
REGULATING AIR TRANSPORT MARKETS

vorgelegt von Diplom-Volkswirt
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aus Berlin

von der Fakultät VII - Wirtschaft & Management
der Technischen Universität Berlin
zur Erlangung des akademischen Grades

Doktor der Wirtschaftswissenschaften
- Dr.rer.oec. -

genehmigte Dissertation

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Tag der wissenschaftlichen Aussprache: 9. Juli 2007

Berlin 2007

D 83

CONTENTS

1	Introduction	1
2	Code-sharing, price discrimination, and welfare losses	5
2.1	Introduction	6
2.2	The model	11
2.3	Code-share agreements with antitrust immunity versus no code-share agreements	14
2.4	Code-share agreements without antitrust immunity	22
2.5	Conclusions	26
3	Price-cap regulation of airports: single-till versus dual-till	28
3.1	Introduction	29
3.2	The model	33
3.3	An unregulated monopolistic airport	37
3.4	Ramsey charges	39
3.5	Single-till versus dual-till	41
3.6	A Ramsey optimal price-cap regulation	46

3.7	Conclusions	48
4	Congestion management under uncertainty in a two-airport system	50
4.1	Introduction	51
4.2	The basic model	55
4.3	Congestion pricing versus slot constraints under uncertain passenger benefits	57
4.4	Regulation regimes under uncertain passenger benefits and demand complementarity	61
4.5	Regulation regimes under uncertain congestion costs	68
4.6	Profit maximizing airport behavior	72
4.7	Conclusions	74
5	Regulation of two-part tariffs and quality choice under uncertainty	77
5.1	Introduction	78
5.2	The model	82
5.3	Welfare vs. profit maximization	86
5.4	Combining quality standards with standards on quantities or prices	88
5.5	Combining price standards with quality standards or quality bonuses	90
5.6	Combining quality bonuses with price standards or quality standards	97
5.7	Conclusions	102
A	Proofs for chapter 2	104
A.1	Proof of Proposition 2.3.1	105

A.2	Proof of Proposition 2.3.3	106
A.3	Proof of Proposition 2.4.3	107
B	Proofs for chapter 4	109
B.1	Proof of Proposition 4.6.1	110
C	Proofs for chapter 5	113
C.1	Proof of Lemma 5.5.1	114
C.2	Proof of Lemma 5.6.2	115

LIST OF FIGURES

2.1	Airlines' networks.	12
2.2	Welfare under code-share agreements with antitrust immunity, \bar{W}^I , and welfare without code-share agreements, \bar{W}^{Nj} with $j \in \{1, 2\}$ ($n = 80$).	21
2.3	Welfare under code-share agreements without antitrust immunity, \bar{W}^C , and welfare without code-share agreements, \bar{W}^{Nj} with $j \in \{1, 2\}$ ($n = 80$).	25
3.1	Passenger and consumer demand for given prices p_1 and p_2 . The demand for flights, D_1 , equals area A+B+C. The demand for commercial services, D_2 , equals the area B + C.	35
3.2	Ramsey charges. p_1^R : aeronautical Ramsey charges. p_2^R : commercial Ramsey charges.	40
3.3	Charges implied by subgame perfect Nash-equilibria under single-till regulation for varying amounts of F	43
3.4	Charges implied by subgame perfect Nash-equilibria under dual-till regulation for varying amounts of αF	44

4.1	Welfare losses due to benefit shocks ($a = b = c = 1, \theta = 1/3$). A: Welfare loss under slot constraints. B: Welfare loss under congestion pricing.	59
4.2	Two airports in a regulated area with separated catchments.	62
4.3	Welfare losses due to benefit shocks with demand complemen- tarity ($a = b = c = 1, \gamma = 9/10, \theta_1 = 1/4, \theta_2 = 0$). A: Welfare loss under slot constraints. B + G: Welfare loss under congestion pricing.	66
4.4	Airport charges and expected welfare under congestion pricing ($a = b = c = 1, \gamma = 9/10, \sigma_\theta^2 = 0$).	72
5.1	Regulation regimes: overview and notation.	84
5.2	First-best quality and quality under regimes $s2$ and $b1$ depend- ing on realizations of κ ($a = b = c = 1, \theta = 0, \sigma^2 = 1/10$).	96
5.3	Linear quality rewards (β) under regimes $b1$ and $b2$ as func- tions of $\sigma^2 \in [0, 1/3]$	100
5.4	First-best quality and quality under regimes $b1$ and $b2$ depend- ing on the realizations of θ ($\sigma^2 = 1/10, \phi = 1$).	100

CHAPTER 1

Introduction

During the last four to five decades most transport and infrastructure industries in Europe as well as the U.S. were liberalized and many public enterprises were privatized. This changed the market environment drastically and led to new challenges for firms, politicians and regulators. This dissertation presents four papers that focus on some of these challenges in the air transport industry.

The next chapter refers to airline markets and analyzes pricing strategies under complementary airline networks and different regulation regimes. The two subsequent chapters are related to airport policies. The first airport chapter analyzes the interdependence between aeronautical and commercial airport activities and its impact on the design of a price-cap regulation regime. While this paper considers non-congested airports the second airport chapter refers to congested airports. It compares slot constraints and congestion pricing as instruments for the management of airport congestion

under uncertainty about passenger benefits and congestion costs. The final chapter focuses on an infrastructure provider's choice of quality and the regulation of demand and quality under uncertainty about market conditions. This chapter can be applied to airports, but the problems considered are of similar relevance for other transport and infrastructure markets such as the water industry and telecommunications or energy markets.

In the following we summarize the contents of the four subsequent chapters.

Chapter 2: Code-sharing, price discrimination, and welfare losses

Airlines frequently use code-share agreements allowing each airline to market seats on directions operated by the partner airlines. Interline passengers can then buy only one ticket for their flights although they are in fact served by two different airlines sequentially. Regulation may allow code-share agreements with antitrust immunity (cooperative price setting), or without antitrust immunity, or not at all. We compare the relative welfare effects of these regulation regimes for complementary airline networks. A crucial point is that such agreements are used to identify and price discriminate interline passengers.

We find that interline passengers always benefit from code-share agreements while non-interline passengers are worse off. Furthermore, we show that the second effect strongly questions the overall usefulness of code-share agreements from a welfare perspective. According to our analysis, and with a view to the literature, welfare is likely to be higher if code-sharing is not allowed.

Chapter 3: Price-cap regulation of airports: single-till versus dual-till

This paper takes up the ongoing debate whether price-cap regulation of airports should take the form of single-till or dual-till regulation. The key difference between single-till and dual-till regulation is that with single-till the price-cap is set in anticipation of the revenues from aeronautical *and* commercial services. The dual-till approach, in contrast, tries to separate out the two airport business branches, particularly by attributing specified portions of airports' costs to the aeronautical and commercial branches.

The contribution of this paper is to model single- and dual-till regulation, evaluate their comparative welfare implications, and compare them to Ramsey charges. We show that single-till regulation dominates dual-till regulation at non-congested airports with regard to social welfare. However, none of them provides an airport with incentives to implement Ramsey charges. A Ramsey optimal price-cap regulation, which achieves this goal, is also presented.

Chapter 4: Congestion management under uncertainty in a two-airport system

In order to control airport congestion many overloaded airports are slot constrained. An airline that wishes to incorporate a slot constrained airport into its networks needs to have a respective permission (slot) to use that airport at a specified time. Because the number of slots is constrained, airline operations at the airport are limited and, consequently, demand and congestion can effectively be controlled and optimized. On the other hand, with congestion pricing an increase of airport charges reduces slot demand until the optimal level of congestion is reached.

In this paper, we analyze the effect of uncertainty and complementary airport demand on the choice of regulation instruments. Analysis is based on a model including a single airport and uncertain passenger benefits that is gradually extended such that it includes a two-airport system and uncertain congestion costs. We demonstrate that uncertainty favors the use of congestion pricing while demand complementarity can favor the use of slot constraints. However, congestion pricing is always the right choice from a welfare perspective. We also show that unregulated monopolistic airports choose prices as instruments, too, however, not the right ones.

Chapter 5: Regulation of two-part tariffs and quality choice under uncertainty

In this paper we focus on utilities, the regulation of demand and quality, as well as on the distribution of welfare. We assume that regulators are uncertain about demand and cost conditions when regulation is chosen and consider four different regulation regimes based on two-part tariffs. The regulation regimes combine: a cap on the fixed fee with either (i) quantity and quality standards, (ii) price and quality standards, (iii) price standards and quality bonuses, or (iv) quantity standards and quality bonuses.

It turns out that there is a clear ranking of the four regimes in terms of expected welfare. The best results are obtained by regime (iv), i.e. with fixed fee caps, quantity standards, and quality bonuses. This is because, first, bonuses are helpful for dealing with uncertainty about quality costs. Second, under demand uncertainty, standards on quantities allow for positive prices *sometimes* which enhances the firm's incentives to adjust quality towards the welfare optimal level.

CHAPTER 2

Code-sharing, price discrimination,
and welfare losses

2.1 Introduction

During the last decades the airline industry experienced major changes. Liberalization significantly increased competition between airlines which affected the development and structure of the market. For instance, incumbent carriers began to use hub-and-spoke systems where passengers are concentrated at a (hub) airport in order to realize economies of scope and economies of density. In contrast to the incumbent hub-and-spoke carriers, low-cost carriers appeared that exclusively offer point-to-point flights normally for a low fare.

Another phenomenon that has appeared during the time of deregulation is airline alliances. At present three major global airline alliances exist: Oneworld, The Star Alliance, and SkyTeam (Doganis, 2006). Moreover, during the last years domestic alliances appeared (Bamberger et al., 2004), (Ito and Lee, 2005). Alliances in general can fall between full integration of the parties and simple market mediated exchanges between them (Chen and Ross, 2003). In the air transport industry alliances constitute a framework for cooperation between airlines, e.g., sharing of sales offices and maintenance facilities, coordinating schedules and aligning airport facilities. Frequently used forms of cooperation between alliance partners and even non-allied airlines include code-share agreements. They allow airlines to market seats on directions operated by partner airlines. An important consequence is that interline passengers can buy only one ticket for their flights although they are in fact served by two different airlines. The total price for this ticket is composed of the sub-fares each airline charges for its part of the connection. In most instances code-share agreements are provided with antitrust immunity which allows partner airlines to set sub-fares for interline passengers cooperatively. However, in the case of American Airlines and British airways

antitrust immunity was denied, i.e. airlines were not allowed to set sub-fares cooperatively.

Current studies consistently argue that in the case of complementary networks code-share agreements generate positive welfare effects (Oum et al., 1996b), (Park, 1997), (Brueckner and Whalen, 2000), (Park and Zhang, 2000), (Brueckner, 2001), (Hassin and Shy, 2004), (Bilotkach, 2005). For instance, one reason is that interline fares are reduced because airlines avoid double marginalization of interline fares. Only with overlapping networks negative welfare effects of code-share agreements with antitrust immunity are supposed to occur. This is because they are expected to lead to collusion and higher fares on city-pair connections served by partner airlines in parallel. In this case interline passengers still benefit from code-share agreements but other passengers can be worse off.

However, it has been widely ignored that even in the case of complementary networks non-interline passengers can be negatively affected by code-share agreements (with or without antitrust immunity). The reason is that without code-share agreements airlines lose their ability to price discriminate and, as a consequence, set only one fare for all passengers on each city-pair connection served entirely by their own (Bilotkach, 2005). In this context, price discrimination means that the sub-fares airlines charge to interline passengers are different from the fares other passengers have to pay for the same trip. This is a third degree price discrimination. Why are code-share agreements essential for price discrimination? Suppose that airlines are not allowed to use code-share agreements. Then, on a city-pair connection that is not entirely served by only one airline but by a combination of different airlines, passengers need to buy tickets from different airlines to make their trip. Observe that in this situation it is difficult for airlines to identify

interline passengers. Consequently, price discrimination cannot be used and interline passengers are charged like other passengers. On the other hand, if airlines make use of code-share agreements they market interline trips as one product which allows for price discrimination of interline passengers.

Now, without code-share agreements fares for each connection depend on the aggregate demand by interline and non-interline passengers and airlines might decide to reduce fares in order to attract additional demand from interline passengers. Then non-interline passengers clearly benefit from the existence of interline passengers, if price discrimination cannot be applied, even in the case of complementary networks. The implementation of code-share agreements, therefore, has two effects. First, it can reduce fares for interline passengers and, second, it can increase fares for non-interline passengers. The second effect has been ignored so far. However, both effects have to be taken into account to evaluate the total welfare effect of code-share agreements.

In this paper we consider a model with two airlines using perfectly complementary networks which implies that airlines do not compete. We analyze three different regulation regimes:¹

1. airlines are not allowed to cooperate using code-share agreements,
2. airlines use code-share agreements with antitrust immunity, and
3. airlines use code-share agreements but antitrust immunity is denied

We show that the detrimental welfare effects of price discrimination with regard to non-interline passengers can compensate the positive welfare effects on interline passengers. This holds for the case of code-share agreements with antitrust immunity, but even more so for the case of code-share agreements

¹These three regulation regimes have also been analyzed by Bilotkach (Bilotkach, 2005).

without antitrust immunity. Taking into account the negative effects which code-share agreements can have on competition in the case of overlapping networks, our results strongly question their overall usefulness from a welfare perspective.

The effects of alliances and in particular code-share agreements on airline fares and welfare has been the subject of intensive theoretical and empirical investigation. The theoretical approach used by Park indicates that the welfare effect of alliances using code-share agreements will depend on whether the partner airlines' networks are parallel or complementary in nature, i.e. whether partner airlines serve connections in parallel or not (Park, 1997). He derives positive welfare effects for complementary networks and negative welfare effects for parallel networks. Positive effects arise because in the complementary case partner airlines jointly enter into markets they did not serve before and, as a consequence, increase competition there. On the other hand, with parallel networks code-share agreements are a means of collusion and lead to welfare losses.

Similar results are provided by Brueckner (Brueckner, 2001). He demonstrates that the welfare effects of international alliances using code-share agreements with antitrust immunity in comparison to code-share agreements without antitrust immunity are detrimental on interhub markets because of collusion. In contrast, markets where each partner airline serves only a part of a city-pair connection are likely to benefit from antitrust immunity. The latter is because cooperative pricing puts downward pressure on interline fares. The results presented by Brueckner are consistent with the theoretical results from Brueckner and Whalen (Brueckner, 2001), (Brueckner and Whalen, 2000). However, the theoretical model developed by Brueckner and Whalen accounts for competition between airline alliances. Zhang and Zhang

analyze competition between strategic alliances without explicitly modeling the effects of code-share agreements (Zhang and Zhang, 2005).

The studies mentioned above consider Cournot behavior on city-pair connections that are served in parallel by competing airlines. In contrast, Bilotkach applies a Bertrand competition approach (Bilotkach, 2005). He points out that code-share agreements are crucial for airlines in order to price discriminate interline passengers. Bilotkach concludes that antitrust immunity is not crucial to eliminate a double-mark up for interline fares because inter-alliance competition can reduce interline fares.

Hassin and Shy concluded that no passengers become worse off but some passengers are strictly better off with code-share agreements using a line of reasoning that is different from the ones presented so far (Hassin and Shy, 2004). Applying a Hotelling model they assume that passengers' preferences for airlines are heterogenous. Then, their basic argument is that code-share agreements generate an additional travel opportunity to passengers which enhances welfare. Namely, passengers who are heavily oriented towards an airline that does not serve a connection entirely by itself can benefit from code-sharing because they get the opportunity to use a flight that is entirely marketed by the preferred airline.

The power of code-share agreements to reduce interline fares has been evidenced by empirical studies. Oum, Park, and Zhang showed that code-share agreements lead to fare reductions and increasing passenger numbers of the market leader (Oum et al., 1996b). Brueckner and Whalen found that allied airlines' interline fares are 25 percent below those charged by non-allied airlines (Brueckner and Whalen, 2000). Park and Zhang found that international alliances lead to a reduction of fares and an increase of passenger numbers in the case of complementary airline networks (Park and

Zhang, 2000). In the other case of parallel networks they conclude that fares are likely to increase while passenger numbers fall. Similar results are provided by Bamberger, Carlton, and Neumann for domestic airline alliances in the U.S. (Bamberger et al., 2004). A positive welfare effect of domestic code-share practices in the U.S. has also been confirmed by Ito and Lee (Ito and Lee, 2005). Regarding the impact of code-share alliances on airline cost structure Goh and Yong found statistically significant but little cost savings (Goh and Yong, 2006).

The paper is organized as follows. In section 2.2 we present our model. In section 2.3 we analyze airline behavior under code-share agreements provided with antitrust immunity and airline behavior using any form of code-share agreements. In section 2.4 we consider airlines using code-share agreements without antitrust immunity. In section 2.5 we present our conclusions.

2.2 The model

We consider an airline market with a fixed network structure including n spoke airports, $n \in \mathbb{N}_+$ and $n \geq 2$, as well as one hub airport. The number of city-pair connections between hub and spoke airports, which we call *direct connections* because they contain a non-stop service, is also determined by n . A city-pair connection between two spoke airports, using a pair of direct connections to form an indirect route will be called *indirect connection*. There are $\binom{n}{2}$ indirect connections. Thus the total number of connections is

$$\bar{n} := n + \binom{n}{2} = \frac{n(n+1)}{2}.$$

There are two airlines. Assume that direct connections $i \in \{1, \dots, n-1\}$ are served by airline 1 and the direct connection n is served by airline 2. Notice

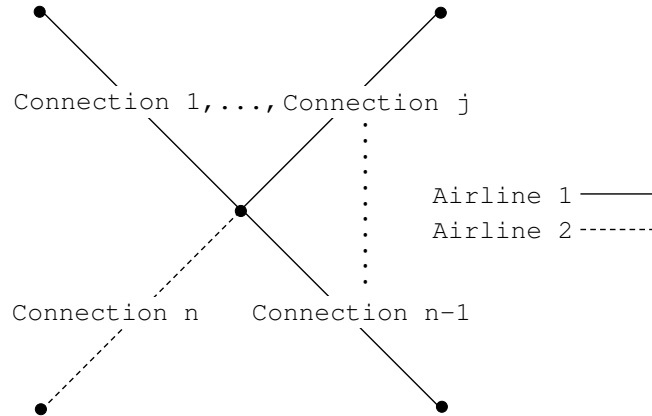


Figure 2.1: Airlines' networks.

that airlines 1 and 2 are not competing for passengers because networks are fully complementary.

The number of (round trip) passengers on each connection is denoted by $q_i \geq 0$ with $i \in \{1, \dots, n, \dots, \bar{n}\}$ where connections $i \in \{1, \dots, n\}$ are direct and connections $i \in \{n + 1, \dots, \bar{n}\}$ are indirect. Figure 2.1 illustrates this case.

Indirect connections can be of two types. First, they can be composed of a pair of direct connections entirely served by airline 1 or, second, of a pair of direct connections where one part is served by airline 1 and the other part by airline 2 which we call *interline connections*. There are $n - 1$ interline connections. Assume that interline connection $n + 1$ includes direct connections 1 and n , interline connection $n + 2$ includes direct connections 2 and n , until $n - 1$ and n . Thus, connections $i \in \{n + 1, \dots, 2n - 1\}$ are interline connections. Indirect connections $i \in \{2n, \dots, \bar{n}\}$ are entirely served by airline 1.

Assume that passengers appreciate direct connections, i.e. passenger demand might be lower at a given price if a connection is served indirectly including transfers at the hub airport. In particular business passengers usually have a preference for direct connections. Let the reservation price for a direct connection be 1 and that for an indirect connection $a \in (0, 1]$.

For connections entirely served by only one airline it holds: airline fares are $p_i \geq 0$ for $i \in \{1, \dots, n; 2n, \dots, \bar{n}\}$ and demand

$$D_i(p_i) = \begin{cases} \max\{0, 1 - p_i\} & \text{for } i \in \{1, \dots, n\} \\ \max\{0, a - p_i\} & \text{for } i \in \{2n, \dots, \bar{n}\}. \end{cases}$$

Interline connections are indirect connections served by two airlines. Each airline charges a sub-fare for its part of the interline connection denoted by $p_{i,j} \geq 0$ with $i \in \{n + 1, \dots, 2n - 1\}$ and $j \in \{1, 2\}$ where j denotes the airline. Hence, interline passengers are charged twice and demand is

$$D_i(p_{i,1} + p_{i,2}) = \max\{0, a - p_{i,1} - p_{i,2}\}$$

Notice that the above demand specifications for indirect connections including interline connections require that fare-arbitrage conditions are satisfied: total fares for indirect connections are not greater than the sum of fares for the relevant direct connections.

The way sub-fares are set depends on the regulation regime. Without code-share agreements airlines are not able to price discriminate between interline and other passengers. Remember that interline connection $i \in \{n + 1, \dots, 2n - 1\}$ is composed of direct connections $i - n$ and n by assumption. Therefore, without code-share agreements, it holds $p_{i,1} = p_{i-n}$ and $p_{i,2} = p_n$ for all $i \in \{n + 1, \dots, 2n - 1\}$. Under code-share agreements with or without

antitrust immunity price discrimination is possible. However, with antitrust immunity sub-fares are set cooperatively by the two airlines, such that the joint profit of airlines 1 and 2 is maximized. In contrast, without antitrust immunity sub-fares are set independently.

We consider the airlines' networks including the choice of aircraft as given and, therefore, fixed airline costs are not relevant for our analysis. Furthermore, assume that airlines do not face capacity constraints. Finally, we assume that variable airline costs are zero. Notice that according to the literature in our case with fully complementary networks code-share agreements should be increasing social welfare.

2.3 Code-share agreements with antitrust immunity versus no code-share agreements

Most code-share agreements are provided with antitrust immunity so that airlines are allowed to coordinate fares. In this case partner airlines set total interline fares in order to maximize joint profits and then share the revenues by splitting the fare into airline specific sub-fares (Brueckner, 2001). This case will be referred by index I .

Setting aside the fare arbitrage conditions, the airlines' behavior in terms of fares on non-interline connections is determined by

$$p_i^I := \arg \max_{p_i} p_i D_i(p_i) = \begin{cases} \frac{1}{2} & \text{for all } i \in \{1, 2, \dots, n\} \\ \frac{a}{2} & \text{for all } i \in \{2n - 1, \dots, \bar{n}\}. \end{cases}$$

Assume that under code-share agreements with antitrust immunity the sub-fares of airlines are equal, i.e. each airline charges exactly one half of the total

fare they agreed upon. Since airlines jointly maximize revenues on interline connections this leads to

$$p_{i,j}^I := \frac{1}{2} \cdot \arg \max_{p_{i,1}+p_{i,2}} (p_{i,1} + p_{i,2}) \cdot D_i(p_{i,1} + p_{i,2}) = \frac{a}{4}$$

for all $i \in \{n + 1, \dots, 2n - 1\}$ and $j \in \{1, 2\}$.² Notice that airlines actually make use of their possibility to price discriminate; the sub-fares for interline passengers are $a/4$ which is strictly lower than the fares for direct connections that are $1/2$. Furthermore, since $\frac{a}{2} < 1$, the fare arbitrage conditions are indeed strictly satisfied.

Now we consider the case that code-share agreements are banned. Indirect connections composed of direct connections exclusively served by airline 1 are not affected by code-share agreements. In contrast, code-share agreements change the picture on interline and direct connections. Without code-share agreements interline passengers buy two tickets and pay the same fare as passengers on direct connections pay. Thus, $p_{i,1} = p_{i-n}$ and $p_{i,2} = p_n$ for all $i \in \{n + 1, \dots, 2n - 1\}$. If code-share agreements are not used, the total demand \hat{D}_i for direct connections $i \in \{1, \dots, n - 1\}$, offered by airline 1, is determined by the demand for direct connection i and interline connection $i + n$:

$$\hat{D}_i(p_i, p_n) := D_i(p_i) + D_{i+n}(p_i + p_n).$$

²One can check that each airline is better off under code-share agreements with antitrust immunity.

The total demand \hat{D}_n for direct connection n , offered by airline 2 includes the demand from passengers on this direct connection and the demands from all interline passengers:

$$\hat{D}_n(p_1, \dots, p_n) := D_n(p_n) + \sum_{i=1}^{n-1} D_{i+n}(p_i + p_n).$$

How do airlines' behave in this situation? Denote critical levels for a by

$$\bar{a} := \frac{1}{2} + \frac{1}{1 + \sqrt{n}} \quad \text{and}$$

$$\tilde{a} := \max \left\{ \frac{9\sqrt{n} + 2n - 1}{6(\sqrt{n} + n)}, \frac{4 + (1 + 7n)\sqrt{2} - 8n}{4 + 4n} \right\}.$$

Regarding \tilde{a} , observe that for $n < 34$ the first term in brackets is relevant and for $n \geq 34$ the second. Moreover, it always holds $\tilde{a} < \bar{a} < 1$. Then denote price vectors

$$(p_1^{N1}, \dots, p_n^{N1}) := (p_1^I, \dots, p_n^I)$$

and $(p_1^{N2}, \dots, p_n^{N2})$ with

$$p_i^{N2} := \frac{a - 1 + n(2 + a)}{1 + 7n}$$

for all $i \in \{1, \dots, n - 1\}$ and

$$p_n^{N2} := \frac{5 - n + 3a(n - 1)}{1 + 7n}.$$

Proposition 2.3.1 *Without code-share agreements the following holds:*

If $a < \tilde{a}$, $(p_1^{N1}, \dots, p_n^{N1})$ is the unique Nash equilibrium.

If $a > \bar{a}$, $(p_1^{N2}, \dots, p_n^{N2})$ is the unique Nash equilibrium.

If $a \in [\tilde{a}, \bar{a}]$, there are exactly two Nash equilibria, $(p_1^{N1}, \dots, p_n^{N1})$ and $(p_1^{N2}, \dots, p_n^{N2})$, of which $(p_1^{N2}, \dots, p_n^{N2})$ is the Pareto-dominant one.

Proof See appendix A.1. ■

Since $(p_1^{N2}, \dots, p_n^{N2})$ exists and is Pareto-dominant from the airlines' point of view if $a \in [\tilde{a}, \bar{a}]$ holds, we consider it to be a focal point in the following. The welfare implications of Proposition 2.3.1 are mixed. First, have a look at passengers' point of view:³

Proposition 2.3.2 *Comparing code-share agreements under antitrust immunity and no code-share agreements at all, the following holds. Passengers on interline connections are better off with code-share agreements. Passengers on direct connections are better off with code-share agreements if and only if $a \geq \tilde{a}$.*

Proof Under code-share agreements with antitrust immunity interline fares are always lower than in a situation without code-share agreements. This is so because $a/2 < p_i^{N1} + p_n^{N1}$ holds for all $a \leq \bar{a}$ and all $i \in \{1, \dots, n-1\}$, and $a/2 < p_i^{N2} + p_n^{N2}$ holds for all $a \geq \tilde{a}$ and all $i \in \{1, \dots, n-1\}$. Furthermore, observe that in a situation without code-share agreements the number of interline passengers is 0 if $(p_1^{N1}, \dots, p_n^{N1})$ realizes. In contrast, under code-share agreements with antitrust immunity the number of interline passengers is always positive. For $a \geq \tilde{a}$ it follows $p_i^{N2} < p_i^I$ for all $i \in \{1, \dots, n\}$. Hence, passengers on direct connections can benefit if there are no code-share agreements with antitrust immunity. ■

What about the effect of code-share agreements with antitrust immunity on total welfare compared to a situation without code-share agreements? Observe that only direct and interline connections, i.e. connections $i \in \{1, \dots, 2n-1\}$, are affected by code-share agreements. To measure the total

³Notice that passengers on indirect connections entirely served by airline 1 are not affected by code-share agreements.

welfare effect of code-share agreements we will focus on the average welfare \bar{W} on these $2n - 1$ connections which is

$$\begin{aligned} \bar{W}(p_1, \dots, p_n; (p_{n+1,1}, p_{n+1,2}), \dots, (p_{2n-1,1}, p_{2n-1,2})) := \\ \frac{1}{2n-1} \cdot \left(\sum_{i=1}^n \left(\int_{p_i}^1 D_i(y) dy + p_i D_i(p_i) \right) + \right. \\ \left. \sum_{i=n+1}^{2n-1} \left(\int_{p_{i,1}+p_{i,2}}^a D_i(y) dy + (p_{i,1} + p_{i,2}) \cdot D_i(p_{i,1} + p_{i,2}) \right) \right). \end{aligned}$$

Denote the average welfare reached on direct and interline connections under code-share agreements with antitrust immunity by

$$\bar{W}^I := \bar{W}(p_1^I, \dots, p_n^I; (p_{n+1,1}^I, p_{n+1,2}^I), \dots, (p_{2n-1,1}^I, p_{2n-1,2}^I))$$

and without code-share agreements at all by

$$\bar{W}^{Nj} := \bar{W}(p_1^{Nj}, \dots, p_n^{Nj}; (p_{n+1,1}^{Nj}, p_{n+1,2}^{Nj}), \dots, (p_{2n-1,1}^{Nj}, p_{2n-1,2}^{Nj}))$$

for $j \in \{1, 2\}$. Denote another critical level for a by

$$\tilde{a} := \frac{24(1+n)^2 - (1+7n)\sqrt{32+37n+23n^2}}{17+34n-19n^2}$$

and note that $\tilde{a} > \bar{a}$ if and only if $n \geq 32$ (and $0 < \tilde{a} < 1$ for all n).

Proposition 2.3.3 $\bar{W}^I > \bar{W}^{N1}$ holds when $N1$ exists (i.e. for all $a \leq \bar{a}$).

If $n < 32$, $\bar{W}^I > \bar{W}^{N2}$ holds when $N2$ exists (i.e. for all $a \geq \tilde{a}$).

If $n \geq 32$, $\bar{W}^I \geq \bar{W}^{N2}$ for $a \geq \tilde{a}$ and $\bar{W}^I < \bar{W}^{N2}$ for $a \in [\bar{a}, \tilde{a})$.

Proof See appendix A.2. ■

Notice that there is a strong dependence between the number of direct and interline connections: the ratio of interline and direct connections $(n - 1)/n$ is increasing in n . Hence, with an increasing number of direct connections the relative importance of interline connections is increasing, too.

Proposition 2.3.3 states an important result: It may happen that welfare is higher without code-share agreements than with code-share agreements under antitrust immunity. Without code-share agreements airlines lose their ability of effective price discrimination. Now, without price discrimination airlines might decide to reduce fares for direct connections in order to attract additional demand from interline passengers. Hence, passengers on direct connections can benefit from the existence of interline passengers if price discrimination is not possible. Furthermore, this might compensate the loss of positive welfare effects code-share agreements have on interline passengers. Notice that this effect of code-share agreements and price discrimination on welfare has been ignored so far. So far code-share agreements were considered to generate only positive welfare effects in the case of complementary airline networks (Park, 1997), (Bilotkach, 2005).

To understand the impact of a on welfare, consider the passengers on direct connections when code-share agreements are not allowed. On the one hand, a critical level \tilde{a} must be reached such that airlines will reduce fares on direct connections in order to attract additional demand from interline passengers. On the other hand, the reduction in fares shrinks with further increases in a . The positive welfare effects arising from the fact that airlines do not price discriminate between passengers on direct connections and interline passengers is, therefore, declining after \tilde{a} is reached. As a consequence, another critical level $\tilde{\tilde{a}}$ exists such that, for $a > \tilde{\tilde{a}}$, code-share agreements with antitrust immunity lead to higher welfare compared to a situation without

code-share agreements. Observe that, first, $\tilde{a} < 1$ holds and, second, $\tilde{a} < \tilde{a}$ holds for $n < 32$. Hence, if a is close enough to 1 then code-share agreements with antitrust immunity will always lead to better welfare results compared to a situation without code-share agreements. Furthermore, for $n < 32$ code-share agreements with antitrust immunity always lead to higher welfare results compared to a situation without code-share agreements. A positive welfare effect of a ban on code-share agreements can only occur for a high number of connections, i.e. $n \geq 32$, and an intermediate value of $a \in [\tilde{a}, \tilde{a}]$.

In reality, the number of relevant interline passengers, in particular at major airports, is potentially very high. Consider an airport with 80 air traffic movements per hour (e.g., Frankfurt airport in Germany). Suppose that passengers accept up to four hours of transfer time and the minimum transfer time is one hour. Then, since on average the number of departing flights will be the half of total air traffic movements, the number of potential interline connections reaches approximately 120. This illustrates that the condition $n > 32$ is likely to be satisfied on medium size and large airports.

Figure 2.2 shows the average welfare with code-share agreements under antitrust immunity and without code-share agreements as a function of a for $n = 80$. For the cases with two Nash equilibria it depicts the focal point equilibrium $N2$ as a solid curve. The figure indicates that the range on which a ban of code-share agreements leads to higher welfare levels is rather small, i.e. the difference $\tilde{a} - \tilde{a}$ is rather small for reasonable numbers of interline connections. However, the positive effect on the passengers for direct flights is always present at equilibrium $N2$, implying that the difference between \bar{W}^I and \bar{W}^{N2} is rather small for *all* $a \geq \tilde{a}$ (compared to the much larger difference between \bar{W}^I and \bar{W}^{N1}).

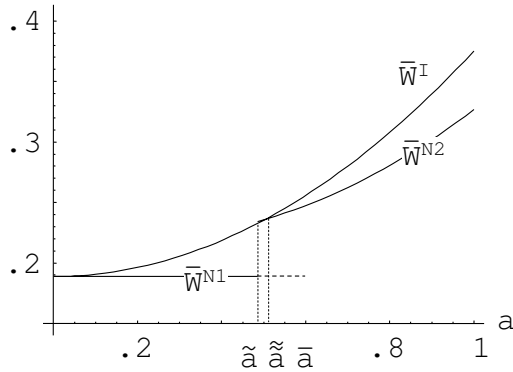


Figure 2.2: Welfare under code-share agreements with antitrust immunity, \bar{W}^I , and welfare without code-share agreements, \bar{W}^{Nj} with $j \in \{1, 2\}$ ($n = 80$).

Recall that in our case airline networks are fully complementary. Considering overlapping networks puts more question marks on the usefulness of code-share agreements from a welfare perspective. With overlapping networks, airlines compete on connections served in parallel. In this case code-share agreements with antitrust immunity have two effects. First, they lead to collusion and higher fares on connections served in parallel. Second, they can lead to increasing fares for passengers on direct connections. The first effect has already been shown in (Park, 1997), (Brueckner, 2001), while the second effect has not been investigated so far. Both effects in conjunction give a strong argument against code-share agreements with antitrust immunity in the case of overlapping airline networks.

2.4 Code-share agreements without antitrust immunity

In some instances, e.g. in the case of American Airlines and British Airways, code-share agreements are not forbidden but at the same time antitrust immunity is denied. Airlines then have to set fares for interline passengers independently (Brueckner, 2001). We now consider the effect of code-share agreements *without* antitrust immunity on airline fares and welfare. Notice that code-share agreements allow for price discrimination between passengers on direct connections and interline passengers even if antitrust immunity is denied (Bilotkach, 2005).

Under code-share agreements without antitrust immunity airlines independently choose their part of the interline fare. Denoting this case by C , a Nash equilibrium $((p_{n+1,1}^C, p_{n+1,2}^C), \dots, (p_{2n-1,1}^C, p_{2n-1,2}^C))$ is then determined by

$$p_{i,j}^C = \arg \max_{p_{i,j}} p_{i,j} (a - p_{i,j} - p_{i,k}^C) = \frac{a - p_{i,k}^C}{2} \Rightarrow p_{i,j}^C = \frac{a}{3}$$

for all $j \in \{1, 2\}$, $j \neq k$, $i \in \{n+1, \dots, 2n-1\}$ and $j \in \{1, 2\}$. It is straightforward to check that the fare arbitrage conditions are satisfied in this case.

We now analyze the welfare effects of code-share agreements without antitrust immunity on interline passengers.

Proposition 2.4.1 *Interline passengers are better off if code-share agreements are provided with antitrust immunity compared to code-share agreements without antitrust immunity. Even if antitrust immunity is denied, interline passengers are better off with code-share agreements compared to a situation without code-share agreements.*

Proof If code-share agreements are provided with antitrust immunity interline passengers pay a fare equal to $a/2$. If code-share agreements are not provided with antitrust immunity interline passengers pay a fare equal to $2p_{ij}^C = 2a/3$. Thus, interline passengers are better off when antitrust immunity is provided. Furthermore, since $p_i^{N1} + p_n^{N1} > 2a/3$ holds for all $a \leq \bar{a}$ and $p_i^{N2} + p_n^{N2} > 2a/3$ holds for all $a \geq \tilde{a}$, interline passengers are better off with than without code-share agreements even if antitrust immunity is denied. ■

For the analysis of total welfare effects of code-share agreements without antitrust immunity denote

$$\bar{W}^C := \bar{W}(p_1^C, \dots, p_n^C; (p_{n+1,1}^C, p_{n+1,2}^C), \dots, (p_{2n-1,1}^C, p_{2n-1,2}^C)).$$

Comparing welfare effects of code-share agreements with and without antitrust immunity leads to:

Corollary 2.4.2 $\bar{W}^C < \bar{W}^I$ *always holds.*

Proof By Proposition 2.4.1 antitrust immunity (strictly) reduces interline fares (at positive demand). Fares for passengers on direct connections and on indirect connections entirely served by airline 1 are not affected by antitrust immunity as long as code-share agreements are used. ■

Corollary 2.4.2 reproduces the standard result for complementary airline networks found by Brueckner (Brueckner, 2001): code-share agreements with antitrust immunity reduce interline fares and increase welfare compared to code-share agreements without antitrust immunity. The reason is that an independent choice of sub-fares creates a double mark-up, since airlines do

not take into account the negative effects of their own sub-fares on the other airline's revenues.

However, suppose airlines had overlapping networks such that they could compete on parallel connections. In this case code-share agreements with antitrust immunity would lead to collusion and higher fares on parallel connections. The overall welfare effect of antitrust immunity, therefore, depends on the share of interline and parallel connections. This has also been pointed out by Brueckner (Brueckner, 2001). It might therefore be preferable, with a view to overlapping networks, to deny antitrust immunity. This leads to the question whether code-share agreements should be allowed without antitrust immunity or not at all.

Proposition 2.4.2 indicates that a situation without code-share agreements is more likely to generate better welfare results than airlines using code-share agreements if antitrust immunity is denied. Denote another critical level for a by

$$\hat{a} := \frac{3(32 + n(43 + 29n))}{80 + 202n + 86n^2}.$$

It holds $\hat{a} > \tilde{a}$, and $\hat{a} < 1$ if and only if $n < 73$.

Proposition 2.4.3 $\bar{W}^C > \bar{W}^{N1}$ holds when $N1$ exists (i.e. for all $a \leq \tilde{a}$).

If $n < 73$, $\bar{W}^C < \bar{W}^{N2}$ holds for all $a \in [\tilde{a}, \bar{a})$ and $\bar{W}^C \geq \bar{W}^{N2}$ holds for all $a \geq \hat{a}$.

If $n \geq 73$, $\bar{W}^C < \bar{W}^{N2}$ holds when $N2$ exists (i.e. for all $a \geq \tilde{a}$).

Proof See appendix A.3. ■

Proposition 2.4.3 indeed implies that code-share agreements lose value compared to the case of non-cooperating airlines if antitrust immunity is denied. Recall that airlines that do not make use of code-share agreements will reduce fares to attract additional demand from interline passengers if

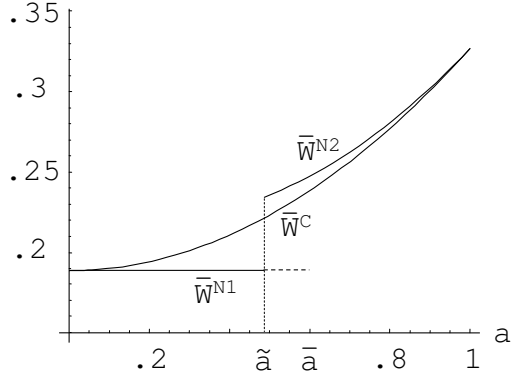


Figure 2.3: Welfare under code-share agreements without antitrust immunity, \bar{W}^C , and welfare without code-share agreements, \bar{W}^{Nj} with $j \in \{1, 2\}$ ($n = 80$).

and only if $a \geq \tilde{a}$ is satisfied. However, as a increases the reduction in fares shrinks. Therefore, code-share agreements without antitrust immunity lead to better welfare results if and only if a exceeds another critical level \hat{a} .

Figure 2.3 demonstrates that there is a high probability that a ban on code-share agreements leads to better welfare results compared to code-share agreements without antitrust immunity. Assuming that $n = 80$ holds it shows \bar{W}^{N1} for $a < \tilde{a}$ (dashed line for $\tilde{a} < a < \bar{a}$), \bar{W}^{N2} for $a \geq \tilde{a}$, and \bar{W}^C . Since $n > 73$, $\bar{W}^{N2} > \bar{W}^C$ holds for all $a \geq \tilde{a}$, implying that non-cooperating airlines lead to higher welfare compared to airlines using code-share agreements without antitrust immunity. On the other hand, for $a < \tilde{a}$, $\bar{W}^C > \bar{W}^{N1}$ holds because the number of interline passengers would be zero without code-share agreements.

2.5 Conclusions

Airline alliances are a common phenomenon in the airline industry. A basic element of alliances are code-share agreements that allow airlines to offer connections they could not offer as one product by their own. Code-share agreements are normally provided with antitrust immunity allowing airlines to cooperatively set fares such that joint profits are maximized.

Our analysis of code-share agreements with and without antitrust immunity is based on (perfectly) complementary airline networks. We demonstrate that the welfare effects of code-share agreements are not straightforward in this situation. This is in contrast to the current literature arguing that in the case of complementary airline networks code-share agreements improve welfare.

A crucial point is that code-share agreements are necessary to identify interline passengers which is the basis for price discrimination. We demonstrate that interline passengers are always better off if code-share agreements are used and price discrimination takes place. This result is consistent with the existing literature on alliances and code-share agreements.

On the other hand, we also demonstrate that price discrimination makes non-interline passengers worse off (or may leave them unaffected). Without price discrimination airlines set only one fare for all passengers on connections served entirely by their own. Thus fares depend on the aggregate demand of non-interline and interline passengers. It is then possible that airlines reduce fares for all passengers in order to attract additional demand from interline passengers. This in turn benefits non-interline passengers. Notice that the positive welfare effects that interline passengers can have on non-interline passengers have been ignored so far.

The probability that fares are reduced after a ban of code-share agreements and without price discrimination depends on, first, the level of demand for special interline connections and, second, the number of interline connections. If both values are high, the probability is high that fares are reduced.

More importantly, we find that a ban of code-share agreements that prevents price discrimination can enhance total welfare, i.e. the positive welfare effects of code-share agreements on interline passengers are smaller than the negative effects on non-interline passengers. The probability for this to happen is, however, low if code-share agreements are provided *with* antitrust immunity. In contrast, there is a high probability that a ban of code-share agreements outperforms the use of code-share agreements *without* antitrust immunity.

It is well known that the case against code-share agreements with antitrust immunity becomes stronger after taking into account that, in practice, airline networks are overlapping. Hence, without antitrust immunity airlines are supposed to compete on some connections served in parallel by partner airlines. The provision of code-share agreements with antitrust immunity leads to collusion and higher fares on these connections and, therefore, generates additional welfare losses. Altogether, the results of our analysis strongly question the usefulness of code-share agreements with or without antitrust immunity from a welfare perspective.

CHAPTER 3

Price-cap regulation of airports:
single-till versus dual-till

3.1 Introduction

Until recently most airports were owned and managed by public authorities. Nonetheless, a growing number of airports in Europe as well as Australia and New Zealand became fully or partially privatized during the last twenty years. Furthermore, many airports in South-America, Africa, and Asia are under review for being privatized (Oum et al., 2004). Airport privatization is almost always accompanied by some form of price regulation. This is basically due to the fact that airports are supposed to exhibit market power. However, Starkie claims that there would be a lack of incentives for airports to exploit it (Starkie, 2001). His conclusion is based on demand complementarities between aeronautical and commercial airport activities in combination with location rents. Aeronautical activities of the airport include the provision of take-off, landing, gangway, and parking capacity for aircraft and passengers. Commercial activities include, e.g., retailing and car parking. Roughly outlined, Starkie argues that increased airport charges do not only reduce the demand for flights, but also the demand for commercial services. This in turn reduces location rents and therefore the returns to the tenant, i.e., the airport itself. Following this reasoning the airport might not want to raise aeronautical charges so that airport regulation might be unnecessary.

In reality there is no fully liberalized airport market in the world, and airport policy makers are basically considering modifications of the present regulatory regimes. An example, on which we will focus in this paper, is the current debate about the single-till and dual-till approach to regulation. It centers around the issue mentioned above, namely, how regulation of aeronautical services should deal with airports' revenues from commercial services. Note that regulating charges on commercial services is not an issue; both approaches are only concerned with price-cap regulation of charges

for aeronautical services. The key difference between single-till and dual-till regulation is that with single-till the price-cap is set in anticipation of the revenues from aeronautical *and* commercial services. Hence, under single-till regulation commercial revenues cover a portion of the airport's overall fixed costs, so that the single-till price-cap for aeronautical services is reduced accordingly. The dual-till approach, in contrast, tries to separate out the two airport business branches, particularly by attributing specified portions of airports' costs to aeronautical and commercial branches. Then, in order to guarantee that airport's aeronautical costs are completely covered by revenues from aeronautical activities, the dual-till price-cap for aeronautical charges is raised accordingly. Recently, in Australia, the United Kingdom, and Germany the question came up whether price-cap regulation could be improved by switching from single-till to dual-till regulation (CAA, 2000), (CAA, 2003), (Niemeier, 2002), (Commission, 2002).

Beesley was one of the first economists to attack single-till regulation (Beesley, 1999). He claims that regulation should concentrate on activities which are characterized by a natural monopoly, and therefore not be affected by the commercial activities. On the other hand, he doubts that it is possible to isolate the aeronautical activities from other airport activities. For this reason he generally rejects the application of a price-cap regulation mechanism to airports. Starkie, in contrast, is in favor of dual-till price-cap regulation (Starkie, 2001). He argues that, for non-congested airports, commercial airport activities should not be regulated because they could provide the airport with an incentive to reduce aeronautical charges. For congested airports, on the other hand, a dual-till regime would lead to higher aeronautical charges, which would have positive effects on the allocation of scarce slot capacity and on investment incentives. The reasoning is in line with the

argument by Starkie and Yarrow (Starkie and Yarrow, 2000). Similar results are presented by Oum, Zhang, and Zhang (Oum et al., 2004) who provide empirical evidence that dual-till price-cap regulation improves economic efficiency in terms of total factor productivity for large, busy airports compared to the single-till approach. Somewhat different are the conclusions of Crew and Kleindorfer (Crew and Kleindorfer, 2001), and Lu and Pagliari (Lu and Pagliari, 2004). They claim that for non-congested airports the use of a single-till system is beneficial. Crew and Kleindorfer emphasize that single-till regulation is conducive to implement a Ramsey-like structure of charges, while Lu and Pagliari point out that it reduces aeronautical charges and, therefore, improves capacity utilization. However, for a congested airport Lu and Pagliari argue (in line with Starkie) in favor of dual-till regulation because then they expect the higher aeronautical charges to improve allocation.

In view of this diversity of views it appears that it would be useful to have an analytical framework that addresses such questions more rigorously. The objective of this paper is to provide a simple framework for the analysis of airport demand, aeronautical and commercial, airport pricing behavior, and of the effects of single- or dual-till price-cap regulation. Analysis will be based on a standard Hotelling model of demand. We will follow the theoretical IO literature in making several accompanying simplifying assumptions (like uniform distribution of consumers). Although this has some drawback in terms of generality and direct empirical implementability, it has the advantage of making decisions of individuals, airports, and regulators very explicit, and it allows for explicit solutions and interpretable expressions.

We will assume that consumers' reservation prices for aeronautical and commercial services are independently and uniformly distributed on a unit square. To take account of the typical demand complementarities on airports

we will also assume that only the ‘fliers’ can consume commercial services while ‘non-fliers’ cannot. Consequently, while the existing literature focuses on the effect of aeronautical charges on commercial airport activities, our model also takes into account the effects of commercial charges on the demand for aeronautical services. We will analyze a two-stage regulation game, taking explicitly into account the regulator’s expectations on airport behavior and their impact on the single- or dual-till price-cap, respectively. In view of the literature mentioned above it should be pointed out that we confine attention to the case of a non-congested airport.

It turns out that due to the specific complementarity of demands for aeronautical and commercial services a monopolistic airport would reduce commercial charges and raise aeronautical ones. This should not be too surprising since, after all, aeronautical services are the core business of airports. The paper also shows, in line with Crew and Kleindorfer and Lu and Pagliari, that single-till regulation dominates dual-till regulation at non-congested airports. This result is based on the fact that the single-till system implements an optimal regulation of the aeronautical charges. However, neither the dual-till nor the single-till approach is able to implement Ramsey charges. The specific complementarity of demands requires the Ramsey charges for aeronautical services to be higher than those for commercial services (as in the monopolistic case). But this cannot be implemented by a regulation of aeronautical charges alone. We finally show that it is possible to implement Ramsey charges by use of a weighted-average price-cap regulation scheme on aeronautical and commercial charges.

The next section presents the model. The behavior of an unregulated monopolistic airport is considered in section 3.3. Section 3.4 analyzes Ramsey charges. The evaluation of single-till and dual-till price-cap regulation

schemes follows in section 3.5. In section 3.6 an analysis of a Ramsey optimal price-cap regulation is provided. The paper closes with some concluding remarks in section 3.7.

3.2 The model

The airport considered is a multi product monopolist which provides aeronautical and commercial services. We assume that the airport possesses market power in both markets, which is in line with several models used by other authors (Crew and Kleindorfer, 2001), (Oum et al., 2004), (Zhang and Zhang, 1997). Moreover, we assume that there is no congestion, i.e. there is excess capacity for both aeronautical and commercial services.

Costs are described as follows. The airport incurs fixed costs of $F \geq 0$. For simplicity all variable airport costs are supposed to be zero (which fits to the assumption of excess capacity). Furthermore, airlines and commercial service providers are assumed to be in perfect competition and to have constant marginal costs. Then we can express consumers' willingness to pay and retail charges as net of the constant marginal costs. It follows that the airport charges for aeronautical and commercial services are identical to the (net) retail charges for consumers.

Turning to the demand side, we account for the fact that demands for the two airport services are heavily interdependent, although the types of services are quite different. The interdependency arises from the fact that the amount of passengers basically determines the demand for commercial airport services. We decide to model this interrelation explicitly.

There is a set of individuals denoted by Q with mass one. Everyone flies at most once and buys at most one unit of a commercial good. Letting $p_1 \geq 0$

denote the charge for a flight and $p_2 \geq 0$ the charge for a commercial good, the consumer surplus of an individual $q \in Q$ who flies and buys is

$$V_1(q) + V_2(q) - (p_1 + p_2)$$

where $V_1(q)$ is the willingness to pay for a flight and $V_2(q)$ that for a commercial good. It is assumed that both $V_1(q)$ and $V_2(q)$ are uniformly and independently distributed over the unit interval, i.e. $V_1(q), V_2(q) \in [0, 1]$. Hence, in V_1 - V_2 -space, all individuals are uniformly and independently distributed over the unit square, as shown in figure 3.1. However, to take account for demand complementarity between aeronautical and commercial airport activities it is assumed that only passengers, i.e. individuals who decide to fly, can buy commercial services. Passengers make use of commercial services if $V_2(q) - p_2 \geq 0$. Individuals fly if they get a positive rent from flying and buying, i.e. if $V_1(q) - p_1 + \max\{0, V_2(q) - p_2\} \geq 0$ is satisfied. From these conditions the demands for the two goods can be derived, as is now explained.

For given charges p_1 and p_2 , the passenger demand D_1 and the demand for commercial airport services D_2 are illustrated in figure 3.1. We show that

$$D_1 = A + B + C.$$

For all individuals in the areas A and B the utility of a flight is at least as high as p_1 , hence, these individuals decide to fly. Note that individuals located in area C also buy a flight although $V_1(q) \leq p_1$. This is so because $p_1 - V_1(q) \leq V_2(q) - p_2$ and, hence, the negative rent from flying is compensated by the positive rent generated from consumption of commercial services. Only individuals located in the areas D and E do not buy a flight, since $p_1 > V_1(q)$

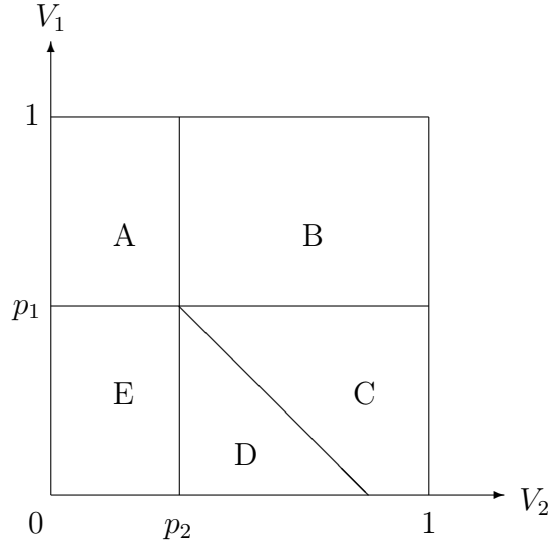


Figure 3.1: Passenger and consumer demand for given prices p_1 and p_2 . The demand for flights, D_1 , equals area A + B + C. The demand for commercial services, D_2 , equals the area B + C.

holds, and the rent generated by consumption is too small to compensate for the disutility resulting from flying. For $p_1 + p_2 \leq 1$ one calculates:

$$\begin{aligned}
 D_1(p_1, p_2) &= 1 - \int_0^{p_2} p_1 dV_2 - \int_{p_2}^{p_1+p_2} p_1 + p_2 - V_2 dV_2 \\
 &= 1 - p_1 p_2 - \frac{p_1^2}{2}.
 \end{aligned} \tag{3.1}$$

Demand for commercial services is

$$D_2 = B + C.$$

For individuals located in the areas A and E the utility for consumption is smaller than p_2 , hence, they will not buy commercial services. Individuals

located in area D do not consume aeronautical services simply because they are not at the airport (they do not fly). For $p_1 + p_2 \leq 1$:

$$\begin{aligned}
D_2(p_1, p_2) &= 1 - \int_0^{p_2} 1 \, dV_2 - \int_{p_2}^{p_1+p_2} p_1 + p_2 - V_2 \, dV_2 \\
&= 1 - p_2 - \frac{p_1^2}{2}.
\end{aligned} \tag{3.2}$$

Since all variable costs are assumed to be zero, the welfare W generated from flying and consuming is simply the sum of all actual buyers' willingness to pay for the two services. As we will now explain, it equals

$$W := 1 - \int_{E \cup D} V_1 \, dV_1 dV_2 - \int_{A \cup E \cup D} V_2 \, dV_1 dV_2. \tag{3.3}$$

With $p_1 = p_2 = 0$ welfare is at its maximum (of 1), and the areas E, D, A are zero. The welfare loss caused by raising charges is given by the double integrals on the right hand side of equation (3.3). For $p_1 + p_2 \leq 1$ it follows:

$$\begin{aligned}
W(p_1, p_2) &= 1 - \int_0^{p_2} \int_0^{p_1} V_1 \, dV_1 \, dV_2 - \int_{p_2}^{p_1+p_2} \int_0^{p_1+p_2-V_2} V_1 \, dV_1 \, dV_2 \\
&\quad - \int_0^{p_1} \int_0^{p_1+p_2-V_1} V_2 \, dV_2 \, dV_1 - \int_{p_1}^1 \int_0^{p_2} V_2 \, dV_2 \, dV_1 \\
&= 1 - \frac{p_1^3}{3} - p_1^2 p_2 - \frac{p_2^2}{2}.
\end{aligned} \tag{3.4}$$

In the above expressions we have confined attention to the case $p_1 + p_2 \leq 1$, which will turn out to be the relevant case for all market regimes to be

considered.¹ The assumption that V_1 and V_2 are independently distributed will be discussed below.

3.3 An unregulated monopolistic airport

Which effect does the integration of commercial activities into the airports' optimization problem have on aeronautical charges? For an illustration, assume that $p_2 = 1$. Then nobody will demand airport commercial services, since $V_2(q) \leq 1$ for every individual q , and it follows that aeronautical demand is $D_1 = 1 - p_1$. Since marginal costs are zero, profit from aeronautical activities is then maximized by $p_1 = 0.5$. Now assume to the contrary that $p_1 = 0$. Then everyone buys a flight, the demand for commercial services is $D_2 = 1 - p_2$, and the profit maximizing charge for commercial services is $p_2 = 0.5$. Now consider an airport which optimizes profits by simultaneous choice of aeronautical and commercial charges. Since the two services are complementary we would expect one price to be reduced below 0.5, and the other raised above 0.5. Which charge will be raised and which one reduced? The airports' maximization problem is given by:

$$\max_{0 \leq p_1, p_2} \Pi(p_1, p_2) \quad (3.5)$$

¹For $p_1 + p_2 > 1$ the following holds. If $p_1, p_2 \leq 1$ then $D_1 = \frac{1}{2}(3 - 2p_1 - 2p_2 + p_2^2)$, $D_2 = \frac{1}{2}(1 - p_2)(3 - 2p_1 - p_2)$, and $W = \frac{1}{6}(7 - 3p_1^2 - 6p_1p_2(1 - p_2) - 6p_2^2 + 2p_2^3)$. If $p_1 > 1$ and $p_2 \leq 2 - p_1$, then $D_1 = D_2 = \frac{1}{2}(2 - p_1 - p_2)^2$ and $W = \frac{1}{3}(-2 + p_1 + p_2)^2(1 + p_1 + p_2)$. If $p_1 > 1$ and $p_2 > 2 - p_1$ then $D_1 = D_2 = W = 0$. If $p_1 \leq 1$ and $p_2 > 1$ then $D_1 = 1 - p_1$, $D_2 = 0$, and $W = \frac{1}{2}(1 - p_1)^2$.

with $\Pi(p_1, p_2) := p_1 D_1(p_1, p_2) + p_2 D_2(p_1, p_2) - F$. For $p_1 + p_2 \leq 1$ equations (3.1) and (3.2) imply

$$\Pi(p_1, p_2) = p_1 - \frac{p_1^3}{2} + p_2 - \frac{3p_1^2 p_2}{2} - p_2^2 - F.$$

The solution for (3.5) is given by $(p_1^M, p_2^M) = (2/3, 1/6)$ where the superscript M is used to denote monopoly charges. It implies $D_1(p_1^M, p_2^M) = 2/3$, $D_2(p_1^M, p_2^M) = 11/18$, $W(p_1^M, p_2^M) \approx 0.81$, and $\Pi(p_1^M, p_2^M) \approx 0.55 - F$.² This shows that simultaneous profit maximization in fact raises aeronautical charges above 0.5 and reduces charges for commercial services below 0.5. This is contrary to the hypothesis mentioned in the literature that an unregulated airport would reduce aeronautical charges in order to raise the profitability of commercial activities (Starkie, 2001).

The intuition for this result is to be seen in the complementary nature of demand for the two goods. Since only passengers can buy commercial services, the demand for the latter is a subset of the demand for flights, i.e. $D_1 > D_2$ (except for $p_2 = 0$ where $D_1 = D_2$). Hence, raising aeronautical charges increases revenues by a larger amount than raising commercial charges.

Because all real airports are regulated in some way it is difficult to verify empirically that a monopolistic airport reduces commercial charges in order to raise charges for aeronautical services. However, current experience with Australian airports provides some support for this result. After replacing price-cap regulation of Australian airports by a system of price-monitoring in 2002, some of them have even doubled aeronautical charges (Forsyth, 2004). This confirms that airports have a strong incentive to raise aeronautical charges in spite the fact that this might have negative effects on revenues

²One checks that the monopolist will never choose a combination with $p_1 + p_2 > 1$.

from commercial activities. Another observation from the airline industry also provides some evidence for the above result. Before the airline industry was liberalized many airlines were in fact regional monopolists. At that time they passed commercial services to passengers for free (e.g. food, beverages, and newspapers), presumably in an attempt to make flights more attractive.

One might wonder whether our result $p_1^M < p_2^M$ would extend to the case that the willingness' to pay for aeronautical and commercial services, V_1 and V_2 , are positively correlated. While the general case is hard to analyze, one easily checks the extreme case of *perfect* correlation, i.e. $V_1 = V_2$. One shows that this case implies $D_1 \geq D_2$. Hence, for less than perfect correlation, our basic relationship $D_1 > D_2$ would continue to hold. Since this is the driving force behind the result $p_1^M < p_2^M$, the latter one would probably extend to the case of positively correlated V_1 and V_2 .

3.4 Ramsey charges

The monopoly solution analyzed in the last section leads to a welfare loss (of approximately 0.19) compared to the welfare maximum (of 1). On the other hand, welfare maximizing charges, $p_1 = p_2 = 0$, do not cover the airport's fixed costs. Denote by $R(p_1, p_2) := p_1 D_1(p_1, p_2) + p_2 D_2(p_1, p_2)$ the revenue of the airport. Assume that $F \leq R(p_1^M, p_2^M)$ so that the monopoly profit is non-negative. Then we can consider Ramsey charges, denoted by (p_1^R, p_2^R) , which are a compromise between welfare maximization and profitability. The corresponding optimization problem is

$$\max_{0 \leq p_1, p_2} W(p_1, p_2) \quad \text{s.t.} \quad \Pi(p_1, p_2) \geq 0. \quad (3.6)$$

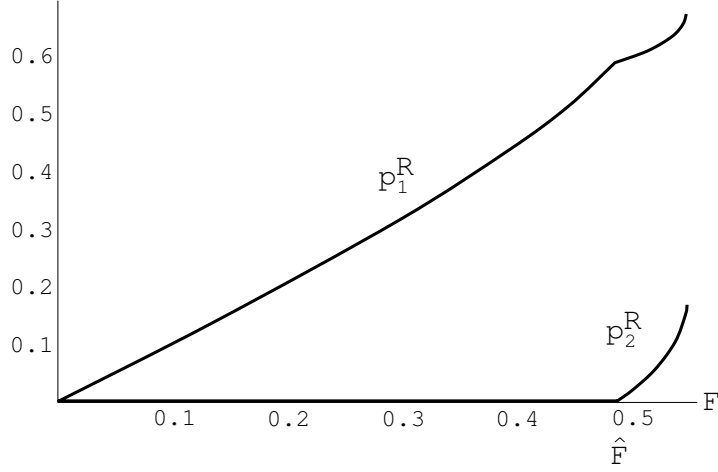


Figure 3.2: Ramsey charges. p_1^R : aeronautical Ramsey charges.
 p_2^R : commercial Ramsey charges.

The solution for (3.6) is plotted in figure 3.2 as a function of F . Observe that $p_2^R = 0$ holds if fixed costs are below a critical amount $\hat{F} \approx 0.485$. Moreover it holds:

Proposition 3.4.1 *Ramsey charges satisfy $p_1^R > p_2^R$ for all $F > 0$.*

Proof For $F \in (0, \hat{F})$ Ramsey charges for the commercial services are $p_2^R = 0$. Consequently, $p_1^R > 0 = p_2^R$ must hold to cover fixed costs.

For $F \in [\hat{F}, R(p_1^M, p_2^M)]$ the first order conditions for (3.6) imply

$$p_1^R = 2 - p_2^R - \sqrt{2 - 4p_2^R + (p_2^R)^2}, \quad (3.7)$$

from which it follows that $p_1^R > p_2^R$. ■

Similar to the monopoly case, aeronautical Ramsey charges are higher than commercial Ramsey charges. The intuition is similar, too. Starting

from $p_1 = p_2 = 0$, raising charges for aeronautical services generates more revenues than raising commercial charges by the same amount.

It has been pointed out that cross-subsidization between commercial and aeronautical airport operations can be welfare enhancing (Zhang and Zhang, 1997). Note, however, our result shows that the desirability of cross-subsidization strongly depends on the amount of fixed costs. If $F \leq \hat{F}$ commercial prices should not be raised above marginal costs. Only for relatively high fixed costs ($F > \hat{F}$) should commercial charges be used to cover a portion of fixed airport costs.

3.5 Single-till versus dual-till

We now address the comparison between single-till and dual-till price-cap regulation and their relation to Ramsey charges. Under both approaches only aeronautical charges are directly regulated by a price-cap (CAA, 2000), (Commission, 2002). Hence, the regulator defines a price cap $\bar{p}^a \geq 0$ with $a \in \{s, d\}$, which restricts aeronautical charges to satisfy $p_1 \leq \bar{p}^a$. The indices denote the price-cap under single-till ($a = s$) or dual-till regulation ($a = d$).

Single-till regulation takes profits from aeronautical as well as commercial activities into account when determining the price-cap. The way of calculating a single-till price-cap is ideally given by

$$\bar{p}^s = \max \left\{ 0, \frac{F - p_2 D_2(p_1, p_2)}{D_1(p_1, p_2)} \right\}. \quad (3.8)$$

Thus, the single-till price-cap is given by the maximum of zero and the average fixed costs per passenger minus the average profits resulting from commercial activities per passenger. Rearranging (3.8) shows that a binding

and positive single-till price-cap ($p_1 = \bar{p}^s > 0$) is equivalent to a zero profit condition (i.e. $R(\bar{p}^s, p_2) = F$ or $\Pi(\bar{p}^s, p_2) = 0$).

A dual-till price-cap is ideally given by

$$\bar{p}^d = \frac{\alpha F}{D_1(p_1, p_2)} \quad (3.9)$$

where $\alpha \in [0, 1]$ is the share of the fixed costs which are attributable to aeronautical services.³ The dual-till price-cap is given by the average fixed costs attributable to aeronautical activities per passenger. Note, if the commercial activities are profitable, i.e. $p_2 D_2 > (1 - \alpha)F$, then it follows that $\bar{p}^s < \bar{p}^d$.

Our analysis of single- and dual-till regulation will be based on the assumptions that the above formulas are to be taken seriously, and that the regulator has rational expectations of the airport's reaction to a price-cap. Formally, this amounts to a regulation game with two stages under perfect information. In the first stage the regulator determines the price-cap \bar{p} , given by either (3.8) or (3.9), and in the second stage the airport chooses charges (p_1, p_2) so as to maximize profit subject to the price-cap and the non-negativity constraints.

Solving backwards, we obtain the airport's optimal strategy, or pair of reaction functions:

$$(p_1^r(\bar{p}), p_2^r(\bar{p})) := \arg \max_{0 \leq p_1, p_2} \Pi(p_1, p_2) \quad \text{s.t. } p_1 \leq \bar{p}$$

One shows that there is indeed a unique solution to the airport's problem.

The price-cap is binding, i.e. $p_1^r = \bar{p}$, if and only if $\bar{p} \leq 2/3$. The non-

³We assume that fixed costs are perfectly attributable to the different airport activities, although we agree with other authors that this might be difficult (Beesley, 1999). However, this is a necessary pre-condition for a dual-till approach to be workable.

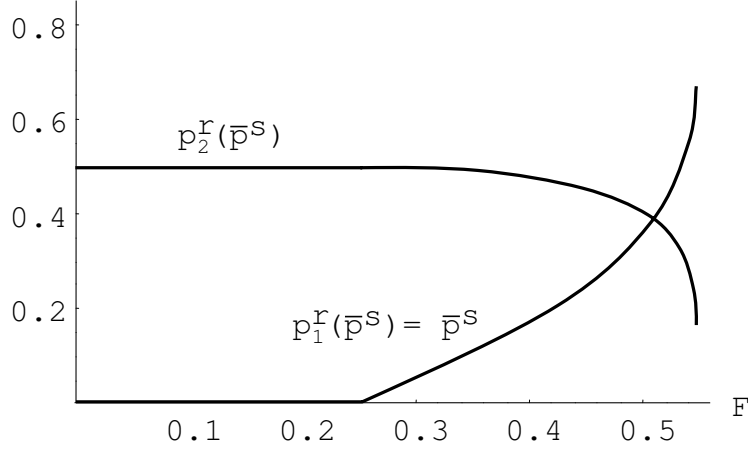


Figure 3.3: Charges implied by subgame perfect Nash-equilibria under single-till regulation for varying amounts of F .

negativity constraint on p_2 is not binding, so that p_2^r is given by the first-order condition $\partial\Pi(p_1^r, p_2^r)/\partial p_2 = 0$.

In the first stage of the regulation game the airport sets \bar{p} . For single-till regulation, \bar{p}^s is the maximum of zero and the solution to

$$\bar{p} = \frac{F - p_2^r(\bar{p})D_2(p_1^r(\bar{p}), p_2^r(\bar{p}))}{D_1(p_1^r(\bar{p}), p_2^r(\bar{p}))}. \quad (3.10)$$

For dual-till regulation, \bar{p}^d is the solution to

$$\bar{p} = \frac{\alpha F}{D_1(p_1^r(\bar{p}), p_2^r(\bar{p}))}. \quad (3.11)$$

Note that the solutions for (3.10) and (3.11) are unique and that they constitute the unique subgame perfect Nash-equilibrium of the regulation game.

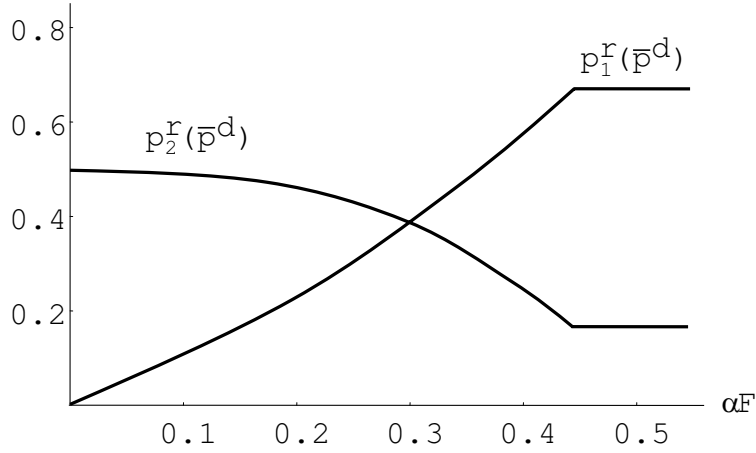


Figure 3.4: Charges implied by subgame perfect Nash-equilibria under dual-till regulation for varying amounts of αF .

Under single-till regulation the Nash-equilibrium depends on F only, while under dual-till regulation it depends on F and α . Figures 3.3 and 3.4 show the charges implied by the Nash-equilibria with varying amounts of F , respectively αF . Under dual-till regulation the airport is allowed to charge monopoly prices if $\alpha F \gtrsim 0.44$ holds. In contrast, under the single-till approach monopoly prices are only allowed for the boundary case $F = R(p_1^M, p_2^M)$. However, which regulation scheme should be preferred? The following proposition and corollary show that single-till regulation (weakly) dominates dual-till regulation from a welfare perspective.

Proposition 3.5.1 *The welfare maximizing price-cap for the aeronautical charges, subject to a zero-profit condition, is equivalent to single-till regulation.*

Proof The welfare maximizing regulation of airport charges is the solution to

$$\max_{0 \leq \bar{p}} W(p_1, p_2) \quad \text{s.t.} \quad \Pi(p_1, p_2) \geq 0 \quad \text{and} \quad (p_1, p_2) = (p_1^r(\bar{p}), p_2^r(\bar{p})).$$

At the solution it holds either $\Pi(p_1, p_2) = 0$ or $\bar{p} = 0$. Hence, the solution must be equivalent to the single-till price-cap, since $\bar{p}^s > 0$ is equivalent to a zero-profit condition as was shown above. ■

Corollary 3.5.2 *Single-till regulation strictly dominates dual-till regulation if $F \in (0, R(p_1^M, p_2^M))$ and $(1 - \alpha)F \neq p_2^s D_2(p_1^s, p_2^s)$.*

Proof The conditions imply that $\bar{p}^d \neq \bar{p}^s$. ■

To provide an intuition for proposition 3.5.1, one can calculate that $\partial W(\bar{p}, p_2(\bar{p}))/\partial \bar{p} \leq 0$ for $\bar{p} \leq 2/3$. Thus, in order to maximize welfare the regulator should try to implement the lowest possible price-cap for aeronautical charges, i.e., the one for which either $\Pi = 0$ or $\bar{p} = 0$. However, this is the one also implemented by single-till regulation. A particular advantage of single-till follows from the fact that it allows complete control of the overall profits of the airport, which is not the case with dual-till regulation.

Note, however, that even the single-till approach cannot implement Ramsey charges, since it regulates only aeronautical charges. That is, we have $(p_1^r(\bar{p}^s), p_2^r(\bar{p}^s)) \neq (p_1^R, p_2^R)$ for all $F < R(p_1^M, p_2^M)$. For this reason, the following section proposes a price-cap regulation scheme which is capable to implement Ramsey charges.

3.6 A Ramsey optimal price-cap regulation

To implement Ramsey charges the aeronautical as well as commercial charges have to be integrated into the price-cap formula. Suppose that the average airport charges with weights (w_1, w_2) are restricted by a cap \bar{p} as follows:

$$w_1 p_1 + w_2 p_2 \leq \bar{p}. \quad (3.12)$$

We show that a price-cap \bar{p} and price-weights (w_1, w_2) exist which guarantee that a profit maximizing airport will reproduce (p_1^R, p_2^R) .

Proposition 3.6.1 *A price-cap of*

$$\bar{p} = \begin{cases} F & \text{for } F \geq \hat{F} \\ p_1^R & \text{for } F < \hat{F} \end{cases}$$

in combination with price weights

$$(w_1, w_2) = \begin{cases} (D_1(p_1^R, p_2^R), D_2(p_1^R, p_2^R)) & \text{for } F \geq \hat{F} \\ (1, 1) & \text{for } F < \hat{F} \end{cases}$$

guarantees that the airport sets $(p_1, p_2) = (p_1^R, p_2^R)$.

Proof Assume $F \geq \hat{F}$. Since $W = W - \Pi + \Pi$, the Lagrangean for the Ramsey problem (3.6) can be expressed as

$$\mathcal{L} = W(p_1, p_2) - \Pi(p_1, p_2) + (1 + \lambda)\Pi(p_1, p_2). \quad (3.13)$$

Since $W - \Pi$ is equivalent to an indirect utility function, rearranging the first order condition for (3.13), after inserting $\partial(W - \Pi)/\partial p_j = -D_j$ given by Roy's identity, produces the following characterization of Ramsey charges:

$$-\frac{1}{D_j(p_1^R, p_2^R)} \sum_{i=1}^2 p_i^R \frac{\partial D_i}{\partial p_j} = \frac{\lambda^R}{1 + \lambda^R}. \quad (3.14)$$

Consider now the optimization problem of a monopolistic airport subject to constraint (3.12). The respective Lagrangean is

$$\mathcal{L} = \Pi(p_1, p_2) + \mu(\bar{p} - w_1 p_1 - w_2 p_2). \quad (3.15)$$

Rearranging the first order condition for (3.15) generates

$$-\frac{1}{w_j} \sum_{i=1}^2 p_i^* \frac{\partial D_i}{\partial p_j} = 1 - \mu^*. \quad (3.16)$$

For $w_j = D_j(p_1^R, p_2^R)$ and $\bar{p} = F$ it follows $\mu^* = 1/(1 + \lambda^R)$. Hence, the conditions (3.14) and (3.16) are equivalent and therefore $(p_1^*, p_2^*) = (p_1^R, p_2^R)$.⁴

For $F < \hat{F}$ the Ramsey price for commercial services $p_2^R = 0$ reflects a boundary solution, and the former result does not hold. However, for $w_1 = w_2 = 1$ the first order conditions of (3.15) imply $p_2^* = 0$. Moreover, with $\bar{p} = p_1^R$, the Ramsey solution will be reproduced for $F < \hat{F}$. ■

Why do price weights $w_1 = w_2 = 1$ provide the airport with no incentives to set $p_2 > 0$? The intuition behind this result is, again, based on the complementarities between the demands for aeronautical and commercial services. With equal price weights in the price-cap formula an increase of p_2

⁴The argument is similar to Laffont and Tirole (Laffont and Tirole, 2000).

has to be compensated by an equiproportional decrease of p_1 . This, however, would not be profitable.

3.7 Conclusions

Airport privatization has almost always been accompanied by some form of price-regulation. Our paper focuses on the current debate whether price-cap regulation of monopolistic airports should take the form of single-till or dual-till regulation.

In order to address this issue we modelled the market interdependency between aeronautical and commercial airport activities and its impact on charges for a non-congested airport. In particular, the demand for aeronautical and commercial services is highly complementary. We showed that this has an important implication: An unregulated monopolistic airport would tend to reduce charges for commercial services in order to raise the charges for flights.

Since first-best charges would imply losses for a non-congested airport we also considered Ramsey charges. As with monopolistic charges, it turned out that Ramsey charges for aeronautical services are higher than the respective charges for commercial services. Moreover, our analysis shows that any cross-subsidization of aeronautical services by profits generated from commercial activities is only welfare enhancing if fixed costs are fairly large.

Furthermore, we point out that at non-congested airports single-till regulation dominates dual-till regulation from a welfare point of view. This result is due to the fact that single-till regulation is equivalent to an optimal price-cap regulation for aeronautical charges. However, even the single-till approach does not provide the monopolist with incentives to implement

Ramsey charges. For a broad range of fixed costs, the aeronautical charges implied by single-till and dual-till regulation are lower than the charges for commercial services. This strongly thwarts the idea of Ramsey charges. It is shown that Ramsey charges can be implemented by use of a weighted average price-cap regulation scheme on both charges.

What can we learn from this analysis for the case of a congested airport? The picture changes somewhat, but a single-till regulation might remain advantageous. In the case of congestion, optimal charges have to take the external congestion costs of an additional flight into account.⁵ This raises airports' revenues and reduces the deficit-problem or even guarantees excessive profits. Therefore, the first-best solution can still be undesired because airport revenues and profits might be very high. If this is the case, we learned that a single-till regulation is preferable because it can more effectively control the overall profits of the airport. On the other hand, compared to dual-till regulation, the application of single-till regulation cuts aeronautical charges and, thus, will raise excess demand. However, coordinating airport access by scheduled slots in combination with e.g. slot auctions or slot trading can reduce the resulting slot allocation problem.

⁵Brueckner shows that the surcharge should be reciprocally proportional to the market shares of airlines (Brueckner, 2002).

CHAPTER 4

Congestion management under
uncertainty in a two-airport system

4.1 Introduction

More than any other transport mode, air transport has realized an impressive growth in the last few decades. However, this did not go along with a respective growth in airport capacity. As a consequence, congestion of airports has become a relevant problem because of delays which are costly for airlines, passengers, and the environment. Since air traffic forecasts show that growth will continue to be high during the next years, congestion problems are expected to increase in the future.

In order to control airport congestion many overloaded airports are slot constrained. An airline that wishes to incorporate a slot constrained airport into its networks needs to have a respective permission (slot) to use that airport at a specified time. Because the number of slots is constrained, airline operations at the airport are limited and, consequently, demand and congestion can effectively be controlled and optimized. There is, however, another possibility to reduce congestion. An increase of airport charges can reduce slot demand until the optimal level of congestion is reached which we shall call congestion pricing. Europe appears to favor the slot policy and while the U.S. is inclined to use congestion pricing.

Under certainty about the environment, slot constraints and congestion pricing as instruments can generate the optimal result from a welfare perspective. This requires that airport capacity is allocated efficiently among airlines and that the regulator has perfect information about the benefits and costs of take-off and landing operations. Both of these premises are not fulfilled in reality.

At present airport slots are basically allocated by grandfather rights or, in other words, by history. This guarantees continuity of airline operations because airlines are allowed to constantly regain slots which they have used

in the past. On the other hand, allocation based on grandfather rights does not account for the airlines' willingness to pay and, therefore, hampers allocative efficiency. To improve runway allocation the use of slot constraints in combination with auctions has been suggested by economists (Rassenti et al., 1982), (Grether et al., 1989).

Additionally, regulators are not perfectly informed about the social benefits and costs of airport operations. The airline industry, in particular, is characterized by a fluctuating demand that is difficult to forecast (Forsyth, 1976). Thus, passenger benefits of airport operations are difficult to predict. The same holds for the social costs of airport operations. Although the airports' costs for operation and maintenance as well as the airlines' congestion costs can be estimated fairly well, the measurement of passengers' and environmental's congestion costs is problematic. For these reasons a regulator has to deal with considerable uncertainty regarding the social benefits and costs of airport operations.

The role of uncertainty for the choice of regulation instruments was extensively analyzed in the field of environmental economics. For instance, Weitzman as well as Adar and Griffin, referring to pollution management (amongst others), showed that under uncertainty about benefits and costs of pollution the expected welfare depends on the choice between prices (e.g., pollution taxes) or quantities (e.g., emission standards) as instruments (Weitzman, 1974), (Adar and Griffin, 1976). They found that prices as instruments generate a higher expected welfare than quantities as instruments if the marginal benefit curve is steeper than the marginal cost curve et vice versa. This also holds for uncertain social costs as long as the benefit and cost curves are not stochastically correlated. Moreover, a positive correlation of benefits

and costs tends to favor quantities as instruments and a negative correlation tends to favor prices as instruments.

We apply these results to a basic airport model and demonstrate that in a situation with uncertain passenger benefits congestion pricing is the right choice from a welfare perspective. This is because the inverse demand function is steeper than the function depicting marginal external congestion costs. However, Weitzman's results are of limited use for airport management because airport demand is interdependent. In principle, two types of interdependencies exist: substitutability, due to airport competition, or complementarity. Airports might compete for passengers or air cargo if they are closely located to each other. Another source for airport competition is the hub-and-spoke networks of airlines, because hub-airports can compete for transfer passengers. With competition an increased use of one airport reduces the demand for other airports. However, due to the network character of the industry, airports normally provide complementary services because flights connect different airports. Thus, an increased use of one airport will usually be followed by an increased use of other airports. In this paper we focus on the second effect which we shall call *demand complementarity*.

To introduce demand complementarity into our analysis we extend the model such that it includes two regulated airports. In fact, demand complementarity challenges the standard results provided by Weitzman (Weitzman, 1974). We demonstrate that demand complementarity can increase the comparative advantage of slot constraints compared to congestion pricing. This is because under congestion pricing the price for take-off and landing operations is fixed but not the number of operations, as under slot constraints. Therefore, under congestion pricing the amount of take-off and landing operations is uncertain. Moreover, the complementarity of airport demands

reinforces the effect of uncertain passenger benefits under congestion pricing. If passenger benefits at one airport are higher than expected this increases the demand at that airport and at other airports, due to demand complementarity. In contrast, with slot constraints airport operations are fixed and independent from benefit shocks. Therefore, benefit shocks at one airport have no effect on other airports, which can increase the comparative advantage of slot constraints compared to congestion pricing. However, the effect of demand complementarity is always dominated by the effect of slopes favoring the use of congestion pricing.

In a next step, the model is extended such that it includes uncertain congestion costs which leads to a negative stochastic correlation between inverse demand and marginal external congestion costs. Weitzman's analysis indicates that this should favor the use of congestion pricing compared to slot constraints (Weitzman, 1974). This is confirmed by our results. All in all our results strongly favor the use of congestion pricing compared to slot constraints.

The analysis of socially optimal regulation is complemented by an investigation of profit maximizing monopolistic airports. Profit maximizing airports can be expected to raise airport charges above the efficient level. However, at overloaded airports, increasing airport charges can constitute an adequate measure to reduce congestion and improve efficiency. Therefore, one might ask whether profit maximizing airport charges can compensate for the negative welfare effects arising from congestion. We show that in a non-cooperative game where airports independently choose prices or slot constraints as instruments, the choice of prices as instruments is a strictly dominant strategy if airport demands are complementary. This is consistent

with the regulator's choice of instruments. However, monopolistic airport charges are too high leading to a deadweight loss.

So far, congestion management under uncertainty has not raised much attention from economists. One exception is Forsyth who applies Weitzman's approach to airports (Forsyth, 1976). In contrast, the impact of competition in the airline market on congestion pricing has raised the attention of economists (Daniel, 1995), (Brueckner, 2002), (Pels and Verhoef, 2004), (Basso, 2005), (Zhang and Zhang, 2006). The relation between the revenues from congestion pricing and the financing of airport capacity has also been considered (Morrison, 1983), (Morrison, 1987), (Gillen et al., 1987), (Gillen et al., 1989), (Oum and Zhang, 1990), (Oum et al., 1996a), (Zhang and Zhang, 1997), (Zhang and Zhang, 2003). For a detailed survey on airport pricing see Basso and Zhang (Basso and Zhang, 2007).

In the next section we present the basic model. Section 4.3 considers a single airport and uncertain passenger benefits. In section 4.4 we present an extended model with two regulated airports and analyze the effect of demand complementarity on the choice of regulation instruments. Then, in section 4.5 we further extend the model by introducing uncertain congestion costs. Profit maximizing airport behavior is considered in section 4.6. In section 4.7 we conclude.

4.2 The basic model

We start considering one monopolistic and congested airport that is under the control of a regulator. The regulator is uncertain about passenger benefits, but has perfect information about congestion costs. During our analysis we extend the model in several steps such that demand complementarities

between two regulated airports and uncertainties regarding congestion costs will be taken into account.

Airport usage is denoted by $q \geq 0$. Average congestion costs are assumed to be identical for all airlines and determined by

$$C(q) := c q \tag{4.1}$$

with $c > 0$. Total congestion costs at the airport is therefore $q C(q) = c q^2$. However, we assume that the airline market is atomistic such that C does not depend on an individual airline's behavior, i.e. C is considered to be exogenous by an airline.

Passenger benefits from airport usage are

$$B(q) := a q - \frac{b}{2} q^2 + \theta q$$

with $a, b > 0$. Benefits are determined by a stochastic term θ with expectation value 0 and variance $\sigma_\theta^2 > 0$. All realizations satisfy $\theta > -a$.

Due to the atomistic market structure airlines are under perfect competition leading to marginal cost pricing. Furthermore, without loss of generality assume that only airlines bear congestion costs, i.e. passengers' congestion costs are zero. For simplicity, we also assume that airlines' variable costs are fully determined by congestion costs. In this situation, the airlines' inverse demand for airport capacity $P(q)$ is determined by the marginal passenger benefits minus average congestion costs:¹

$$P(q) := B'(q) - C(q) = a - (b + c) q + \theta. \tag{4.2}$$

¹Denote x as *individual* airline's airport usage. Then, individual airline's profits are $x (B'(q) - C(q) - p)$, since airline fares are determined by B' . Equilibrium in the airline market requires that airline's profits are zero for any x , hence, equation (4.2) follows.

The implied demand for an airport charge $p \geq 0$ is

$$D(p) := \max \left\{ 0, \frac{a - p + \theta}{b + c} \right\}.$$

Observe that inverse demand is independent from activities at other airports.

Welfare is

$$W(q) := B(q) - q C(q) = a q - \frac{b + 2c}{2} q^2 + \theta q.$$

The regulator chooses between congestion pricing or slot constraints as regulation regimes to maximize (expected) welfare. Under congestion pricing, airport charges p are used to manage demand. With slot constraints airlines need to have take-off or landing permissions (slots) to incorporate regulated airports into their networks, and the number of slots q is limited by the regulator in order to manage the amount of airport usage demanded. In the following we assume that slots are efficiently allocated to passengers with the highest benefits by, say, slot auctions (Rassenti et al., 1982), (Grether et al., 1989). All formal expressions that follow will be given for the case that non-negativity constraints are not binding (which can be assured by appropriate choice of parameters).

4.3 Congestion pricing versus slot constraints under uncertain passenger benefits

Under congestion pricing the regulator chooses airport charges

$$\hat{p} := \arg \max_p E[W(D(p))] = \frac{a c}{b + 2c}$$

where $E[\cdot]$ is the expected value operator. Under slot constraints the regulator determines airport usage by

$$\hat{q} := \arg \max_q E[W(q)] = \frac{a}{b + 2c}.$$

Notice that, if passenger benefits would not be uncertain, i.e. $\sigma_\theta^2 = 0$, then welfare would be the same under both instruments. What is the right choice of regulation instruments under the current model specifications? Without calculating expected welfare under congestion pricing and slot constraints we can give a clear ranking of regulation instruments by using results derived by Weitzman as well as Adar and Griffin (Weitzman, 1974), (Adar and Griffin, 1976). They showed that under uncertainty about benefits and costs of pollution the expected welfare depends on the choice between prices (e.g., pollution taxes) or quantities (e.g., emission standards) as instruments. In particular, they demonstrated that, in a linear model, the welfare effects of regulation instruments depend on the steepness of the marginal benefits and the marginal costs functions of emissions as follows:

Prices as instruments generate a higher expected welfare than quantities as instruments if the marginal benefits function of emissions is steeper than the marginal costs function of emissions.

In our context, airport usage is similar to emissions in the context of resource management. More specifically, the inverse demand function determines the marginal benefits (marginal passenger benefits minus marginal airline costs that are equal to the average congestion costs) of ‘emissions’. The marginal costs of ‘emissions’ are given by the marginal external congestion costs that are

$$\frac{\partial q C(q)}{\partial q} - C(q) = C(q).$$

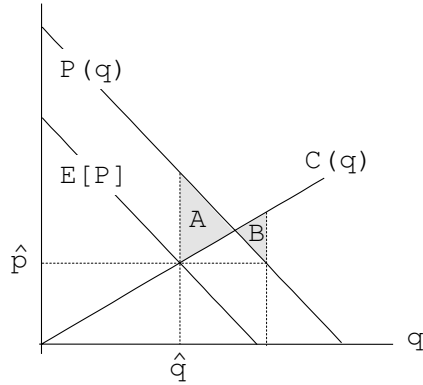


Figure 4.1: Welfare losses due to benefit shocks ($a = b = c = 1, \theta = 1/3$). *A*: Welfare loss under slot constraints. *B*: Welfare loss under congestion pricing.

Proposition 4.3.1 *Suppose that congestion costs are known with certainty and that airport demands are independent. Then, expected welfare is higher under congestion pricing than under slot constraints if passenger benefits are uncertain.*

Proof The steepness of the inverse demand function is $b + c$ while that of the marginal external congestion costs function is determined by c . Thus, by the results of Weitzman as well as Adar and Griffin the proposition follows (Weitzman, 1974), (Adar and Griffin, 1976). ■

Notice that the inverse demand is falling in q because, first, the passengers' willingness to pay is decreasing in airport usage and, second, average congestion costs are increasing in airport usage. On the other hand, the increase of marginal external congestion costs is only determined by average congestion costs. Therefore, the effect of airport usage on inverse demand is stronger than on marginal external congestion costs.

Figure 4.1 illustrates the effect of slopes on the ranking of regulation instruments. It depicts expected inverse demand $E[P]$, realized inverse demand P , and marginal external congestion costs or, respectively, average congestion costs C . The slope of inverse demand is $-(b+c)$ and the slope of C is c . Now, \hat{p} and \hat{q} are determined by the intersection of $E[P]$ and C . In the figure, the realization of demand is higher than expected, i.e. $\theta > 0$ realized, implying that airport charges or, respectively, slot constraints have been set too low. As a consequence, welfare loss is the area A under slot constraints and area B under congestion pricing. Due to the relative slopes of the functions, it holds $A > B$. Hence, welfare loss under congestion pricing is lower than under slot constraints. The reason is that under the former airport charges are fixed but airport usage is determined by realized demand. Therefore, with congestion pricing airport usage is higher than expected in this situation. Furthermore, this increase in airport usage has a stronger effect on benefits than on external congestion costs because the inverse demand is steeper than the average congestion costs function.

If demand is lower than expected, i.e. $\theta < 0$ realizes, then congestion pricing also enhances welfare compared to slot constraints. With this realization, airport charges have been set too high. This leads to a reduction of airport usage compared to expected demand. On the other hand, under slot constraints airport usage is fixed at the ex ante optimal level. However, since inverse demand is steeper than the marginal external congestion costs function, reducing airport usage has a stronger effect on external congestion costs than on passenger benefits. The total welfare effect of reducing airport usage under congestion pricing is therefore positive.

So far, we assumed that airport demand is independent of other airports' activities. Then the total welfare generated by the use of different airports

could easily be calculated by summing over different airports' welfares. However, under demand complementarity this simple approach is not possible. In the next section we extend our model and analysis by introducing demand complementarity.

4.4 Regulation regimes under uncertain passenger benefits and demand complementarity

In this section we, first, present the extended model specifications that introduce demand complementarity between airports. Second, we analyze the effects of demand complementarity regarding the choice of regulation regimes.

Modeling demand complementarity

From now on we consider two monopolistic airports in a regulated area and some outside airports. Each regulated airport serves perfectly separated catchment areas. Figure 4.2 illustrates. Passengers are assumed to make only direct flights (no transfers). Based on these assumptions there is no competition between airports for passengers.

Airports 1 and 2 are under the control of a regulator maximizing (expected) social welfare of that area. The other airports are not. For instance, assume that they belong to a different jurisdiction. Airports 1 and 2 are assumed to be symmetric with regard to cost and (expected) demand conditions. Capacity usage at airport i is denoted by $q_i \geq 0$ and average congestion costs at that airport are $C_i(q_i) := c q_i$ with $i \in \{1, 2\}$.

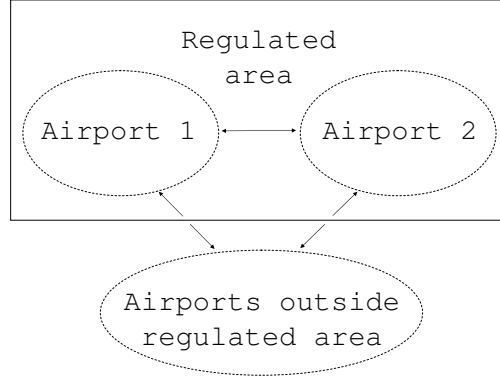


Figure 4.2: Two airports in a regulated area with separated catchments.

Airlines connecting airports 1 and 2 need to use airport facilities at both airports and will serve customers at both airports. We capture this demand complementarity by introducing a parameter $\gamma \in (-b, b)$ into the total benefit function of passengers from airports 1 and 2:

$$\bar{B}(q_1, q_2) := \gamma q_1 q_2 + a (q_1 + q_2) - \frac{b}{2} (q_1^2 + q_2^2) + \theta_1 q_1 + \theta_2 q_2 \quad (4.3)$$

with demand shocks θ_i that are identically and independently distributed. \bar{B} implies inverse demand for airport i

$$P_i(q_1, q_2) := \frac{\partial \bar{B}}{\partial q_i} - C_i(q_i) = \gamma q_j + a - (b + c) q_i + \theta_i \quad (4.4)$$

and airport demand

$$D_i(p_1, p_2) := \max \left\{ 0, \frac{(a + \theta_j - p_j) \gamma + (a + \theta_i - p_i) (b + c)}{(b + c)^2 - \gamma^2} \right\} \quad (4.5)$$

with $j \neq i$. By equation (4.4) the inverse demand of airport i depends on the level of activities at airport j . Increased use of one airport induces a parallel

shift of the inverse demand curve of the other airport inside the regulated area. For instance, if $\gamma > 0$ then an increase of airport j 's activities increases the inverse demand of airport i where the intensity of this effect depends on the level of γ . Since, by assumption, airports 1 and 2 do not compete, we focus on positive values for γ .

Under this model specifications welfare is

$$\bar{W}(q_1, q_2) := \bar{B}(q_1, q_2) - \sum_{i=1}^2 q_i C_i(q_i).$$

Observe that welfare can also be expressed by the line integral

$$\bar{W}(q_1, q_2) = \oint_{(0,0)}^{(q_1, q_2)} \left(\sum_{i=1}^2 (P_i(x_1, x_2) - C_i(x_i)) dx_i \right).$$

Note that the integrability condition is satisfied since income effects are zero (Crew and Kleindorfer, 1979). This implies that the solution of the line integral is independent of the particular path along which integration is taken. Therefore, one way to calculate welfare is

$$\begin{aligned} \bar{W}(q_1, q_2) &= \int_0^{q_1} (P_1(x_1, 0) - C_1(x_1)) dx_1 + \int_0^{q_2} (P_2(q_1, x_2) - C_2(x_2)) dx_2 \\ &= \gamma q_1 q_2 + a(q_1 + q_2) - \frac{b+c}{2} (q_1^2 + q_2^2) + \theta_1 q_1 + \theta_2 q_2. \end{aligned} \quad (4.6)$$

Demand complementarity and the choice of regulation regimes

Under congestion pricing airport charges will be set at

$$(\bar{p}_1, \bar{p}_2) := \arg \max_{p_1, p_2} E[\bar{W}(D_1(p_1, p_2), D_2(p_1, p_2))].$$

Calculating expected welfare under congestion pricing and, thereafter, solving simultaneously first order conditions for optimal airport charges gives the symmetric solution

$$\bar{p}_1 = \bar{p}_2 = \frac{a c}{b + 2 c - \gamma}.$$

The optimal airport charge \bar{p}_i is increasing in γ . This is because airport demand increases if γ increases and, thus, charges also have to be raised to limit congestion to the ex ante optimal level. Expected welfare under congestion pricing is

$$E[\bar{W}(\bar{p}_1, \bar{p}_2)] = \frac{a^2}{b + 2 c - \gamma} + \frac{b (b + c)^2 - (b + 2 c) \gamma^2}{(b + c - \gamma)^2 (b + c + \gamma)^2} \sigma_\theta^2. \quad (4.7)$$

Under a slot policy, constraints will be set at

$$(\bar{q}_1, \bar{q}_2) := \arg \max_{q_1, q_2} E[\bar{W}(q_1, q_2)]. \quad (4.8)$$

Calculating expected welfare under slot constraints and, thereafter, solving simultaneously first order conditions for optimal slot constraints gives the symmetric solution

$$\bar{q}_1 = \bar{q}_2 = \frac{a}{b + 2 c - \gamma}. \quad (4.9)$$

Observe that \bar{q}_i is also increasing in γ . This is because an increased use of one airport increases the benefits of using the other airport. The expected social welfare under slot constraints is

$$E[\bar{W}(\bar{q}_1, \bar{q}_2)] = \frac{a^2}{b + 2 c - \gamma}. \quad (4.10)$$

With regard to the choice of regulation regimes under demand complementarity the following holds.

Proposition 4.4.1 *Suppose that congestion costs are known with certainty. Then, expected welfare is higher under congestion pricing than under slot constraints if passenger benefits are uncertain and airport demand is complementary.*

Proof Comparison of equations (4.10) and (4.7) gives

$$E[\bar{W}(\bar{q}_1, \bar{q}_2)] - E[\bar{W}(\bar{p}_1, \bar{p}_2)] = -\frac{b(b+c)^2 - (b+2c)\gamma^2}{(b+c-\gamma)^2(b+c+\gamma)^2} \sigma_\theta^2 < 0,$$

since $\gamma < b$. ■

Notice that demand complementarity can favor the use of slot constraints in comparison to congestion pricing. However, due to Proposition 4.4.1, the effect of demand complementarity is never strong enough to outstrip the effect of relative slopes favoring the use of congestion pricing. The following example illustrates.

Assume $a = b = c = 1$ and $\gamma = 9/10 < 1$. For congestion pricing and slot constraints one obtains $\bar{p} = \bar{q} = 10/21$. Suppose $\theta_1 = 1/4$ and $\theta_2 = 0$ have realized such that demand at airport 1 is higher than expected. Therefore, under congestion pricing $D_1 = 0.63 > 10/21$ and $D_2 = 0.55 > 10/21$ realize. Observe that in this situation demand at airport 2 is greater than expected although $\theta_2 = 0$ holds, which is due to demand complementarity.

Figure 4.3 illustrates this situation. Figure 4.3a shows for airport 1 expected inverse demand $E[P_1]$, inverse demand under congestion pricing $P_1(x_1, 0.55)$, and marginal external congestion costs C_1 . Figure 4.3b shows for airport 2 expected inverse demand $E[P_2]$, inverse demand under congestion pricing $P_2(0.63, x_2)$, and marginal external congestion costs C_2 . One

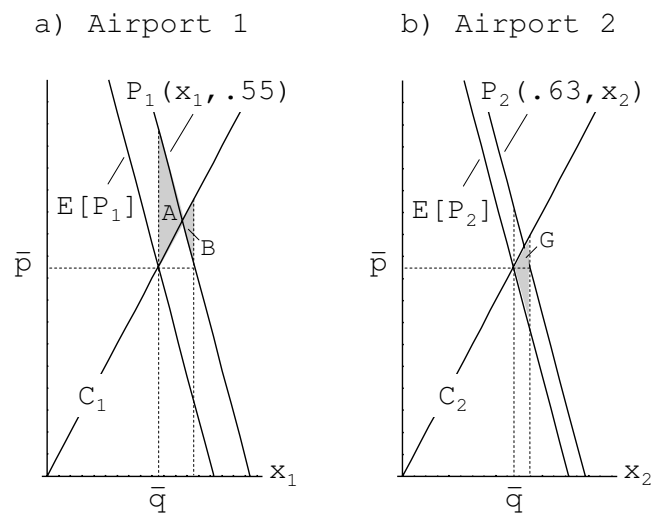


Figure 4.3: Welfare losses due to benefit shocks with demand complementarity ($a = b = c = 1$, $\gamma = 9/10$, $\theta_1 = 1/4$, $\theta_2 = 0$). A : Welfare loss under slot constraints. $B + G$: Welfare loss under congestion pricing.

way to calculate the welfare change from switching between congestion pricing and slot constraints is

$$\begin{aligned}
& \bar{W}(10/21, 10/21) - \bar{W}(0.63, 0.55) \\
&= \oint_{(0.63, 0.55)}^{(10/21, 10/21)} \left(\sum_{i=1}^2 (P_i(x_1, x_2) - C_i(x_i)) dx_i \right) \\
&= \int_{0.63}^{10/21} (P_1(x_1, 0.55) - C_1(x_1)) dx_1 + \int_{0.55}^{10/21} (P_2(10/21, x_2) - C_2(x_2)) dx_2 \\
&= (-A + B) + G = -0.005 < 0, \tag{4.11}
\end{aligned}$$

where A , B , and G refer to the respective areas shown in Figure 4.3. Thus, changing from congestion pricing to slot constraints reduces total welfare by 0.005.

Welfare changes at airport 1 clearly suggests that the introduction of slot constraints leads to welfare losses, since $-A + B < 0$. However, slot constraints reduce operations at airport 1 *and* reduce demand at airport 2. This is where demand complementarity comes into play.

Under slot constraints demand shocks at airport 1 lead to higher airport charges at airport 1 but do not affect demand at airport 2. Therefore, with slot constraints demand at airport 2 was anticipated correctly, i.e. $P_2 = E[P_2]$, such that welfare losses at airport 2 are 0. Congestion pricing, in contrast, reinforces demand uncertainty between airports, which leads to welfare losses at airport 2. This effect, in itself, indicates a relative disadvantage of congestion pricing. The welfare loss of congestion pricing which

is due to demand complementarity is measured by the area G in Figure 4.3 and is increasing in γ .²

As can be seen in Figure 4.3, the relative advantage of congestion pricing over slot constraints is greatly reduced by demand complementarity. That is, the difference $A - B$ which would prevail without demand complementarity is *much* larger than the difference $A - (B + C)$ that prevails with demand complementarity. Still, Proposition 4.4.1 shows that area A must always be larger than $B + G$, implying that congestion pricing is always the right choice of instruments.

A basic assumption underlying the results derived so far is that congestion costs are known by the regulator. This, however, is not fulfilled in practice. For that reason we analyze the impact of uncertain congestion costs on the choice of regulation instruments in the following section.

4.5 Regulation regimes under uncertain congestion costs

To include uncertain congestion costs into our model with two regulated monopolistic airports and several outside airports we introduce a second stochastic term $\kappa > 0$ with expectation value 1 and variance σ_κ^2 that is independently distributed from benefit shocks θ_i . Assume that uncertain average congestion costs are

$$\tilde{C}_i(q_i) := c \kappa q_i$$

²Notice that it would not be correct to infer from Figure 4.3, or (4.11), that passengers at airport 1 realize welfare losses while passengers at airport 2 realize welfare gains due to a change from congestion pricing to slot constraints. The ‘distribution’ of the areas A, B and G to the airports is only an artifact of the chosen path of integration.

for $i \in \{1, 2\}$. Observe that we assume a perfect stochastic correlation between the average congestion costs at regulated airports. Think, for instance, of an increase of fuel costs or general wage levels. Analogously to (4.4), (4.5) and (4.6) inverse airport demand is

$$\tilde{P}_i(q_1, q_2) := \gamma q_j + a - (b + c\kappa) q_i + \theta_i, \quad (4.12)$$

with $j \neq i$, airport demand is

$$\tilde{D}_i(p_1, p_2) := \max \left\{ 0, \frac{(a + \theta_j - p_j) \gamma + (a + \theta_i - p_i) (b + c\kappa)}{(b + c\kappa)^2 - \gamma^2} \right\},$$

and welfare is

$$\tilde{W}(q_1, q_2) := \bar{B}(q_1, q_2) - \sum_{i=1}^2 q_i \tilde{C}_i(q_i).$$

We can now turn to the effect of uncertain congestion costs on the choice of regulation instruments. Again, we make use of Weitzman's analysis to get a first intuition (Weitzman, 1974). He also found the following:

If high marginal costs of emissions are associated with low marginal benefits of emissions then prices as instruments tend to generate higher expected welfare than quantities as instruments.

Notice that high marginal costs of emissions are associated with low marginal benefits of emissions if both functions are negatively stochastically correlated. In our model, the stochastic correlation between inverse demand and

marginal external congestion costs (= average congestion costs) is indeed negative:

$$\begin{aligned} \frac{E\left[\left(\tilde{P}_i - E[\tilde{P}_i]\right)\left(\tilde{C}_i - E[\tilde{C}_i]\right)\right]}{\sigma_\theta \sigma_\kappa} &= -\frac{c q_i^2 E[(\kappa^2 - 1)]}{\sigma_\theta \sigma_\kappa} \\ &= -\frac{c q_i^2 \sigma_\kappa}{\sigma_\theta} < 0. \end{aligned}$$

This suggests that uncertainty about congestion costs will favor congestion pricing as optimal instruments. That this really is the case will be demonstrated by an example.

Assume that both stochastic terms are uniformly distributed. Supports are $[-\sqrt{3}\sigma_\theta^2, \sqrt{3}\sigma_\theta^2]$ for θ , $[1 - \sqrt{3}\sigma_\kappa^2, 1 + \sqrt{3}\sigma_\kappa^2]$ for κ with $\sigma_\kappa^2 \in [0, 1/3]$, and $a = b = c = 1$. In this example, there exist upper bounds for σ_θ^2 such that non-negativity constraints for inverse airport demands or, respectively, airport demands will not bind. In the following we assume that σ_θ^2 satisfies the upper bounds for both regulation regimes, slot constraints and congestion pricing.

Slot constraints will be set at

$$(\tilde{q}_1, \tilde{q}_2) := \arg \max_{q_1, q_2} E\left[\tilde{W}(q_1, q_2)\right]. \quad (4.13)$$

Calculating expected welfare under slot constraints and solving first order conditions leads to

$$\tilde{q}_1 = \tilde{q}_2 = \frac{1}{3 - \gamma}. \quad (4.14)$$

Expected welfare under slot constraints is

$$E\left[\tilde{W}(\tilde{q}_1, \tilde{q}_2)\right] = \frac{1}{3 - \gamma}. \quad (4.15)$$

Observe, since $b = c = 1$, (4.14) is identical to (4.9) and (4.15) is identical to (4.10). Thus, under slot constraints cost uncertainty does not affect regulation and resulting expected welfare.

Under congestion pricing airport charges will be set at

$$(\tilde{p}_1, \tilde{p}_2) := \arg \max_{p_1, p_2} E \left[\tilde{W}(D_1(p_1, p_2), D_2(p_1, p_2)) \right].$$

Denote

$$\lambda := 6 \sigma_\kappa (\gamma - 1), \quad \mu := \sqrt{3} (3 \sigma_\kappa^2 - (\gamma - 2)^2) \quad \text{and} \quad (4.16)$$

$$\phi_- := \ln \left(\frac{2 - \sqrt{3 \sigma_\kappa^2 - \gamma}}{2 + \sqrt{3 \sigma_\kappa^2 - \gamma}} \right) \quad (4.17)$$

implying $\lambda, \mu, \phi_- < 0$. Calculating expected welfare under congestion pricing and solving first order conditions leads to

$$\tilde{p}_1 = \tilde{p}_2 = \frac{\lambda + \mu \phi_-}{\lambda + 2 \mu \phi_-}. \quad (4.18)$$

Observe that (4.18) together with definitions (4.16) and (4.17) imply that airport charges are independent of benefit shocks. Note, $\lambda < 0 \Leftrightarrow \tilde{p}_i < 1/2$.

Figure 4.4 depicts prices and expected welfare under congestion pricing as functions of $\sigma_\kappa^2 \in [0, 1/3]$, assuming $\sigma_\theta^2 = 0$ and $\gamma = 9/10$. Observe that prices are falling in σ_κ^2 . Recall that congestion pricing and slot constraints lead to the same welfare results under perfect information. In Figure 4.4 there is perfect information for $\sigma_\kappa^2 = 0$. Now, expected welfare under congestion pricing is increasing in σ_κ^2 while expected welfare under slot constraints stays constant. This demonstrates that uncertainty about congestion costs, leading to a negative correlation between inverse demand and marginal external congestion costs, tends to favor congestion pricing as instruments.

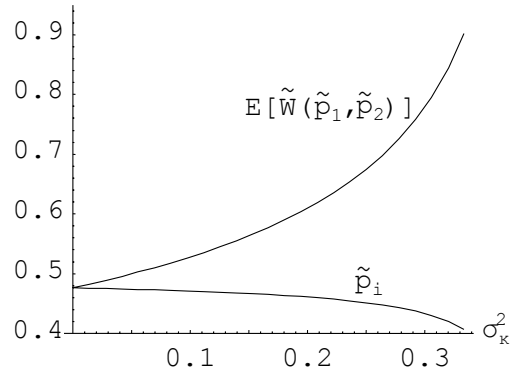


Figure 4.4: Airport charges and expected welfare under congestion pricing ($a = b = c = 1, \gamma = 9/10, \sigma_\theta^2 = 0$).

Inspections of plots show that the same qualitative results are obtained for all relevant combinations of σ_θ^2 and γ .

4.6 Profit maximizing airport behavior

In this section we analyze profit maximizing airport behavior in order to check the need for airport regulation. Notice, although airports are assumed to have perfectly separated catchment areas airport profits nevertheless are interdependent, due to demand complementarity. In order to analyze the effect of uncertainty and demand complementarity on profit maximizing airports we model the interaction between airports 1 and 2 as a two-stage game. In the first stage the airports simultaneously decide between slot constraints or pricing as instruments to allocate airport capacity. At this stage, it is possible that airports choose the same or different instruments. In the second stage, airports individually and simultaneously decide on their own, specific slot constraints or, respectively, pricing levels. Finally, benefit and cost

shocks realize. The analysis is carried out for the example described in the previous section.

Suppose first that both airports choose prices as instruments. Airport profits are

$$\Pi_i(p_1, p_2) := p_i \tilde{D}_i(p_1, p_2)$$

implying reaction functions

$$\arg \max_{p_i} E[\Pi_i(p_1, p_2)].$$

Denote

$$\phi_+ := \ln \left(\frac{2 - \sqrt{3\sigma_\kappa^2 + \gamma}}{2 + \sqrt{3\sigma_\kappa^2 + \gamma}} \right)$$

and notice that $\phi_- < \phi_+ < 0$ for $\gamma, \sigma_\kappa^2 > 0$.

Since expectation values of benefit shocks are zero, we can write expected profits as

$$\begin{aligned} E[\Pi_i(p_1, p_2)] &= \int_{1-\sqrt{3\sigma_\kappa^2}}^{1+\sqrt{3\sigma_\kappa^2}} p_i \frac{(1-p_j)\gamma + (1-p_i)(1+\kappa)}{(1+\kappa)^2 - \gamma^2} \cdot \frac{1}{2\sqrt{3\sigma_\kappa^2}} dy \\ &= p_i \frac{(p_i - p_j)\phi_+ - (2 - p_i - p_j)\phi_-}{4\sqrt{3\sigma_\kappa^2}}. \end{aligned}$$

with $j \neq i$. Calculation of reaction functions and fixed points leads to the unique Nash equilibrium

$$p_1^N = p_2^N := \frac{2\phi_-}{3\phi_- + \phi_+} \quad (4.19)$$

satisfying $p_i^N < 2/3$ for $i \in \{1, 2\}$. In equilibrium expected profits are

$$E[\Pi_i(p_1^N, p_2^N)] = -\frac{\phi_-^2 (\phi_- + \phi_+)}{\sqrt{3} \sigma_\kappa^2 (3\phi_- + \phi_+)^2} \quad (4.20)$$

with

$$\lim_{\sigma_\theta^2 \rightarrow 0} E[\Pi_i(p_1^N, p_2^N)] = \frac{2(2 + \gamma)}{(2 - \gamma)(4 + \gamma)^2}.$$

The other constellations where both airports choose slot constraints as instruments or where airports choose different instruments are analyzed in the appendix which shows:

Proposition 4.6.1 *If $\gamma > 0$ then from the airports' perspective prices strictly dominate slot constraints as instruments.*

Proof See the appendix. ■

Inspections of plots show that $\tilde{p}_i < p_i^N$ for all relevant combinations of σ_κ^2 and γ . Hence, welfare can be enhanced by regulating and reducing monopolistic airport charges.

4.7 Conclusions

In order to control airport congestion, two different policy options are under discussion: slot constraints and congestion pricing. The former requires airlines to buy slots for the operation of flights at congested airports. The latter reduces the demand for take-off and landing operations by rising airport charges. Under perfect information about the benefits and costs of airport operations both instruments can reach optimal welfare results. In contrast, under uncertainty the choice of instruments makes a difference and strongly favors the use of congestion pricing compared to slot constraints.

One reason for this result is that the inverse demand function is steeper than the marginal external congestion costs function. Notice that inverse demand is falling in airport usage for two reasons: because average congestion costs are increasing in airport usage *and* because the passengers' marginal willingness to pay is decreasing in airport usage. In contrast, marginal external congestion costs are fully determined by average congestion costs. Therefore, the effect of airport usage on the marginal willingness to pay for airport capacity is stronger than the effect it has on marginal external congestion costs.

Another reason for choosing prices as instruments is uncertainty with regard to congestion costs. If congestion costs are uncertain then average congestion costs affect marginal external congestion costs as well as inverse demand such that there is a negative stochastic correlation between both functions. This further favors the use of congestion pricing compared to slot constraints.

We also demonstrated that complementarity between airport demands can work in favor of slot constraints compared to congestion pricing. The reason is that slot constraints fix airport demand and, as a consequence, block a reinforcement of uncertainty between different airports. However, although congestion pricing might not manage demand complementarity as good as slot constraints, the positive welfare effects of congestion pricing mentioned before are always dominant such that congestion pricing is the right choice even if demand complementarity is strong.

Finally, we considered profit maximizing monopolistic airports in a two-stage game. At first, airports independently choose slot constraints or prices as instruments. In the next stage they apply these instruments. It turns out that under demand complementarity profit maximizing airports are strictly

better off with prices as instruments compared to slot constraints. This is consistent with the regulator's choice of regulation instruments. However, profit maximizing airport charges are too high and do not maximize expected welfare. Hence, profit maximizing monopolistic airports produce a deadweight loss indicating the need for regulation.

CHAPTER 5

Regulation of two-part tariffs and
quality choice under uncertainty

5.1 Introduction

It is common international practice that utilities in the transport, telecommunications, energy, and water sector are regulated. Regulatory objectives usually include the optimization and redistribution of welfare. The former targets the demand performance but also quality. The definition of what quality is, however, strongly depends on the services in question. In the transport sector quality is frequently measured by congestion. Air navigation service providers and airports are asked to optimize delays in air transport operations because congestion is costly for airlines, passengers, and also the environment. In the postal sector, an important variable which determines quality is delivery speed. In the electricity, gas, and water sector, quality is measured by the number and duration of service interruptions. In the telecommunications sector quality is measured by the installation speed of telephone services and the number of trouble reports (Al et al., 2004).

It is well known that monopolies tend to overcharge consumers from a welfare perspective. However, the effect monopolistic behavior has on quality is not straightforward. Spence as well as Sheshinski demonstrated that both is possible: monopolies might choose quality too low or too high from a welfare perspective (Spence, 1975), (Sheshinski, 1976). This is because a monopoly firm chooses quality choice according to the preferences of the *marginal* user. In contrast a welfare maximizer chooses quality according to the preferences of the *representative* user. Hence, if and only if the marginal user is also representative, then the monopoly choice with regard to quality is consistent with welfare maximization. Otherwise, if the marginal user has a higher preference for quality compared to the representative user, then the monopoly chooses quality too high, et vice versa.

The effect regulation has on quality is also diverse and depends on the regulation regime considered. Under a rate-of-return regulation, which is common in the U.S., the return on the invested capital is constrained which determines prices. This form of regulation has the effect of raising the capital stock (Averch and Johnson, 1962). Hence, quality depends on whether it is capital-using or not (Spence, 1975). In comparison, under a cost-plus regulation, which is common in Europe, prices are determined by a maximum return on total costs. Since quality improvements will increase costs which can be reimbursed by higher prices, this stimulates quality performance (Pazner, 1975), (Spence, 1975), (Sheshinski, 1976).

At the present time the price-cap approach has become the international standard where price constraints are set for a certain period of time in advance, normally for 5 or 6 years, and are not adjusted to the actual cost performance of the regulated firm. For that reason prices are independent from costs during that period. As a consequence, cost reductions will increase profits, which enhances the incentive to actually generate efficiency gains in terms of costs. However, a side-effect is that firms will also reduce costs by reducing quality. Therefore, a price-cap regulation is expected to lead to a poor quality performance (Spence, 1975), (Sheshinski, 1976), (Baron, 1981).

Various regulation instruments are available to control quality. They include minimum quality standards, bonus and penalty payments, and the publication of quality measures (Rovizzi and Thompson, 1995), (Sappington, 2005). In practice different measures of price and quality regulation are often combined. For example, the price-cap of the British air navigation service provider depends on an index that is based on the average delays of flights. Reductions of average delays loosens the price-cap while increases in delays tightens it. Hence, this regulation regime combines a price-cap regulation

approach with bonus payments that are granted via variations of the price-cap. Similar regimes are applied to water companies, local telecommunication service providers as well as energy network providers in the Netherlands, Norway, UK, and the U.S. (Vasington, 2003), (Ajodhia and Hakvoort, 2005).

Observe that welfare effects of this approach are ambivalent; a higher quality can increase welfare but higher prices will usually reduce demand and welfare. An additional complication is that welfare and distributional objects can be conflicting. For most utilities it holds that welfare optimal prices fail to raise sufficient revenues to allow cost recovery. Therefore, sub-optimal prices are usually accepted in order to prevent the firm from making losses. The question is, how to design a regulation regime that optimizes demand as well as quality and at the same time distributes welfare such that, on the one hand, consumers' surplus is positive and, on the other hand, firms are able to cover costs.

According to the Tinbergen Principle a separate instrument should be used to address each regulation objective (Tinbergen, 1952). The regulation objectives we address in this paper are, first, optimization of demand, second, optimization of quality and, third, distribution of welfare. We identify and analyze a set of four different regulation regimes where every regime includes one instrument to address each of these regulation objectives. All regimes refer to two-part tariffs, where consumers pay a price per unit of demand and a fixed fee.¹ Throughout this paper it is assumed that quality is verifiable, i.e. quality can be observed and verified to third parties.

The regulation regimes considered in this paper combine standards, bonuses, and a fixed fee cap as regulation instruments. By 'standards' we refer to fixed

¹Sappington and Sibley developed a regulation mechanism for utilities that also includes two-part tariffs (Sappington and Sibley, 1988). A crucial element of their mechanism is subsidization of the utility. The revenues to pay subsidies are suggested to be raised by fixed fees.

levels, prescribed by the regulator, of either prices, demand, or quality. For the quality dimension we will also investigate ‘bonuses’ in the form of a linear increase of a fixed fee cap as a reward for quality. This leads to four different types of regulation regimes including:

1. standards on quantities and quality, plus a fixed fee cap
2. standards on prices and quality, plus a fixed fee cap
3. standards on prices and quality bonuses in the fixed fee cap
4. standards on quantities and quality bonuses in the fixed fee cap.

Under perfect information all four regulation regimes can be employed to generate a first best allocation and to distribute welfare among the firm and consumers. However, in practice regulators hardly possess perfect information about market conditions. For this reason we analyze the potential of these regulation regimes to optimize welfare under demand and cost uncertainty.

In this paper we use a model that is refined in several steps. We demonstrate that quality bonuses are useful in order to deal with uncertainty about costs. Moreover, it turns out that quality bonuses in combination with quantity standards lead to the best results in terms of expected welfare. This is because quantity standards provide enhanced incentives to adjust quality towards the welfare optimal level. The reason for that is that prices are variable under quantity standards and, therefore, a higher quality can lead to higher prices and profits.

Lewis and Sappington considered regulation regimes including standards on prices, quality, and fixed fees using a model with asymmetric information where the firm’s information is superior to the information of the regulator

(Lewis and Sappington, 1992). However, the other regulation regimes considered in this article have not been subject of an integrated investigation to our knowledge. So far the literature focussed on the relation between monopoly behavior and product quality and the relation between regulation regimes such as rate-of-return, cost-plus, and price-cap regulation and quality (Pazner, 1975), (Spence, 1975), (Sheshinski, 1976), (Baron, 1981). Ways to deal with quality in procurement were analyzed by Laffont and Tirole (Laffont and Tirole, 1993). Sector specific studies with regard to quality supply are also presented, e.g. (Vasington, 2003), (Al et al., 2004), (Ajodhia and Hakvoort, 2005). For a detailed survey of the relevant literature on the regulation of service quality see Sappington (Sappington, 2005).

The next section presents a description of the model and the regulation regimes considered. In section 5.3 we compare welfare optimal and monopolistic behavior. Quantity standards as well as price standards in combination with quality standards are compared in section 5.4. Quality standards as well as quality bonuses in combination with price standards are compared in section 5.5. Quantity standards and price standards in combination with quality bonuses are compared in section 5.6. Finally, section 5.7 provides conclusions.

5.2 The model

We consider a monopoly firm that charges consumers using two-part tariffs consisting of a fixed fee and a unit price. The firm chooses fixed fees, quantities that imply a unit prices, and quality $s \geq 0$. Suppose that s is a quality index that gives a verifiable indication of the quality level provided by the firm. For instance, the index can show the number and duration of service

interruptions owing to deficient network conditions in telecommunications or energy markets or the average delay per flight owing to airports or air navigation service providers. Notice that the case we consider in this model is equivalent to a situation with an upstream monopoly firm that provides its services to firms in a downstream market under perfect competition (Basso, 2006).

The monopoly firm should be regulated. We consider a regulation game with two stages.

- Stage 1: the regulator has imperfect information about market conditions, i.e. demand and cost conditions, and maximizes expected welfare by choosing the regulation regime.
- Stage 2: the firm learns about realized market conditions. It therefore maximizes actual profits by choice of price, quantity, and quality in accordance with regulation and market conditions.

In addition to fixed fee caps, we consider different options to regulate demand and quality. Demand can be regulated by quantity or price standards, i.e. fixed quantity or price levels prescribed by the regulator. Quality can be regulated by standards or by linear bonuses in the fixed fee cap. Combination of these different instruments leads to four different regulation regimes denoted by $s1$, $s2$, $b1$, and $b2$ (Figure 5.1 illustrates):

- Regime $s1$: standards on quantity and on quality, and fixed fee caps.
- Regime $s2$: standards on prices and on quality, and fixed fee caps.
- Regime $b1$: price standards and a linear relationship between fixed fee caps and quality. According to this relationship, an increase of quality raises the fixed fee cap and provides bonuses in terms of the opportunity

		Quality	
		Standards	Bonuses
Demand	Quantity standard	s1	b2
	Price standard	s2	b1

Figure 5.1: Regulation regimes: overview and notation.

to increase fixed fees. The formula for fixed fee caps also contains a critical service quality which has to be reached such that the firm is allowed to charge consumers with positive fixed fees.

- Regime *b2*: quantity standards and a linear relationship between fixed fee caps and quality (similar to that under regime *b1*).

Consumers are assumed to have identical preferences. All elements of the model are expressed per consumer. For given quantity $x \geq 0$, quality s , and a stochastic term θ , the inverse demand is $P(x, s)$ with $\partial P/\partial x < 0$, $\partial P/\partial s \geq 0$, and $\partial P/\partial \theta \geq 0$. The respective demand function is $D(p, s)$ where $p \geq 0$ is the unit price. The stochastic term θ has support $[\underline{\theta}, \bar{\theta}]$, expectation value 0, and variance $\sigma^2 > 0$.

Costs per customer depend on quality and a stochastic term $\kappa \in \mathbb{R}$, but not on quantities. They are denoted C with $\partial C/\partial s$, $\partial^2 C/\partial s^2 > 0$, and $\partial C/\partial \kappa \geq 0$. κ is independent from θ . Notice that later on we will refine the model by taking resort to a linear demand function and a quadratic cost

function. In a final step we will also assume that demand shocks θ follow a uniform distribution.

For simplicity, we assume that, first, quantities do not affect the firms costs, and, second, service quality is independent from quantities. For most infrastructure providers, e.g., airports or network providers in the transport and energy sector, variable costs are indeed low. The second assumption seems to be more critical but its relaxation will be left for future research.

Omitting the dependency on θ and κ we obtain the following expressions. Consumer surplus is

$$CS(x, s) := \int_0^x P(y, s) dy - x P(x, s).$$

Let $\tilde{p} \in \mathbb{R}$ denote the fixed fee. Consumption takes place if and only if the participation constraint

$$\tilde{p} \leq CS(x, s)$$

is satisfied (recall that consumers are identical). Welfare is

$$W(x, s) := \int_0^x P(y, s) dy - C(s)$$

if the participation constraint is satisfied and 0 otherwise.

The regulated firm is assumed to obtain perfect information about demand and cost conditions, i.e. the firm learns about the exact values of θ and κ in stage two of the game. Therefore, in this stage the firm maximizes actual profits. Profits per consumer are

$$\Pi(x, s, \tilde{p}) := x P(x, s) + \tilde{p} - C(s)$$

if the participation constraint is satisfied and 0 otherwise.

5.3 Welfare vs. profit maximization

In this section we identify the first-best welfare maximizing allocation. Then we use it to benchmark the behavior of a profit maximizing monopoly firm. This is to explain the rationale for regulation in this setting.

For a given realization of θ and κ , welfare optimal behavior is determined by

$$(x^*, s^*, \tilde{p}^*) := \arg \max_{x, s, \tilde{p}} W(x, s) \text{ s.t. } CS(x, s) \geq \tilde{p}$$

leading to the first order conditions

$$P(x^*, s) = 0, \quad \int_0^{x^*} P_s(y, s^*) dy = C_s(s^*), \quad \text{and} \quad (5.1)$$

$$\tilde{p}^* \leq CS(x^*, s^*).$$

These conditions reproduce the familiar textbook result that welfare optimization requires marginal cost pricing. Optimal quality is reached if the increase in benefits due to a marginal increase of quality is equal to the marginal costs of quality. Notice that welfare optimal fixed fees are not unique.

Under linear pricing rules without fixed fees, the first-best solution would lead to losses. On the other hand, with two-part tariffs cost recovery requires

$$\tilde{p}^* \geq C(s^*).$$

Notice that $C(s^*) < \int_0^{x^*} P_s(y, s^*) dy$ holds which shows that even in the case of cost recovery there is a potential to redistribute welfare towards customers.

Now we turn to the behavior of a profit maximizing firm

$$(x^m, s^m, \tilde{p}^m) := \arg \max_{x, s, \tilde{p}} \Pi(x, s) \text{ s.t. } \tilde{p} \leq CS(x, s).$$

It is straightforward to show that the conditions shown in (5.1) also hold for a profit maximizing monopolist which implies $(x^m, s^m) = (x^*, s^*)$. However, in contrast to welfare maximization, under profit maximization the participation constraint is binding:

$$\tilde{p}^m = CS(x^*, s^*).$$

This shows that monopolistic behavior is fully consistent with welfare maximization (Oi, 1971). Thus, if it were not for distributional concerns, no regulation would be a welfare maximizing regulation in this setting. Actually, economic regulation of monopolistic firms normally follows distributional objectives (Feldstein, 1972), (Auerbach and Pellechio, 1978), (Laffont and Tirole, 1993). Under perfect information, all four regulation regimes sketched in Figure 5.1 achieve first-best allocation and allow for the redistribution of welfare. Notice that this would not be a possible task for regulation regimes based on linear pricing. For this reason we focus on regulation regimes based on two-part tariffs.

However, in this model, and in reality, regulation policy has to be chosen under uncertainty, i.e. prior to the realization of θ and κ . Thus the regulator may fail to maximize welfare due to uncertainty about market conditions. The question, therefore, is how to design a regulation regime that shifts welfare towards consumers and deals with uncertainty such that welfare losses are minimized. In the following sections we analyze the potential of the different regulation regimes to redistribute and optimize *expected* welfare in

an uncertain world. The next section compares regimes $s1$ and $s2$. Section 5.5 compares regimes $s2$ and $b1$. Section 5.6 compares regimes $b1$ and $b2$.

5.4 Combining quality standards with standards on quantities or prices

In this section we compare regulation regimes $s1$ and $s2$. Regime $s1$ combines quantity and quality standards. Regime $s2$ combines price and quality standards. Thus, they both make use of quality standards (and fixed fee caps). The question is whether the regulator should combine quality standards with quantity or with price standards.

Optimal quantity standards under regime $s1$ solve

$$x^{s1} := \arg \max_x E[W(x, s)].$$

leading to the first order condition $E[P(x^{s1}, s)] = 0$. Hence, the quantity standard is set such that the expected price is equal to zero which is equal to marginal costs of quantities.

Price standards under regime $s2$ are

$$p^{s2} := \arg \max_p E[W(D(p, s), s)].$$

with first order condition

$$E \left[P(D(p^{s2}, s), s) \cdot \frac{\partial D(p^{s2}, s)}{\partial p} \right] = 0. \quad (5.2)$$

Since $\partial D/\partial p < 0$, it follows that condition (5.2) holds if and only if $p^{s2} = 0$ is satisfied. Even without looking at the first-order conditions for the quality standards we obtain a clear ranking of regimes $s1$ and $s2$:

Proposition 5.4.1 *When quality standards are chosen, expected welfare is higher with price standards (regime $s2$) than with quantity standards (regime $s1$).*

Proof Zero-price standards under regime $s2$ imply optimal demand for any realization of θ . In contrast, quantity standards are only optimal on expectation. ■

It is worth mentioning that Proposition 5.4.1 is consistent with results presented by Weitzman as well as Adar and Griffin (Weitzman, 1974), (Adar and Griffin, 1976). Referring to pollution management (amongst others), they showed that under uncertainty about benefits and costs of pollution expected welfare depends on the regulator's choice between prices (e.g., pollution taxes) or quantities (e.g., emission standards) as instruments. They demonstrate that the optimal choice of instruments depends on the steepness of the marginal benefit and the marginal cost curve for emission reduction. Prices as instruments generate a higher expected welfare than quantities as instruments if the marginal benefit curve is steeper than the marginal cost curve et vice versa. Observe that in our case the slope of the marginal cost curve is zero. In contrast, the slope of the inverse demand curve is assumed to have a strictly negative slope. Hence, the inverse demand curve is always steeper than the marginal cost curve for quantities. This indicates that price standards enhance expected welfare compared to quantity standards which is consistent with Proposition 5.4.1.

A regulation regime based on standards fully determines the firm's behavior. It then prevents the firm from using its superior information gathered in

stage two of the game in order to react flexibly to actual market conditions. Therefore, we now compare regimes s_2 and b_1 . The latter includes bonuses for quality thus leaving room for the firm's choice of quality.

5.5 Combining price standards with quality standards or quality bonuses

To analyze and compare regimes s_2 and b_1 , we will take resort to a more specific model structure assuming that inverse demand is linear and of type

$$P(x, s) = \max\{0, s(a - bx + \theta)\} \quad (5.3)$$

with $a, b > 0$ and $\theta > -a$.² This implies demand

$$D(p, s) = \max\left\{0, \frac{s(a + \theta) - p}{bs}\right\}.$$

Furthermore, assume that the expectation value of cost parameter κ is equal to 1 and that $\kappa > 0$ holds. The firm's costs are assumed to be

$$C(s) = \frac{s^2 c \kappa}{2}$$

with $c > 0$.

It follows that welfare is

$$W(x, s) = sx \left(a - \frac{bx}{2} + \theta \right) - \frac{s^2 c \kappa}{2}$$

if the participation constraint is satisfied and 0 otherwise.

²The form of the inverse demand function follows Tirole (Tirole, 1988). In contrast to Tirole's specification we add a stochastic term.

Before turning to the discussion of the next regime $b1$, we state the first-best solution for the refined model specification. For comparison we also need to calculate quality standards under regime $s2$. Straightforward calculations lead to the first-best allocation:

$$(x^*, s^*) = \left(\frac{a + \theta}{b}, \frac{(a + \theta)^2}{2bc\kappa} \right). \quad (5.4)$$

Profits in terms of individual consumers are

$$\Pi(x, s, \tilde{p}) = xs(a - bx + \theta) + \tilde{p} - \frac{s^2 c \kappa}{2} \quad (5.5)$$

if the participation constraint is satisfied and 0 otherwise.

Under regime $s2$ we have $p^{s2} = 0$ and optimal quality standards of

$$s^{s2} := \arg \max_s E[W(D(0, s), s)] = \frac{a^2 + \sigma^2}{2bc}$$

implying an expected welfare of

$$E[W(D(0, s^{s2}), s^{s2})] = \frac{(a^2 + \sigma^2)^2}{8b^2c}. \quad (5.6)$$

Under regime $b1$ we have standards on unit prices to regulate demand, as under regime $s2$. The difference between these two regimes is that under regime $s2$ quality is determined by standards while under regime $b1$ there is a linear relation between fixed fee caps and quality. Assume that under regime $b1$ a marginal increase of quality increases fixed fee caps by an amount $\beta \geq 0$. The formula for fixed fee caps also contains a critical service quality $\bar{s} \in \mathbb{R}$ which has to be reached such that the firm is allowed to charge consumers

with positive fixed fees. Observe that \bar{s} can be negative. Altogether, under regime *b1* the cap constraint for fixed fees is

$$\tilde{p} \leq \beta (s - \bar{s}). \quad (5.7)$$

Notice that under regime *s2* quality is fully determined by standards and does not depend on whether fixed fee caps are binding or not. This is different under regime *b1* where the firm benefits from bonuses, in terms of the possibility to increase fixed fees, if and only if the fixed fee cap is binding. Therefore, in this case the firm's quality reactions depend on whether fixed fee caps are binding or not. The firm's reaction functions under regime *b1* are

$$\begin{aligned} (s_r^{b1}, \tilde{p}_r^{b1}) &:= \arg \max_{s, \tilde{p}} \Pi(D(p, s), s, \tilde{p}) \\ \text{s.t.} \quad &\min\{\beta (s - \bar{s}), CS(D(p, s), s)\} - \tilde{p} \geq 0. \end{aligned} \quad (5.8)$$

Observe that with non-binding fixed fee caps fixed fees are determined by the participation constraint.

Reasons for the choice of zero-price standards under regime *b1*

We first focus on the regulator's choice of price standards. It turns out to be difficult to derive a closed form solution for the regulator's optimal choice of price standards and linear rewards. However, numerical simulations demonstrate that the regulator sets $p^{b1} = 0$. In the following we provide two reasons for this choice.

If fixed fee caps are binding the firm's quality reactions s_r^{b1} are determined by the first-order condition

$$\frac{p^2}{b (s_r^{b1})^2} + \beta - c \kappa s_r^{b1} = 0. \quad (5.9)$$

Condition (5.9) demonstrates that the regulator can stimulate quality by price standards *or* by bonuses. Hence, there is no need to use strictly positive price standards to stimulate quality performance, which would imply suboptimal low demand levels, because quality performance can also be stimulated by bonuses. Using zero-price standards to regulate demand and linear rewards to regulate quality would also be in line with the Tinbergen-Principle claiming that a separate instrument should be used to address each regulation objective (Tinbergen, 1952).

Recall that bonuses were introduced because the firm should be enabled to react flexibly according to actual market conditions. Now, besides its negative effects on demand, positive price standards also imply rigidities with regard to cost shocks. From (5.9) it follows that

$$\frac{ds_r^{b1}}{d\kappa} = -\frac{bc (s_r^{b1})^4}{2p^2 + bc\kappa (s_r^{b1})^3} < 0.$$

Observe that the absolute value of $ds_r^{b1}/d\kappa$ is declining in p . Thus, under zero-price standards, the sensibility of the firm's quality choice to cost information is at its maximum.

Moreover, numerical solutions using a uniform distribution for demand shocks θ and a discrete distribution of costs shocks κ confirm that zero-price standards are indeed welfare optimal under regime $b1$. For these reasons we assume in the following that price standards under regimes $b1$ and $s2$ are similar, i.e. we assume that $p^{b1} = p^{s2} = 0$ holds.

Quality choice and welfare effects under regime $b1$ in comparison to regime $s2$

Denote critical values for quality by

$$\tilde{s}^{b1} := \frac{(a + \theta)^2 (2b\beta - (a + \theta)^2)}{4b^2 c \kappa \beta} \text{ and}$$

$$\tilde{\bar{s}}^{b1} := \frac{2b\beta - (a + \theta)^2}{2bc\kappa}$$

implying $\tilde{s}^{b1} \leq \tilde{\bar{s}}^{b1}$ and $\tilde{s}^{b1} = \tilde{\bar{s}}^{b1} \Leftrightarrow 2b\beta = (a + \theta)^2$.

Lemma 5.5.1 *With zero-price standards and quality bonuses (regime $b1$) the firm's reaction functions are as follows. Choice of quality is:*

$$s_r^{b1}(\beta, \bar{s}) = \begin{cases} \frac{\beta}{c\kappa} & \text{for } \bar{s} \geq \tilde{\bar{s}}^{b1} \\ \frac{2b\bar{s}\beta}{2b\beta - (a + \theta)^2} & \text{for } \tilde{s}^{b1} < \bar{s} < \tilde{\bar{s}}^{b1} \\ \frac{(a + \theta)^2}{2bc\kappa} & \text{for } \bar{s} \leq \tilde{s}^{b1}. \end{cases}$$

Choice of fixed fees is:

$$\tilde{p}_r^{b1}(\beta, \bar{s}) = \begin{cases} \beta(s_r^{b1} - \bar{s}) & \text{for } \bar{s} \geq \tilde{\bar{s}}^{b1} \\ CS(x, s_r^{b1}) & \text{for } \bar{s} < \tilde{\bar{s}}^{b1} \end{cases}.$$

Proof See Appendix C.1. ■

Notice that fixed fee caps lead to a strictly positive consumer surplus if and only if $\bar{s} > \tilde{\bar{s}}^{b1}$ holds. In this case quality does not necessarily depend on the choice of \bar{s} . Hence, the regulator can use \bar{s} as an instrument to split

welfare between the firm and consumers without necessarily affecting total welfare. The regulator's choice of β is

$$\beta^{b1} := \arg \max_{\beta} E[W(D(0, s_r^{b1}(\beta)), s_r^{b1}(\beta))].$$

Since a positive consumer surplus requires a non-binding participation constraint, assume by Lemma 5.5.1 that the regulator sets \bar{s} such that $\bar{s} > \tilde{s}^{b1}$ holds for all $\theta \in [\underline{\theta}, \bar{\theta}]$ and all $\kappa > 0$. Then the solution is

$$\beta^{b1} = \frac{a^2 + \sigma^2}{2b}.$$

Observe that $s_r^{b1}(\beta^{b1}) = s^{s2}/\kappa$ holds. This shows that under regime $b1$ and in contrast to regime $s2$ quality is adjusted according to actual cost conditions. In the case of high costs quality is reduced et vice versa, i.e. $\kappa > 1 \iff s^{b1} < s^{s2}$ holds. Figure 5.2 illustrates (for $a = b = c = 1$, $\theta = 0$, and $\sigma^2 = 1/10$) that there is a close relationship between the firm's quality reactions under regime $b1$ and the first-best quality compared to quality under regime $s2$.

Denoting $E[1/\kappa] := \phi \geq 1$, the expected welfare under 'regime $b1$ ' is

$$E[W(D(0, s_r^{b1}(\beta^{b1})), s_r^{b1}(\beta^{b1}))] = \frac{(a^2 + \sigma^2)^2}{8b^2c} \phi. \quad (5.10)$$

Proposition 5.5.2 *When zero-price standards are chosen and consumer surplus is positive for any realization of θ and κ , expected welfare is higher with quality bonuses (regime $b1$) than with quality standards (regime $s2$).*

Proof If the regulator chooses regime $b1$ then, by Lemma 5.5.1, consumer surplus is positive for all $\theta \in [\underline{\theta}, \bar{\theta}]$ and all $\kappa > 0$ if and only if $\bar{s} > \tilde{s}^{b1}$ for all $\theta \in [\underline{\theta}, \bar{\theta}]$ and all $\kappa > 0$, and expected welfare is given by (5.10).

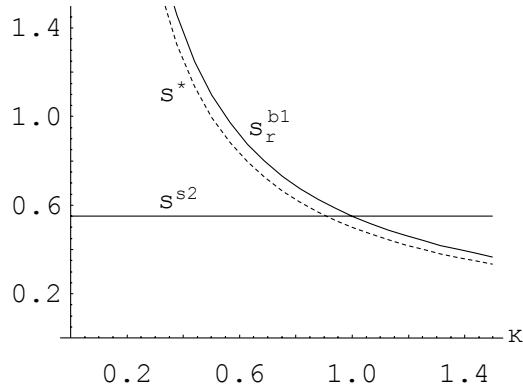


Figure 5.2: First-best quality and quality under regimes $s2$ and $b1$ depending on realizations of κ ($a = b = c = 1, \theta = 0, \sigma^2 = 1/10$).

If the regulator chooses regime $s2$ then expected welfare is given by (5.6).

Comparison shows

$$E[W(D(0, s_r^{b1}(\beta^{b1})), s_r^{b1}(\beta^{b1}))] - E[W(D(0, s^{s2}), s^{s2})] = \frac{(a^2 + \sigma^2)^2}{8b^2c} (\phi - 1) \geq 0.$$

■

Observe that regime $s2$ and regime $b1$ perform equally well if costs are deterministic, i.e. $\phi = 1$ holds. However, with uncertain costs bonuses enhance expected welfare because they allow for adjustments to actual market conditions.

5.6 Combining quality bonuses with price standards or quality standards

In this section we analyze whether a move from zero-price standards towards quantity standards can lead to further enhancements in expected welfare. Regime $b2$ is a combination of quantity standards with quality bonuses. The bonus scheme is described by (5.7), as under regime $b1$, i.e. it is a relaxation of the fixed fee cap. Without further analysis we can derive the following proposition:

Proposition 5.6.1 *Regime $b1$ is (weakly) dominated by regime $b2$.*

Proof If quantity standards are chosen so high that $P(x, s) = 0$ holds for all $\theta \in [\underline{\theta}, \bar{\theta}]$ regime $b2$ reproduces regime $b1$. Hence, the welfare results under regime $b2$ will be at least as good as under $b1$. ■

The question is whether it is possible to enhance expected welfare by restricting quantity standards such that prices can become strictly positive when demand shocks are high. Notice that under regime $b2$, in contrast to regime $b1$, prices are variable. So, if a high demand realizes the firm could increase its prices and possibly profits by increasing quality. We will demonstrate that this kind of reaction enhances expected welfare under regime $b2$ compared to regime $b1$.

The firm's reaction functions under regime $b2$ are

$$(s_r^{b2}, \tilde{p}^{b2}) := \arg \max_{s, \tilde{p}} \Pi(x, s) \text{ s.t. } \min\{\beta(s - \bar{s}), CS(x, s)\} - \tilde{p} \geq 0.$$

We denote critical values for quality by

$$\tilde{s}^{b2} := \frac{x(2(a + \theta) - bx)(2\beta - bx^2)}{4c\kappa\beta} \text{ and}$$

$$\tilde{s}^{b2} := \frac{(x(a + \theta - bx) + \beta)(2\beta - bx^2)}{2c\kappa\beta}$$

implying $\tilde{s}^{b2} \leq \tilde{s}^{b2}$ and $\tilde{s}^{b2} \leq \tilde{s}^{b2} \Leftrightarrow 2\beta = bx^2$.

Lemma 5.6.2 *With quantity standards and quality bonuses (regime b2) the firm's reaction functions are as follows. Choice of quality is:*

$$s_r^{b2}(x, \beta, \bar{s}) = \begin{cases} \frac{x(a + \theta - bx) + \beta}{c\kappa} & \text{for } \bar{s} \geq \tilde{s}^{b2} \\ \frac{2\bar{s}\beta}{2\beta - bx^2} & \text{for } \tilde{s}^{b2} < \bar{s} < \tilde{s}^{b2} \\ \frac{x(2(a + \theta) - bx)}{2c\kappa} & \text{for } \bar{s} \leq \tilde{s}^{b2} \end{cases}$$

for $\theta > bx - a$. For $\theta \leq bx - a$, it holds $s_r^{b2}(x, \beta, \bar{s}) = s_r^{b1}(\beta, \bar{s})$ of Lemma 5.5.1. Choice of fixed fees is:

$$\tilde{p}_r^{b2}(x, \beta, \bar{s}) = \begin{cases} \beta(s_r^{b2} - \bar{s}) & \text{for } \bar{s} \geq \tilde{s}^{b2} \\ CS(x, s_r^{b2}) & \text{for } \bar{s} < \tilde{s}^{b2} \end{cases}$$

if and only if $\theta > bx - a$ is satisfied. For $\theta \leq bx - a$, it holds $\tilde{p}_r^{b2}(x, \beta, \bar{s}) = \tilde{p}_r^{b1}(\beta, \bar{s})$ of Lemma 5.5.1.

Proof See Appendix C.2. ■

By Lemma 5.6.2, consumer surplus is strictly positive if and only if $\bar{s} > \max\{\tilde{s}^{b1}, \tilde{s}^{b2}\}$. In this case quality does not necessarily depend on the choice of \bar{s} . This shows that, similar to regime b1, the regulator can use \bar{s} as an instrument to vary fixed fee caps in order to split welfare between the firm and consumers without necessarily affecting total welfare.

For a given β and for strictly positive prices (i.e. $\theta > bx - a$) it holds $s_r^{b2} > s_r^{b1}$. This shows that the firm's quality choice is more sensitive to demand under regime b2 (quantity standards) in comparison to regime b1

(price standards) if demand shocks are high. The reason is that with regime $b2$ a higher quality can increase prices, revenues, and profits, which is not possible under regime $b1$ due to the fixed price standards. Observe that this relation does not depend on the level of price standards used under regime $b1$. No matter whether zero-price standards or positive price standards are chosen, an increase of quality cannot increase prices when there is a price standard.

Under regime $b2$ the regulator's choice of quantity standards and linear rewards is:

$$(x^{b2}, \beta^{b2}) := \arg \max_{x, \beta} E[W(x, s_r^{b2}(x, \beta))].$$

Since the firm's reactions are piecewise defined in θ , for further analysis we assume that demand shocks are uniformly distributed with support $[\underline{\theta}, \bar{\theta}] = [-\sqrt{3}\sigma^2, \sqrt{3}\sigma^2]$, the density of κ is $f(\kappa)$, and $a = b = c = 1$. Then expected welfare is

$$E[W(x, s_r^{b2}(x, \beta))] = \int_0^\infty \int_{-\sqrt{3}\sigma^2}^{\sqrt{3}\sigma^2} \left(\int_0^x \max\{0, s_r^{b2} \cdot (1 + \theta - y)\} dy - \frac{\kappa (s_r^{b2})^2}{2} \right) \frac{f(\kappa)}{2\sqrt{3}\sigma^2} d\theta d\kappa.$$

Positive consumer surplus requires a non-binding participation constraint. Therefore, assume that the regulator chooses \bar{s} such that $\bar{s} > \max\{\tilde{s}^{b1}, \tilde{s}^{b2}\}$ holds for all $\theta \in [\underline{\theta}, \bar{\theta}]$ and for all $\kappa > 0$.

Figure 5.3 depicts β^{b1} and β^{b2} as functions of $\sigma^2 \in [0, 1/3]$ showing that linear rewards are higher under regime $b1$ than under regime $b2$. The reason is that quantity standards increase quality under regime $b2$ because prices are variable and can become positive while under regime $b1$ prices are fixed. Therefore, β^{b2} can be reduced compared to β^{b1} without necessarily reducing quality.

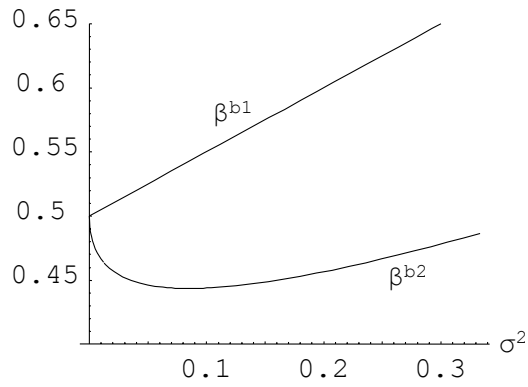


Figure 5.3: Linear quality rewards (β) under regimes $b1$ and $b2$ as functions of $\sigma^2 \in [0, 1/3]$.

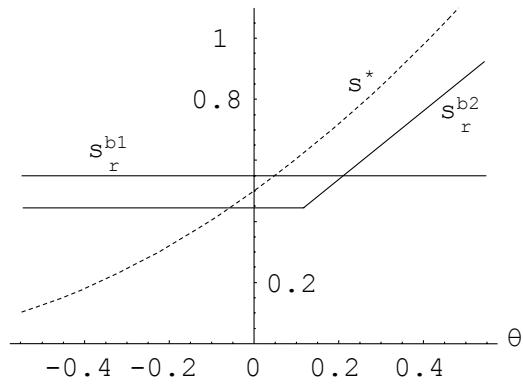


Figure 5.4: First-best quality and quality under regimes $b1$ and $b2$ depending on the realizations of θ ($\sigma^2 = 1/10, \phi = 1$).

Observe, that the linear rewards depicted in Figure 5.3 are general with regard to the distribution of κ , i.e. they hold for all $\phi \geq 1$. Thus, expected welfare must be higher under regime $b2$ than under regime $b1$. This is because the regulator could reach the same welfare results under regime $b2$ as under regime $b1$ by choosing $\beta^{b2} = \beta^{b1}$ and quantity such that prices are always 0, see Proposition 5.6.1. However, since, in fact, $\beta^{b2} < \beta^{b1}$ for all $\sigma^2 > 0$, regime $b2$ leads to better results in terms of expected welfare compared to regime $b1$.³

Figure 5.4 depicts quality choices s_r^{b2} , s_r^{b1} , as well as first-best quality s^* for $\sigma^2 = 1/10$ and $\phi = 1$. The figure shows that there is a close relationship between first-best quality s^* and quality under regime $b2$ compared to regime $b1$. Observe that quality reactions under regime $b2$ form a kink for strictly positive values of θ , since it holds $x^{b2} > E[x^*]$. This illustrates that it is useful to set quantity standards such that zero-prices are reached even if demand is somewhat higher than expected.

We can now summarize the comparison between all regulation regimes considered in this paper. When quality bonuses are chosen, expected welfare is higher with quantity standards (regime $b2$) than with zero-price standards (regime $b1$) for all $\sigma^2 > 0$ and all $\phi \geq 1$. Expected welfare under regime $b1$ is higher than under regime $s2$ (Proposition 5.5.2), which in turn is higher than under regime $s1$ (Proposition 5.4.1). Therefore, with regard to the choice of regimes we conclude that the regulator uses a combination of fixed fee caps, quantity standards, and quality bonuses, i.e. regime $b2$.

³Notice that we could verify the optimality of $p^{b1} = 0$ by investigation of plots for some specifications of our example.

5.7 Conclusions

It is well known that monopolies tend to produce a deadweight loss if they use linear tariffs. In contrast, with two-part tariffs their behavior regarding demand and quality choice is consistent with welfare maximization. This is because the firm fully internalizes welfare by fixed fees which, however, leaves no room for welfare gains to consumers. For this reason we analyze various regulation regimes that allow for welfare maximization and distribution.

The four regulation regimes considered are based on two-part tariffs. They combine fixed fee caps with (i) quantity and quality standards, (ii) price and quality standards, (iii) zero-price standards and quality bonuses, or (iv) quantity standards and quality bonuses. The bonuses are granted by linear rewards via relaxations of the fixed fee caps.

Regulators and firms are usually uncertain about actual market conditions at the time regulation policy is fixed. Assuming that firms learn about market conditions afterwards, they will maximize actual profits and welfare. Since regulation is chosen under uncertainty, it is likely to generate welfare losses. The question we address in this paper is how to design regulation regimes such that welfare losses are minimized.

We showed that there is a clear ranking of the regulation regimes considered. Comparing regimes that make exclusive use of standards to regulate demand and quality, i.e. regimes (i) and (ii), we showed that quantity standards are outperformed by price standards. Hence, once quality standards are chosen it is better to use price standards instead of quantity standards. Comparing regimes that use price standards in combination with quality standards or quality bonuses, i.e. regimes (ii) and (iii), we showed that quality standards are outperformed by quality bonuses. Hence, once price standards are chosen it is better to use quality bonuses instead of quality standards.

Finally, comparing regimes that make use of quality bonuses in combination with price or quantity standards, i.e. regimes (iii) and (iv), we showed that price standards are outperformed by quantity standards. Hence, once quality bonuses are chosen it is better to use quantity standards instead of price standards. Observe that the choice of quantity standards as instruments to regulate demand should depend on whether quality standards or quality bonuses are used.

It follows that the best results in terms of expected welfare are reached by a regulation regime that combines fixed fee caps and quantity standards with quality bonuses. This is because, first, bonuses are helpful for dealing with uncertainty about quality costs. Second, under demand uncertainty, standards on quantities allow for positive prices *sometimes* which enhances the firm's incentives to adjust quality towards the welfare optimal level.

A possible extension of the model would be to consider strategic interactions between the regulator and the firm with regard to the choice of technology. In fact, the firm might want to relax fixed fee caps by increasing costs. For instance, if fixed fee caps are set in a cost-plus fashion then the firm is likely to increase costs until the fixed fee cap equals consumer surplus. In order to avoid cost inefficiencies it might, therefore, be useful to determine the fixed fee cap for a certain period of time in advance, say five years. This would be similar to the way price-caps are set today and could enhance cost efficiency. The reason is that the firm could increase profits by reducing costs because fixed fee caps are not directly linked to costs. However, in contrast to a traditional price-cap regulation, quality is controlled by bonuses (or standards) and will not be negatively affected by regulation.

APPENDIX A

Proofs for chapter 2

A.1 Proof of Proposition 2.3.1

Reaction functions of airline 1 on directions $i \in \{1, \dots, n-1\}$ are

$$\begin{aligned} p_i^r(p_n) &:= \arg \max_{p_i} \hat{D}_i(p_i, p_n) \\ &= \begin{cases} \frac{1}{2} & \text{for } p_n \geq 1 - \sqrt{2} + a \\ \frac{1}{4}(1 + a - p_n) & \text{for } p_n \leq 1 - \sqrt{2} + a. \end{cases} \end{aligned} \quad (\text{A.1})$$

On directions $i \in \{1, \dots, n-1\}$ demand conditions are symmetric for airline 1. Reaction functions (A.1) demonstrate that it might be useful for airline 1 to charge fares that are below $p_i^I = 1/2$ in order to exploit demand from interline passengers. Notice, if this strategy is useful on any direction $i \in \{1, \dots, n-1\}$ then it will be useful on *all* those directions (due to symmetry). For that reason it is sufficient to depict reaction functions of airline 2 for symmetric fares $p := p_1 = \dots = p_{n-1}$ of airline 1 to identify the existing set of Nash equilibria. Noting that

$$\hat{D}_n(\underbrace{p, \dots, p}_{n-1}, p_n) = \max\{0, 1 - p_n\} + (n-1) \max\{0, a - p - p_n\}$$

it holds

$$\begin{aligned} p_n^r(p) &:= \arg \max_{p_n} \hat{D}_n(p, \dots, p_{n-1}, p_n) \\ &= \begin{cases} \frac{1}{2} & \text{for } p \geq a - \frac{1}{1 + \sqrt{n}} \\ \frac{1}{2n}(1 + (a - p)(n-1)) & \text{for } p \leq a - \frac{1}{1 + \sqrt{n}}. \end{cases} \end{aligned} \quad (\text{A.2})$$

Note that the reaction functions (A.1) and (A.2) are discontinuous (at the point of discontinuity, they are actually correspondences instead of functions). An intersection of the upper parts of the reaction functions, $p_i^r(p_n) =$

$1/2 \geq a - 1/(1 + \sqrt{n})$ and $p_n^r(p) = 1/2 \geq 1 - \sqrt{2} + a$ exists if and only if $a \leq \hat{a}$ and implies equilibrium $(p_1^{N1}, \dots, p_n^{N1})$. An intersection of the lower parts of the reaction functions, $p_i^r(p_n) = (1 + a - p_n)/4 \leq a - 1/(1 + \sqrt{n})$ and $p_n^r(p) = (1 + (a - p)(n - 1))/(2n) \leq 1 - \sqrt{2} + a$, exists if and only if $a \geq \tilde{a}$ and implies equilibrium $(p_1^{N2}, \dots, p_n^{N2})$. Finally, $p_i^r(p_n) = 1/2 \geq a - 1/(1 + \sqrt{n})$ and $p_n^r(1/2) = (1 + (a - 1/2)(n - 1))^2/(4n) \leq 1 - \sqrt{2} + a$ is a contradiction, as well as $p_i^r(1/2) = (1 + a - 1/2)/4 \leq a - 1/(1 + \sqrt{n})$ and $p_n^r(p) = 1/2 \geq 1 - \sqrt{2} + a$.

The Nash equilibrium $(p_1^{N2}, \dots, p_n^{N2})$ is Pareto-dominant for $a \in [\tilde{a}, \bar{a}]$ if and only if both airlines strictly prefer this equilibrium over $(p_1^{N1}, \dots, p_n^{N1})$. Now, recall that the number of interline passengers is 0 in equilibrium $N1$. Thus, starting from equilibrium $N2$ each airline can unilaterally realize profits as high as under equilibrium $N1$ by charging fares equal to $1/2$. However, $N2$ is a Nash-equilibrium where both airlines have a unique best response. Thus, both airlines are strictly better off in equilibrium $N2$ than in $N1$.

A.2 Proof of Proposition 2.3.3

Consider equilibrium $N1$ (which exists for $a \leq \bar{a}$ and is the unique equilibrium for $a < \tilde{a}$). Without code-share agreements interlining does not take place. Furthermore, fares on direct connections are equal to fares under code-share agreements with antitrust immunity. $\bar{W}^I > \bar{W}^{N1}$ follows.

Notice that, due to symmetry, we have in any equilibrium identical prices for $i = 1, \dots, n - 1$. Letting $p_i =: p$, $p_{i1} =: p_{.1}$, and $p_{i2} =: p_{.2}$ for $i = 1, \dots, n - 1$, then for $p \leq 1$ and $p_{.1} + p_{.2} \leq a$ the expression for \bar{W} simplifies to

$$\begin{aligned} \bar{W} &= \frac{1}{2n-1} \cdot \left((n-1) \left(\int_p^1 (1-y) dy + p(1-p) \right) \right. \\ &+ \int_{p_n}^1 (1-y) dy + p_n(1-p_n) \\ &+ \left. (n-1) \left(\int_{p_{.1}+p_{.2}}^a (a-y) dy + (p_{.1}+p_{.2})(1-p_{.1}-p_{.2}) \right) \right). \quad (\text{A.3}) \end{aligned}$$

Consider equilibrium $N2$ (which exists and is the relevant one for $a \geq \tilde{a}$). Using (A.3) one obtains:

$$\bar{W}^I = \frac{3(a^2(n-1) + n)}{16n-8} \text{ and } \bar{W}^{N2} =$$

$$\frac{2n^2(7+22n) + a^2(n-1)(5+n(19+32n)) - 12a(n-1)(1+n)^2 - 2(4+n)}{2(2n-1)(1+7n)^2}.$$

It is straightforward to show that $\bar{W}^{N2} > \bar{W}^I$ holds if and only if $a < \tilde{a}$ is satisfied. Moreover, $\tilde{a} < \tilde{\tilde{a}}$ holds if and only if $n \geq 32$. Therefore, if $n < 32$ or $n \geq 32$ and $a \geq \tilde{\tilde{a}}$ it follows $\bar{W}^I \geq \bar{W}^{N2}$.

A.3 Proof of Proposition 2.4.3

Consider equilibrium $N1$ (which exists for $a \leq \bar{a}$ and is the unique equilibrium for $a < \bar{a}$). Without code-share agreements interlining does not take place. Furthermore, fares on direct connections are equal to fares under code-share agreements without antitrust immunity. $\bar{W}^C > \bar{W}^{N1}$ for all $a \leq \bar{a}$ follows.

Consider equilibrium $N2$ (which exists and is the relevant one for $a \geq \tilde{a}$). Equation (A.3) leads to

$$\bar{W}^C = \frac{20 a^2 (n - 1) + 27 n}{72 (2 n - 1)}.$$

\bar{W}^{N2} is given in the proof of Proposition 2.3.3.

It is straightforward to show that $\bar{W}^{N2} > \bar{W}^C$ holds if and only if $a < \hat{a}$ is satisfied. One also checks that $\hat{a} > \tilde{a}$ always holds, and that $\hat{a} \leq 1 \Leftrightarrow n < 73$. Hence, the proposition follows.

APPENDIX B

Proofs for chapter 4

B.1 Proof of Proposition 4.6.1

Assume that both airports choose slot constraints as instruments. Airport profits are $q_i \tilde{P}_i(q_1, q_2)$ and reaction functions are $\arg \max_{q_i} E[q_i \tilde{P}_i(q_1, q_2)]$ with $E[q_i \tilde{P}_i(q_1, q_2)] = q_i(1 + \gamma q_j - 2q_i)$ and $j \neq i$. Calculation of reaction functions and fixed points leads to the unique Nash equilibrium with quantities $1/(4 - \gamma)$, leading to profits

$$\frac{2}{(\gamma - 4)^2}. \quad (\text{B.1})$$

Without loss of generality, assume that airport 1 chooses prices as instruments and airport 2 chooses slot constraints. Denote

$$\Psi := \ln \left(\frac{2 - \sqrt{3 \sigma_\kappa^2}}{2 + \sqrt{3 \sigma_\kappa^2}} \right)$$

implying $\Psi < 0$. Airport 1's profits are $p_1 \tilde{D}_1(p_1, q_2)$ and reaction functions are $\arg \max_{p_1} E[p_1 \tilde{D}_1(p_1, q_2)]$ with

$$E[p_1 \tilde{D}_1(p_1, q_2)] = -\frac{p_1 (q_2 \gamma + 1 - p_1) \Psi}{2 \sqrt{3 \sigma_\kappa^2}}.$$

The expression for $\tilde{D}_1(p_1, q_2)$ directly follows from (4.12).

Airport 2's profits are $q_2 \tilde{P}_2(p_1, q_2)$ and reaction functions are $\arg \max_{q_2} E[q_2 \tilde{P}_2(p_1, q_2)]$ with

$$E[q_2 \tilde{P}_2(p_1, q_2)] = q_2 \left(1 - 2q_2 - \frac{\gamma (q_2 \gamma + 1 - p_1) \Psi}{2 \sqrt{3 \sigma_\kappa^2}} \right).$$

The expression for $\tilde{P}_2(p_1, q_2)$ directly follows from (4.12) in combination with $\tilde{D}_1(p_1, q_2)$.

Calculation of reaction functions and fixed points leads to the unique Nash equilibrium with airport 1 choosing the price

$$\frac{2\sqrt{3}\sigma_{\kappa}^2(4+\gamma)+\gamma^2\Psi}{16\sqrt{3}\sigma_{\kappa}^2+3\gamma^2\Psi}$$

and airport 2 choosing the quantity

$$\frac{4\sqrt{3}\sigma_{\kappa}^2+\gamma\Psi}{16\sqrt{3}\sigma_{\kappa}^2+3\gamma^2\Psi}.$$

In equilibrium, airport 1's profits are

$$-\frac{\Psi\left(2\sqrt{3}\sigma_{\kappa}^2(4+\gamma)+\gamma^2\Psi\right)^2}{2\sqrt{3}\sigma_{\kappa}^2\left(16\sqrt{3}\sigma_{\kappa}^2+3\gamma^2\Psi\right)^2} \quad (\text{B.2})$$

with limit $\sigma_{\kappa}^2 \rightarrow 0$ equal to

$$\frac{(\gamma-4)^2(2+\gamma)^2}{2(16-3\gamma^2)^2}$$

and airport 2's profits are

$$\frac{576\sigma_{\kappa}^3+\gamma\Psi\left(12\sigma_{\kappa}(1-2\gamma)\gamma\Psi+\sqrt{3}\left(48\sigma_{\kappa}^2(\gamma-2)+\gamma^3\Psi^2\right)\right)}{6\sigma_{\kappa}\left(16\sqrt{3}\sigma_{\kappa}^2+3\gamma^2\Psi\right)^2} \quad (\text{B.3})$$

with limit $\sigma_{\kappa}^2 \rightarrow 0$ equal to

$$\frac{(4+\gamma)^2(4-\gamma^2)}{2(16-3\gamma^2)^2}.$$

Now we compare expected profits when instruments are chosen. If the other firm chooses the price as instrument, the expected profit with the price

as instrument is (4.20) and that with the quantity as instrument is (B.3). Inspections of plots for all possible combinations of $\gamma > 0$ and σ_κ^2 shows that (4.20) $>$ (B.3), hence prices are a better choice in this case. For the limiting case $\sigma_\kappa^2 \rightarrow 0$ this can be shown analytically.

If the other firm chooses the quantity as instrument, the expected profit with the price as instrument is (B.2) and that with the quantity as instrument is (B.1). Inspections of plots for all possible combinations of $\gamma > 0$ and σ_κ^2 shows that (B.2) $>$ (B.1), hence prices are a better choice in this case as well. For the limiting case $\sigma_\kappa^2 \rightarrow 0$ this can be shown analytically. It follows that for $\gamma > 0$ it is a dominant airport strategy to choose prices as instruments.

APPENDIX C

Proofs for chapter 5

C.1 Proof of Lemma 5.5.1

The firm will raise \tilde{p} until the fixed fee cap or the consumer's participation constraint binds.

Suppose that the firm sets \tilde{p} such that the fixed fee cap is binding, i.e. $\tilde{p} = \beta(s - \bar{s})$, and the participation constraint can be ignored. Then, maximizing profit, derived from (5.5), leads to

$$s_r^{b1}(\beta, \bar{s}) = \frac{\beta}{c\kappa}.$$

At this solution the fixed fee cap is binding if $CS(x, s_r^{b1}(\beta, \bar{s})) \geq \beta(s_r^{b1}(\beta, \bar{s}) - \bar{s})$ which is equivalent to $\bar{s} \geq \tilde{s}^{b1}$.

Suppose that the firm sets \tilde{p} such that the participation constraint is binding, i.e. $\tilde{p} = CS(x, s)$, and the fixed fee cap can be ignored. Then maximizing profit leads to

$$s_r^{b1}(\beta, \bar{s}) = \frac{(a + \theta)^2}{2bc\kappa}.$$

At this solution the participation constraint is binding if $CS(x, s_r^{b1}(\beta, \bar{s})) \leq \beta(s_r^{b1}(\beta, \bar{s}) - \bar{s})$ which is equivalent to $\bar{s} \leq \tilde{s}^{b1}$.

Notice that $\tilde{s}^{b1} < \tilde{\tilde{s}}^{b1}$ (unless $2b\beta = (a + \theta)^2$). Thus, if $\bar{s} \in (\tilde{s}^{b1}, \tilde{\tilde{s}}^{b1})$, then it is optimal to stay at the borderline between the other two cases, such that $CS(x, s_r^{b1}(\beta, \bar{s})) = \beta(s_r^{b1}(\beta, \bar{s}) - \bar{s})$. This is equivalent to

$$s_r^{b1}(\beta, \bar{s}) = \frac{2b\bar{s}\beta}{2b\beta - (a + \theta)^2}.$$

To summarize, if $\bar{s} \geq \tilde{\tilde{s}}^{b1}$, the firm chooses $s = \beta/c\kappa$ and $\tilde{p} = \beta(s - \bar{s})$. If $\bar{s} \leq \tilde{s}^{b1}$, the firm chooses $s = (a + \theta)^2/(2bc\kappa)$ and $\tilde{p} = CS(D(0, s), s)$. If

$\bar{s} \in (\tilde{s}^{b1}, \tilde{\tilde{s}}^{b1})$, then $s = (2b\bar{s}\beta)/(2b\beta - (a + \theta)^2)$ and $\tilde{p} = CS(D(0, s), s) = \beta(s - \bar{s})$.

C.2 Proof of Lemma 5.6.2

Prices are 0 for $\theta \leq bx - a$ and positive for $\theta > bx - a$. In the first case regime $b2$ is similar to regime $b1$ leading to $s_r^{b2} = s_r^{b1}$ and $\tilde{p}_r^{b2} = \tilde{p}_r^{b1}$.¹ We now focus on the second case where prices are positive.

Suppose that the firm sets \tilde{p} such that the fixed fee cap is binding, i.e. $\tilde{p} = \beta(s - \bar{s})$, and the participation constraint can be ignored. Then, maximizing profit (5.5) leads to

$$s_r^{b2}(x, \beta, \bar{s}) = \frac{x(a + \theta - bx) + \beta}{c\kappa}. \quad (\text{C.1})$$

At this solution the fixed fee cap is binding if $CS(x, s_r^{b2}(\beta, \bar{s})) \geq \beta(s_r^{b2}(\beta, \bar{s}) - \bar{s})$ which is equivalent to $\bar{s} \geq \tilde{\tilde{s}}^{b2}$.

Suppose that the firm sets \tilde{p} such that the participation constraint is binding, i.e. $\tilde{p} = CS(x, s)$, and the fixed fee cap can be ignored. Then, maximizing profit (5.5) leads to

$$s_r^{b2}(x, \beta, \bar{s}) = \frac{2\bar{s}\beta}{2\beta - bx^2}. \quad (\text{C.2})$$

At this solution the participation constraint is binding if $CS(x, s_r^{b2}(\beta, \bar{s})) \leq \beta(s_r^{b2}(\beta, \bar{s}) - \bar{s})$ which is equivalent to $\bar{s} \leq \tilde{\tilde{s}}^{b2}$.

¹Notice that at $\theta = bx - a$ all expressions in Lemma 5.6.2 are identical to those in Lemma 5.5.1.

Notice that $\tilde{s}^{b2} < \tilde{\tilde{s}}^{b2}$ (unless $2\beta = bx^2$). Thus, if $\bar{s} \in (\tilde{s}^{b2}, \tilde{\tilde{s}}^{b2})$, then it is optimal to stay at the borderline between the other two cases, such that $CS(x, s_r^{b2}(\beta, \bar{s})) = \beta (s_r^{b2}(\beta, \bar{s}) - \bar{s})$. This is equivalent to

$$s_r^{b2}(x, \beta, \bar{s}) = \frac{2\bar{s}\beta}{2\beta - bx^2}. \quad (\text{C.3})$$

To summarize, if $\bar{s} \geq \tilde{\tilde{s}}^{b2}$, the firm chooses $s = (x(a + \theta - bx) + \beta)/(c\kappa)$ and $\tilde{p} = \beta(s - \bar{s})$. If $\bar{s} \leq \tilde{s}^{b1}$, the firm chooses $s = 2\bar{s}\beta/(2\beta - bx^2)$ and $\tilde{p} = CS(x, s)$. If $\bar{s} \in (\tilde{s}^{b2}, \tilde{\tilde{s}}^{b2})$, then $s = 2\bar{s}\beta/(2\beta - bx^2)$ and $\tilde{p} = CS(x, s) = \beta(s - \bar{s})$.

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