constraint is given by:

$$(7.2) \quad (1 - F(p, e))(w - c + (p_0 - c_0)(1 - G(p_0))) - e + T \geq 0.$$

Of course, the transfer provided by the regulator must be such that the budget constraint (7.2) binds. This allows to formulate the regulator’s problem as follows:

$$\begin{aligned} \max_{(w, p, p_0, e)} \quad & CS(p, p_0, e) + (1 + \lambda)\Pi_I(p, p_0, e) - \lambda(1 - F(p, e))(p - w) \\ \text{s.t.} \quad & (7.1). \end{aligned}$$

This expression of the maximand shows that, since the airport has no fixed access charge to appropriate the airline’s profit, the airline’s profit does no longer contribute to the airport’s break-even constraint. Hence, leaving the airline with some profit $(1 - F(p, e))(p - w)$ has a social cost.

We then obtain the following results. The prices for both services (p^o, p_0^o) are now given by:

$$(7.3) \quad \frac{p^o - c_s(p_0^o)}{p^o} = \frac{\lambda}{1 + \lambda} \frac{1}{\varepsilon(p^o, e^o)} \left(\theta + 1 - \theta \frac{\partial}{\partial p} \frac{1 - F}{f}(p^o, e^o) \right),$$

$$(7.4) \quad \frac{p_0^o - c_0}{p_0^o} = \frac{\lambda}{1 + \lambda} \frac{1}{\zeta(p_0^o)}.$$

First, and as expected, the price of commercial services is set at its Ramsey-Boiteux level (see Equation (7.4)). Because commercial services are conditional to transportation services, the price of the former is independent of the price of the latter.

Second, since the airport cannot extract the airline company’s profit through a fixed access charge, the airport must therefore use the unit price w for aeronautical services as an instrument to satisfy the break-even condition (7.2). The unit price is distorted upward and the price of transportation services $P(w, e)$ set by the airline increases above its Ramsey-Boiteux level. This effect is the standard double marginalization problem. That problem also depends on the intensity of competition on the market for transporta-

tion services. If $\theta = 0$, which amounts to having a perfectly competitive airline, then Equation (7.3) coincides with the Ramsey-Boiteux benchmark. Put differently, the distortions associated to the double marginalization problem vanish when the airline market is perfectly competitive; by contrast, these distortions are reinforced when the airline has a strong market power on the market for transportation services.

Third, the optimal regulation rule for the investment is given by:

$$(7.5) \quad -\frac{\partial F}{\partial e}(p^o, e^o) \left(p - c_s(p_0^o) - \theta \frac{\lambda}{1+\lambda} \frac{1 - F(p^o, e^o)}{f(p^o, e^o)} \right) - \frac{1}{1+\lambda} \int_{v \geq p^o} \frac{\partial F}{\partial e}(v, e^o) dv \\ = 1 + \theta \frac{\lambda}{1+\lambda} (1 - F(p^o, e^o)) \frac{\partial}{\partial e} \left(\frac{1 - F}{f} \right).$$

We find, again, that when the airline market is perfectly competitive (i.e., $\theta = 0$), then the investment level coincides with the Ramsey-Boiteux outcome. When the airline has some market power, reducing the investment level allows to lower the price charged by the airline company and somewhat alleviates the double marginalization issue illustrated above. Moreover, because the airline's profits do not contribute to the balancing of the budget of the airport, they have a smaller social value. This also calls for reducing the airport's investment level.

Next proposition summarizes these findings.

Proposition 6. *When the airport can only charge the airline a unit price w for aeronautical services, the optimal regulation is such that with respect to the Ramsey-Boiteux benchmark: (i) the price of transportation services increases; (ii) the price of commercial services remains the same; (iii) the optimal level of investment e^o decreases.*

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. The inefficiencies brought by the double marginalization phenomenon are reduced as the airline has less and less market power, though.

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 have raised the question of extending the regulation perimeter to these activities.

The optimal regulation encompasses the prices of aeronautical and commercial services as well as investment decisions undertaken by the airport. 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 scheme, which prevents any under- or over-investment in the infrastructure. We also show that, under certain conditions, 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, which arises 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, 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.

The nature of the investment undertaken by the airport could also be investigated. If the airport's investment impacts only the demand for commercial services (but not that for transportation services), then our analysis can be immediately adapted and similar insights should emerge. The main difference is that investment impacts the private and social marginal costs of transportation services, but not the level of their demand. Regulation still allows to correct the prices and the investment incentives of the unregulated airport.

In practice, investment may be multi-dimensional, some dimensions improving transportation services but others enhancing only commercial services. When investment decisions are not observable by the regulator, providing the airport with the optimal incentives may entail further socially costly distortions on the prices of the airport's activities.

All these extensions are left for future research.

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APPENDIX

Proof of Proposition 1. 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:

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

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:

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

Dividing the first two equations by p and p_0 respectively gives Equations (3.4) and (3.5). The last equation already corresponds to Equation (3.6). ■

Proof of Proposition 2. The regulator's 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:

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

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

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

where we 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:

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

Dividing the first equation by p and the second one by p_0 yields Equations (3.7) and (3.8) respectively.

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

$$\int_{v \geq p} (v - p) \frac{\partial f}{\partial e}(v, e) dv - \frac{\partial F}{\partial e}(p, e)s_0(p_0) + (1 + \lambda) \left(-\frac{\partial F}{\partial e}(p, e)(p - c_{pr}(p_0)) - 1 \right) = 0.$$

Integrating by part the first term of this equation yields:

$$\int_{v \geq p} (v - p) \frac{\partial f}{\partial e}(v, e) dv = \left[(v - p) \frac{\partial F}{\partial e}(v, e) \right]_p^{\bar{v}} - \int_{v \geq p} \frac{\partial F}{\partial e}(v, e) dv.$$

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

$$\int_{v \geq p} (v - p) \frac{\partial f}{\partial e}(v, e) dv = - \int_{v \geq p} \frac{\partial F}{\partial e}(v, e) dv.$$

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

$$-\frac{\partial F}{\partial e}(v, e) \left(p - c_{pr}(p_0) + \frac{1}{1 + \lambda} s_0(p_0) \right) - \frac{1}{1 + \lambda} \int_{v \geq p} \frac{\partial F}{\partial e}(v, e) dv = 1.$$

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 (3.9). $\blacksquare$

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

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

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

$$\begin{aligned} \max_{(p, p_0, e)} \quad & CS(p, p_0, e) + (1 + \lambda)\Pi_I(p, p_0, e) \\ \text{s.t.} \quad & -\frac{\partial F}{\partial e}(p, e)(p - c_{pr}(p_0)) = 1. \end{aligned}$$

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

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

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:

$$-(1 + \lambda)g(p_0)(p_0 - c_0)(1 - F(p, e)) + \lambda(1 - F(p, e))(1 - G(p_0)) + \mu \left(-\frac{\partial F}{\partial e}(p, e)(1 - G(p_0) - g(p_0)(p_0 - c_0)) \right) = 0.$$

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

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

$$-\int_{v \geq p} \frac{\partial F}{\partial e}(v, e)dv - (1 + \lambda)\frac{\partial F}{\partial e}(p, e)(p - c_s(p_0)) + \mu \left(-\frac{\partial^2 F}{\partial e^2}(p, e)(p - c_{pr}(p_0)) \right) = 1 + \lambda,$$

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). $\blacksquare$

Proof of Proposition 4. Suppose that the regulator chooses β^* , β_0^* , $\bar{P}^*$, $\bar{e}^*$ and s^* as specified in Proposition 4. Then, the airport chooses p , p_0 and e to solve:

$$\begin{aligned} \max_{(p, p_0, e)} & (1 - F(p, e))(p - c + (p_0 - c_0)(1 - G(p_0))) - e + s^*(\bar{e}^* - e) \\ \text{s.t.} & \quad \beta^* p + \beta_0^* p_0 \leq \bar{P}^*. \end{aligned}$$

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:

$$\begin{aligned} -f(p, e)(p - c + (p_0 - c_0)(1 - G(p_0))) + 1 - F(p, e) - \mu\beta^* &= 0, \\ (1 - F(p, e))(1 - G(p_0) - (p_0 - c_0)g(p_0)) - \mu\beta_0^* &= 0, \\ -\frac{\partial F}{\partial e}(p, e)(p - c + (p_0 - c_0)(1 - G(p_0))) - 1 - s^* &= 0. \end{aligned}$$

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

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

$$(8.2) \quad \frac{p_0 - c_0}{p_0} = \frac{1}{\zeta(p_0)} - \frac{\mu\beta_0^*}{(1 - F(p, e))g(p_0)p_0},$$

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

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.

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 $\bar{P}^* = \beta^* p^{rb} + \beta_0^* p_0^{rb}$. Second, evaluating

(8.2) at $(p^{rb}, p_0^{rb}, e^{rb})$ yields:

$$\frac{p_0^{rb} - c_0}{p_0^{rb}} = \frac{1}{\zeta(p_0^{rb})} - \frac{\mu\beta_0^*}{(1 - F(p^{rb}, e^{rb}))g(p_0^{rb})p_0^{rb}} = \frac{\lambda}{1 + \lambda} \frac{1}{\zeta(p_0^{rb})},$$

where the second equality directly stems from the Ramsey-Boiteux price of commercial activities defined in Equation (3.8). Solving this equation for μ and using $\beta_0^* = (1 - F(p^{rb}, e^{rb}))(1 - G(p_0^{rb}))$ gives:

$$\begin{aligned} \mu &= \frac{1}{1 + \lambda} \frac{1}{\zeta(p_0^{rb})} \frac{(1 - F(p^{rb}, e^{rb}))g(p_0^{rb})p_0^{rb}}{\beta_0^*} \\ &= \frac{1}{1 + \lambda} \frac{1 - G(p_0^{rb})}{g(p_0^{rb})p_0^{rb}} \frac{(1 - F(p^{rb}, e^{rb}))g(p_0^{rb})p_0^{rb}}{(1 - F(p^{rb}, e^{rb}))(1 - G(p_0^{rb}))} \\ &= \frac{1}{1 + \lambda}. \end{aligned}$$

The multiplier $\mu = 1/(1 + \lambda) > 0$ is well-defined and strictly positive, i.e., the constraint must indeed be binding. Replacing μ and β^* 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:

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

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 (3.7).

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

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

which is equivalent to:

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

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 β^* , β_0^* , $\bar{P}^*$, $\bar{e}^*$ and s^* as specified in Proposition 4 successfully implements the optimal regulation scheme $(p^{rb}, p_0^{rb}, e^{rb})$. $\blacksquare$

Proof of Proposition 5. 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 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:

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

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:

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

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. Assume that the airline sets the price of transportation services p such that:

$$(8.4) \quad p = w + \theta \frac{1 - F(p, e)}{f(p, e)}.$$

Let μ be the multiplier associated to the equality constraint (8.4). The objective of the regulator is given by:

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

which has to be maximized subject to the airport's break-even constraint:

$$(1 - F(p, e))(w - c + (p_0 - c_0)(1 - G(p_0))) - e + T \geq 0.$$

We rewrite that constraint as:

$$(8.5) \quad \Pi_I - (1 - F(p, e))(p - w) + T \geq 0.$$

As usual, transfer T is such that (8.5) is binding, which allows to formulate the regulator's problem as follows:

$$\begin{aligned} \max_{(w,p,p_0,e)} \quad & CS + (1 + \lambda)\Pi_I - \lambda(1 - F(p, e))(p - w) \\ \text{s.t.} \quad & (8.4). \end{aligned}$$

Denote by $\mathcal{L}$ the Lagrangean associated to this maximization problem. The first-order condition with respect to w ($\partial\mathcal{L}/\partial w = 0$) immediately gives (we omit some notations to ease the exposition) $\mu = \lambda(1 - F) > 0$.

Optimizing with respect to p_0 immediately yields that $p_0^o = p_0^{rb}$.

The first-order condition with respect to p ($\partial\mathcal{L}/\partial p = 0$) can be rewritten as follows after some manipulations:

$$\frac{p - c_s(p_0)}{p} = \frac{\lambda}{1 + \lambda} \frac{1}{\varepsilon(p)} \left(\theta + 1 - \theta \frac{\partial}{\partial p} \left(\frac{1 - F}{f} \right) \right).$$

It remains to optimize with respect to e . Notice that:

$$\int_{v \geq p} (v - p) \frac{\partial f}{\partial e}(v, e) dv = \left[(v - p) \frac{\partial F}{\partial e}(v, e) \right]_p^{\bar{v}} - \int_{v \geq p} \frac{\partial F}{\partial e}(v, e) dv = - \int_{v \geq p} \frac{\partial F}{\partial e}(v, e) dv,$$

where the second equality stems from the fact that $\frac{\partial F}{\partial e}(\bar{v}, e) = 0$. Using this last equality and the value of the multiplier μ , the first-order condition with respect to e ($\partial\mathcal{L}/\partial e = 0$) rewrites as (7.5).

Last, since $\frac{\partial}{\partial p} \frac{1-F}{f}(p, e) < 0$ and $\frac{\partial}{\partial e} \frac{1-F}{f}(p, e) > 0$, it comes immediately that $e^o \leq e^{rb}$.