Essays in Transport Economics and Operations Management

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Abstract

This dissertation studies three topics in transport economics and operations management. The first topic is on the economic regulation of congested airports. The second one is revenue sharing between airlines and airports. In the third topic, we investigate the impact of strategic customer behavior on the channel profits.

Chapter 2 studies the effects of concession revenue sharing between an airport and its airlines. It is found that the degree of revenue sharing will be affected by how airlines' services are related to each other (complements, independent, or substitutes). It is further found that airport competition results in a higher degree of revenue sharing than in the case of single airports. The airport-airline chains may nevertheless derive lower profits through the revenue-sharing rivalry, and the situation is similar to the Prisoner's Dilemma. As the chains move further away from their joint profit maximum, welfare rises beyond the level achievable by single airports. The (equilibrium) revenue-sharing proportion at an airport is also shown to decrease in the number of its carriers, and to increase in the number of carriers at the competing airport.

Chapter 3 considers price-cap regulation of an airport where the airport facility (e.g., its runway) is congested and air carriers have market power. In the case of airports, there are two versions of price-cap regulation: the single-till approach and the dual-till approach. We show that when airport congestion is not a major problem, single-till price-cap regulation dominates dual-till price-cap regulation with respect to social welfare. Furthermore, we identify situations where dual-till regulation performs better than single-till regulation when there is significant airport congestion. For instance, when the airport can cover the airport costs associated with aeronautical services simply through an efficient aeronautical charge, then dual-till regulation yields higher welfare.

Chapter 4 investigates the impact of customer and firm discounting as well as

downstream retailer competition on the benefit of decentralization when customers are strategic. We consider a dynamic two-period model consisting of one manufacturer who sells a product through multiple retailers under linear wholesale price contracts. No firm can credibly commit to future prices or quantities. Customers are strategic in the sense that they compare current surplus with future surplus, and choose the timing of their purchases to maximize the present value of their payoffs. With strategic customers, we find that a decentralized channel may have higher profit than that of a centralized channel. We show that in addition to the double marginalization effect, both customer and firm discounting and retailer competition are also driving factors of the higher decentralized channel profit.

Preface

This preface provides a statement of co-authorship for the work contained in this thesis.

The work in Chapter 2 was undertaken collaboratively with Profs. Anming Zhang and Xiaowen Fu. A version of the chapter has been published in the September-November 2010 issue (Volume 44, Issues 8-9) of the *Transportation Research Part B (Methodological)* on pages 944-959. Profs. Anming Zhang and Xiaowen Fu initiated the research project, and invited me to join them. Many results were derived in a series of weekly discussions with Prof. Anming Zhang. I derived and prepared most results in Sections 3 and 4 of the manuscript, that is, sections on "competing airports" and "pure revenue-sharing contract".

The work found in Chapter 3 was identified by myself, and the research project was undertaken with Prof. Anming Zhang. A version of this chapter has been recently accepted by the *Journal of Regulatory Economics*. I came up with the initial ideas and identified the research questions through many discussions with Prof. Anming Zhang. I derived all the main results and wrote most of the manuscript. Prof. Anming Zhang edited the manuscript and the response letters to the journal editor and the reviewers.

The work found in Chapter 4 was done entirely on my own. A version of the chapter was prepared by myself and submitted for publication. Many people gave me comments and suggestions on the paper, including my supervisors: Profs. Maurice Queyranne and Anming Zhang.

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My special and sincere thanks go to my loving family. I would like to thank my parents for their belief in me and their love in my whole life. To my beautiful wife, Liujing, I want to thank her for her love and support. Life is so colorful with her and my lovely daughter, Sophie. I also want to thank my parents-in-law for their help in raising my daughter.

Dedication

To my beautiful wife, Liujing, and my lovely daughter, Sophie.

Chapter 1

Introduction

Traditional aeronautical operations used to be the dominant income source for airports. However, a modem airport derives revenues from two facets of its business: the traditional aeronautical operation and the commercial (concession) operation. The former refers to aeronautical activities associated with runways, aircraft parking and terminals, whereas the latter refers to non-aeronautical activities that occur within terminals and on airport land, including terminal concession (e.g. duty-free shops, restaurants, etc.), car rental and car parking. For the last two decades, commercial revenues have grown faster than aeronautical revenues. As a result, the non-aeronautical revenues have become the main income source of many airports. For example, at medium to large U.S. airports, commercial revenues consist of 75%-80% of the total airport revenue (Doganis, 1992).

Given the fact that the demand for concession activities is mainly from passengers, airports have incentives to induce airlines to lower ticket prices. Lower ticket prices will help airlines attract more passengers; this in turn will increase concession activities at airports. Airlines may not necessarily be better off by just reducing the ticket prices. The passengers volume will be higher but the per-passenger profit will be lower. In order to give airlines the right incentive to lower the ticket prices, airports share concession revenues with airlines. Revenue sharing between airports and airlines is getting popular in practice. For instance, Tampa International Airport in the U.S. has been sharing revenue with its airlines since 2000. As of 2006, it shared 20% of its net revenue with signatory airlines of the airport. (Fu and Zhang, 2010). This phenomenon motivates us to investigate the effects of concession revenue sharing between airports and airlines.

The research project is presented in Chapter 2. We find that the degree of revenue sharing will be affected by how airlines' services are related to each other (complements, independent, or substitutes).[1] Roughly speaking, in equilibrium, the degree of revenue sharing, i.e., the sharing proportion, decreases as the competition among airlines' services increases. In particular, when carriers provide strongly substitutable services to each other, the airport has an incentive to charge airlines, rather than to pay airlines, a share of concession revenue. In these situations, while revenue sharing improves profit, it reduces social welfare.

It is further found that airport competition results in a higher degree of revenue sharing than in the case of single airports. The airport-airline chains may nevertheless derive lower profits through revenue-sharing rivalry, and the situation is similar to the Prisoner's Dilemma. As the chains move further away from their joint profit maximum, welfare rises beyond the level achievable by single airports. The (equilibrium) revenue-sharing proportion at an airport is also shown to decrease in the number of its carriers, and to increase in the number of carriers at competing airports. Finally, the effects of a 'pure' sharing contract are compared to those of two-part sharing contract. It is found that whether an airport is subject to competition is critical to the welfare consequences of alternative revenue sharing arrangements.

Airports have traditionally been owned and managed by governments. Starting with the privatization of airports in the UK in the late 1980s, more and more airports have been privatized or partially privatized around the world, including in Europe, Australia and New Zealand. Asia, South America and Africa are also in the process of privatizing their airports (e.g. Oum et al., 2004; Winston and de Rus, 2008). As the ownership of airports changes from public to private, the objective of airports will likely become profit maximization instead of social welfare maximization. Price regulations may thus be needed.

In the case of airports, there are two main types of price regulation, namely, price-cap regulation and rate-of-return regulation. As the name suggests, price-cap regulation puts an upper bound on the price that a regulated firm can charge. Since

[1] For example, there is no direct flight from Vancouver to Austin. However, the Vancouver-Denver-Austin route can be purchased directly from Air Canada's website. Air Canada operates the Vancouver-Denver route, and United Airlines operates the Denver-Austin route. In this case, Air Canada and United Airlines provide *complementary* services at the Denver airport. If airlines provide services on the same route, then their services are *substitutable*. If airlines' flights are not related to each other, then they provide *independent* services.

price-cap regulation gives firms incentives to be cost efficient, it is often referred to as "incentive regulation". Under rate-of-return regulation, the regulated firm is allowed to charge the price that would prevail in a competitive market, which is equal to the efficient cost of production plus a market-determined rate of return on capital. The cost-based nature of rate-of-return regulation suggests that firms will not benefit from cost reduction, which is the major critique of rate-of-return regulation (Averch and Johnson, 1962).

For airports, there are two versions of price-cap regulation: the single-till approach and the dual-till approach. The distinction between the two approaches has again to do with the fact that an airport derives revenues from two facets of its business: the traditional aeronautical operations and the commercial operations. Many papers have compared the relative merits of the single-till and dual-till price-cap regulations, but there have been only a few theoretical studies on this on-going debate.[2] This motivates us to compare the single-till and dual-till schemes.

The work is presented in Chapter 3. Our main objective is to contribute to a better understanding of airport regulation by comparing single-till and dual-till price-cap regulations. We study price-cap regulation of an airport where the airport facility (e.g., its runway) is congested and air carriers have market power. We have extended Czerny (2006)'s work by introducing congestion delays and oligopoly airlines at an airport. We have shown that when airport congestion is not a major problem, single-till price-cap regulation dominates dual-till price-cap regulation with respect to social welfare. Furthermore, we identify situations where dual-till regulation performs better than single-till regulation when airport congestion is a significant problem. For instance, if the airport can, with only the efficient aeronautical charge, cover the airport cost associated with aeronautical services, then dual-till regulation yields higher welfare than single-till regulation.

In Chapter 4, we consider a different topic. We investigate the impact of customer and firm discounting as well as retailer competition on the benefits of decentralization when customers are strategic. Accustomed to frequent sales and promotions, many consumers will wait for better prices even if their willingness-to-pay is higher

[2]To the best of our knowledge, Czerny (2006) and Crew and Kleindorfer (2000) are the only analytical papers that show that the single-till approach is socially more desirable than the dual-till scheme. Although several other studies, e.g. Lu and Pagliari (2004), intuitively argue that single-till regulation performs better than dual-till regulation at non-congested airports while dual-till regulation dominates at congested airports, they do not show the results analytically.

than the current retail price. Strategic or forward-looking customers anticipate future price reductions, and optimize their purchase timing to maximize their expected payoffs. There is much evidence of strategic customer behavior in practice. For example, the Wall Street Journal (McWilliams, 2004) reported that Best Buy found that around 20% of its customers were not profitable, and labeled them as "devils". Due to these customers' behavior of waiting for sales, applying for refunds and rebates, etc., they represent a loss in profit for Best Buy. Melnikov (2001) provides evidence from the US printer market that supports the hypothesis of forward-looking behavior among customers. The author finds that customer discounting has a significant impact on demand. Song and Chintagunta (2003) show that empirical data from the digital camera category are consistent with the presence of strategic customer behavior. In the video-game industry, Nair (2007) finds similar evidence of consumer forward-looking behavior. In that study, simulations reveal a profit loss of nearly 30% when strategic customer behavior is ignored, and demonstrate that increased information about consumer discounting is valuable. Even in the specialized market of college textbooks, Chevalier and Goolsbee (2005) find strong evidence that students are strategic and have rational expectations of publishers' revision behavior.

The existing literature on strategic customer behavior finds that the profit of a decentralized channel can be higher than that of a centralized channel. Double marginalization is identified as the key driving force, e.g. Arya and Mittendorf (2006), Desai et al. (2004), Su and Zhang (2008). None of them considers downstream retailer competition. Customer and firm discounting is not a major feature in their models.[3] In practice, however, customers and firms often discount their future payoffs. Competition among retailers is commonplace. Therefore, we want to investigate the impact of discounting and retailer competition on the benefit of decentralization with strategic customers.

Although the marketing, economics and operations management literature on strategic customer behavior is rich, few articles examine strategic customer behavior in a decentralized channel, especially with downstream retailer competition. We develop a dynamic two-period model consisting of one manufacturer who sells a

[3] Arya and Mittendorf (2006), and Su and Zhang (2008) assume no customer and firm discounting, and claim that adding customer and firm discounting will not alter their conclusion, which is easily verified. Desai et al. (2004) assume a common discount factor for both customers and firms. It is not difficult to verify that considering different customer and firm discount factors will not affect their main results.

product through multiple retailers under linear wholesale price contracts. No firm can credibly commit to future prices or quantities. Customers are strategic in the sense that they compare current surplus with future surplus, and choose the timing of their purchases to maximize the present value of their payoffs. With strategic customers, we find that a decentralized channel may have higher profit than that of a centralized channel. We show that in addition to the double marginalization effect, both customer and firm discounting and retailer competition are also driving factors for higher decentralized channel profit.

The dissertation is organized as follows. Chapter 2 investigates revenue sharing between airlines and airports. Chapter 3 considers price-cap regulation of congested airports. Chapter 4 studies the impact of discounting and competition on the benefit of decentralization with strategic customers. Chapter 5 summarizes the dissertation, outlines our related on-going research, and discusses future research directions.

Chapter 2

Revenue Sharing with Multiple Airlines and Airports [1]

2.1 Introduction

An airport derives revenue from two facets of its business: the traditional aeronautical operations and the commercial (concession) operations. The former refer to aviation activities associated with runways, aircraft parking and terminals, whereas the latter refer to non-aeronautical activities occurring within terminals and on airport land, including terminal concessions (duty-free shops, restaurants, etc.), car rental and car parking. For the last two decades, commercial revenues have grown faster than aeronautical revenues and, as a result, have become the main income source of many airports. At medium to large US airports, for instance, commercial business represents 75-80% of the total airport revenue (Doganis, 1992). ATRS (2008) studied 142 airports worldwide and found a majority of these airports derived 40-75% of their revenues from non-aviation services, a major part of which is revenue from concession services (with large hub airports relying, on average, even more on

[1] A version of the chapter has been published in the September-November 2010 issue (Volume 44, Issues 8-9) of the *Transportation Research Part B (Methodological)* on pages 944-959. We are very grateful to two anonymous referees for their helpful comments. We also thank Mikio Takebayashi and seminar participants at Kyoto University, Technical University of Berlin and Chinese University of Hong Kong for helpful comments. Financial support from the Social Science and Humanities Research Council of Canada (SSHRC), Hong Kong RGC Grant (RGC-PolyU5412/07H), HKPOLYU CRG Grant G-YG09 and the Li and Fung Institute for Supply Chain Management and Logistics at Chinese University of Hong Kong are gratefully acknowledged.

concession income). Further, commercial operations tend to be more profitable than aeronautical operations (e.g. Jones et al., 1993; Starkie, 2001; Francis et al., 2004), owing in part to prevailing regulations and charging mechanisms (e.g. Starkie, 2001).

Paralleling the growth of concession revenues, revenue sharing between airports and airlines is getting popular in practice. As documented in Fu and Zhang (2010), there are cases, such as Tampa International Airport in the US and Ryanair in Europe, where airports and airlines share concession revenues.[2] In many other cases, revenue sharing is in effect when airports allow airlines to hold shares or control airport facilities. For example, Terminal 2 of Munich airport was jointly invested by the airport operating company FMG (60%) and the airport's dominant carrier, Lufthansa (40%) (Kuchinke and Sickmann, 2005). Commercial profits generated from this terminal are thus shared between FMG and Lufthansa. Fu and Zhang (2010) found that concession revenue sharing has important competitive and welfare implications: it allows the airport and airlines to internalize a multi-output complementarity between the passenger flights and the concession consumption brought about by the flights, which may improve social welfare. Essentially, passengers traveling through the airport also create a demand for concession consumption. As an airport depends on airlines to bring in passengers, concession revenue sharing will encourage the carriers to expand output, which may in turn improve profit for the whole airport-airlines chain (as well as improve welfare). However, revenue sharing can cause a negative effect on airline competition as an airport may strategically share revenue with its dominant carriers, further strengthening these airlines' market power. The US Federal Aviation Administration (FAA) has expressed concerns over airports' practice of offering particular airlines favorable terms, on the ground that such a special treatment may harm competition in the airline market downstream (FAA, 1999).[3] Since 1995, the EU's competition authorities have ruled against several major airports in

[2]Tampa has been sharing revenue with its carriers for several years. In 2004, it shared $7 million out of a total budget of $30 million (see the 2004 Annual Report of Tampa International Airport). On the other hand, Ryanair has identified airport car parking as one of its business opportunities and cooperated with the leading airport parking company BCP. In its negotiations with some airports, Ryanair asked for parking revenue sharing as a condition to serve the airports.

[3]Previous studies (e.g. FAA, 1999; GAO, 1997; Dresner et al., 2002; see also Hartmann, 2006, for a useful review on the topic) suggest that airline entry may be deterred if the dominant airline controls key airport facilities. Apparently, such a strategy by the dominant carrier would require at least implicit consent/cooperation from the airport. In the US, large and medium airports that meet a certain threshold of airline concentration are now required to submit competition plans as mandated by the 'Wendell H. Ford Aviation Investment and Reform Act for the 21st Century' legislated in 2000.

Belgium, Finland and Portugal concerning their practices of charging lower prices to home carriers (Barbot, 2006, 2009a).

For the last several years, the effects of vertical relationships between airports and airlines have received growing attention from researchers. In addition to Fu and Zhang (2010), Auerbach and Koch (2007) and Barbot (2009a,b) found that cooperation between an airport and its airlines can bring benefits to the alliance members in terms of increased traffic volume and operation efficiency. In this paper we extend this literature on airport-airline vertical cooperation, focusing on the effects of concession revenue sharing. More specifically, we consider that carriers may provide complementary, independent or substitutable services to each other, and that the proportions of revenue sharing may be outside of the $[0, 1]$ range. The latter allows us to compare alternative sharing arrangements. Further, unlike the previous studies, our analysis is mostly conducted under general demand and cost functional forms. Moreover, as elaborated below, our work also extends the existing literature to the general case of multiple competing airports with each having an arbitrary number of carriers.

We find that the degree of revenue sharing will be affected by how airlines' services are related to each other. In particular, when carriers provide substitutable services to each other, they might need to pay to the airport a share of concession revenue (so-called the 'negative sharing') if substitutability is sufficiently strong and the fixed (transfer) payments between the airport and carriers are feasible (referred to as the 'two-part revenue sharing'). The negative sharing allows the airport to penalize the over-competing carriers so as to support airfares downstream and improve profit. In these situations, while revenue sharing improves total airport-airlines channel profit, it reduces social welfare. If the fixed payments are not feasible, under the resulting 'pure revenue sharing' the airport will, for the cases of independent or complementary services, share less concession revenue with its carriers than would be under the two-part revenue sharing. For the substitutes case, however, the sharing-proportions comparison between the two types is in general ambiguous. In the special case of negative sharing, the pure revenue sharing will, for sufficiently symmetric carriers, result in not only a higher sharing proportion, but also a higher welfare level, than the two-part revenue sharing.

Our second objective in this paper is to extend the airport literature by investigating revenue sharing for multiple, competing airports. Very few papers have examined competing airports analytically. For example, Fu and Zhang (2010) ex-

amined revenue sharing only for a monopoly airport. The few exceptions include Gillen and Morrison (2003), who examined two competing airports in the context of a full-service carrier and a low-cost carrier. More recently, Basso and Zhang (2007) provided a more general examination of airport competition with congestion and non-atomistic airlines at each airport, and Barbot (2009a) examined airport-airline interactions (collusion, in particular) using a spatial model similar to that of Basso and Zhang. The issues of concession revenues and revenue sharing were not considered in these papers, however.

This lack of analytical studies on airport competition is understandable given the local monopoly nature of an airport. The situation is changing, however. The world has experienced a rapid growth in air transport demand since the 1970s, and many airports have been built or expanded as a result. This has led to a number of multi-airport regions such as greater London in the UK and several metropolitan areas in the US (e.g. San Francisco, Chicago, New York, Washington, Dallas, Detroit, Houston, and Los Angeles) within which airports may compete with each other. At the same time, the dramatic growth of low-cost carriers (e.g. Southwest in the US and Ryanair in Europe) has enabled some smaller and peripheral airports to cut into the catchment areas of large airports. Starkie (2008) conducted an overview of UK airports from the perspective of a business enterprise. He concluded that effective competition across airports is possible and a competitive airport industry can be financially viable. Taken together, these observations suggest that it is important to investigate the effects of revenue sharing in the context of multiple, competing airports.

We find that airport competition will result in a higher degree of revenue sharing than would be had in the case of single airports. Nevertheless, the airport-airline chains may derive lower profits through this revenue-sharing rivalry. As the airport-airline chains move further away from their joint profit maximum, social welfare rises beyond the level achievable by single airports. Our analysis also shows that the airline market structure can have a bearing on revenue sharing arrangements not only at the airport in question, but also at its competing airports. Specifically, the (equilibrium) revenue-sharing proportion at an airport decreases in the number of its carriers, but increases in the number of carriers at the competing airport. In terms of the welfare consequences of alternative revenue sharing arrangements, whether an airport is subject to competition is critical: for competing airports, ‘no sharing’ is worse than ‘pure sharing’ which is in turn worse than the two-part sharing. For single

airports however, both no-sharing and pure-sharing might be better than the two-part sharing when airlines provide substitutable services to each other.

The paper is organized as follows. Section 2.2 sets out the basic model and examines the revenue-sharing equilibrium for a single airport with multiple airlines. Section 2.3 examines revenue sharing for the general case of competing airports with each having an arbitrary number of carriers. Section 2.4 investigates the pure revenue sharing and compares its effects with those of the two-part revenue sharing. Section 2.5 contains concluding remarks.

2.2 Single airport with multiple airlines

2.2.1 Basic model

Consider, in this section, that a single airport provides aeronautical service to airlines, for which it imposes a charge. In our modeling this charge is represented by a per-passenger fee $w(>0)$, and is regulated and cannot be changed unilaterally by either the airport or airlines.[4] We have two carriers, labeled as $i = 1,2$, operating from the airport, although the analysis and results extend immediately to the n-carrier case (see, e.g., Section 2.3.2). They face inverse demands $p^i(q_1,q_2)$, which satisfy the usual properties of $p^i_i < 0$ and $p^1_1 p^2_2 - p^1_2 p^2_1 > 0$ with subscripts denoting partial derivatives.[5] The airlines' revenue from providing aviation service is then given by $R^i(q_1,q_2) = p^i(q_1,q_2)q_i$.

The revenue functions can be used to define how one airline's output is related to the other's. There are three possible cases:

(i) *Complements*: two carriers offer complementary services in the sense that

$$R^i_j(q_1,q_2) = p^i_j(q_1,q_2)q_i > 0, \qquad R^i_{ij} > 0. \tag{2.1}$$

That is, increasing carrier j's output increases both the total and marginal revenues of carrier i (here, and below, if the indices i and j appear in the same

[4]Since price discrimination (on aeronautical charges) by an airport is prohibited by the International Air Transport Association (IATA) rules, all airlines serving the airport face the same w.

[5]While $p^i_i < 0$ indicates the usual property of downward-sloping demands, $p^1_1 p^2_2 - p^1_2 p^2_1 > 0$ refers to the property of 'own effects' dominating 'cross effects' in demand functions. As noted by Dixit (1986, p. 108), the dominance of own-effects over cross-effects is a standard assumption in models of oligopoly.

expression, then it is to be understood that $i \neq j$).[6] In the present context, services provided by a trunk airline and a feeder airline – with their passengers connecting at the airport – may be considered as complements. Another example would be that two airlines engage in some form of strategic alliances or code-sharing arrangements (e.g. Brueckner, 2001; Brueckner and Whalen, 2000).

(ii) *Independent services*: two carriers' services are unrelated in demand as

$$R^i_j(q_1, q_2) = p^i_j(q_1, q_2)q_i = 0. \tag{2.2}$$

Note, in this case, that $R^i_j = 0$ implies $R^i_{ij} = 0$.

(iii) *Substitutes*: raising a carrier's output reduces the other's total and marginal revenues,

$$R^i_j(q_1, q_2) = p^i_j(q_1, q_2)q_i < 0, \qquad R^i_{ij} < 0. \tag{2.3}$$

For instance, two competing trunk carriers likely provide substitutes at an airport, and so do two competing feeder carriers.

We consider that for each passenger going through the airport, a concession revenue $h(> 0)$ is derived. Assuming further (for simplicity) zero costs for providing concession services by the airport, then h represents a net surplus per passenger.[7] How total concession revenue hq_i is shared between the airport and airlines is modeled as a two-stage game. In the first stage, the airport offers carrier i to share proportion r_i of revenue hq_i in exchange for a fixed fee f_i, subject to the carrier's participation constraint. No restriction is imposed on r_i, and so r_i can be less than zero or

[6]The first inequality in (2.1) shows (gross) complements between the airline services, whereas the second inequality implies 'strategic complements' (Bulow et al., 1985). That the former implies the latter holds for most (but not all) plausible demand structures; it certainly holds when demand functions are linear. In other words, the fact that services are complements is conducive to their strategic complementarity. Restricting attention to strategic complementarity is a standard practice in oligopoly models (Dixit, 1986; Tirole, 1988). Similar observations on 'substitutes' and 'strategic substitutes' hold for the substitutes case discussed next. We shall, as is common in the literature, refer to these two cases simply as 'complements' and 'substitutes.'

[7]This formulation of concession surplus has been used in, e.g., Zhang and Zhang (1997, 2003); Oum et al. (2004) and Fu and Zhang (2010). It is, nevertheless, a simple representation where concession surplus is strictly complementary to passenger volume. For an alternative and perhaps more realistic formulation, see Czerny (2006).

greater than one. In the second stage, airlines choose quantities to maximize individual profits.[8] The subgame perfect equilibrium of this two-stage game is referred to as the 'revenue sharing equilibrium'.

Prior to examination of the revenue-sharing equilibrium, two things about the sharing contract $(r_i, f_i), i = 1, 2$, are worth noting. First, assuming that airline i gets a share of revenue hq_i means that the airport is able to know who is flying in which airline. This can happen after boarding, as passengers may present their boarding cards, but not necessarily before boarding. Second, the contract being a pair (r_i, f_i) suggests a 'two part' revenue-sharing scheme under which fixed payments are possible. Such a model can be used to examine the incentive for vertical airport-airline cooperation – i.e. taking account of the profit for the airport-airline channel as a whole - and may also be consistent with situations in which airports and airlines can commit to medium-/long-term cooperation. Nonetheless, such fixed payments between airports and airlines might not be feasible in certain situations, owing to the difficulty in their agreeing to the right amount of payments, or to the preference for simpler revenue-sharing arrangements that do not involve any medium-/long-term commitment. In Section 2.4, we will examine a 'pure' sharing contract that restricts fixed payments f_i to zero.

2.2.2 Revenue-sharing equilibrium

The revenue-sharing equilibrium is solved in the standard backward induction.

Stage two: Given sharing contract (r_i, f_i), each carrier's profit is:

$$\pi^i(q_1, q_2) = R^i(q_1, q_2) - C_i(q_i) - wq_i + r_i hq_i - f_i, \tag{2.4}$$

where $C_i(q_i)$ denotes carrier i's production cost. Thus for carrier i, the total operating cost net of fixed payment f_i equals $C_i(q_i) + wq_i$. The Cournot-Nash equilibrium is characterized by the first-order conditions,

$$\pi_i^i(q_1, q_2) = R_i^i(q_1, q_2) - C_i^{'}(q_i) - w + r_i h = 0, \tag{2.5}$$

[8]This implies carriers interact with each other in Cournot fashion. Recent studies on airport pricing and capacity investment that have incorporated imperfect competition of air carriers at an airport (e.g. Brueckner, 2002; Pels and Verhoef, 2004; Zhang and Zhang, 2006; Basso, 2008) have assumed Cournot behavior. Brander and Zhang (1990, 1993), for example, find some empirical evidence that rivalry between duopoly airlines is consistent with Cournot behavior.

and the second-order conditions $\pi^i_{ii}(q_1,q_2) = R^i_{ii}(q_1,q_2) - C''_i(q_i) < 0$. Both the second-order conditions and the stability condition, $J \equiv \pi^1_{11}\pi^2_{22} - \pi^1_{12}\pi^2_{21} > 0$, are assumed to hold over the entire region of interest.[9]

The solution to (2.5) yields the second-stage equilibrium quantities, which are functions of the first-stage variables (r_1, r_2). Since fixed payments f_1 and f_2 enter the airlines' profit functions (2.4) as constants, they will not affect the equilibrium quantities. Denoting the equilibrium quantities as $q^*_i(r_1,r_2)$, substituting them into (2.5) and totally differentiating the resulting identity with respect to r_i, we obtain

$$\frac{\partial q^*_i}{\partial r_i} = -\frac{h\pi^j_{jj}}{J}, \qquad \frac{\partial q^*_j}{\partial r_i} = \frac{h\pi^j_{ji}}{J}. \tag{2.6}$$

It follows immediately that $\partial q^*_i/\partial r_i > 0$, while $\partial q^*_j/\partial r_i$ having the same sign as $\pi^i_{ji} = R^i_{ji}$, which by (2.1)–(2.3) leads to:

Lemma 2.1 *(i) $\partial q^*_i/\partial r_i > 0$ and (ii) $\partial q^*_j/\partial r_i > 0, = 0$, and < 0 for carriers' producing complements, independent services, and substitutes, respectively.*

Thus an increase in the share of concession revenue to carrier i increases i's output. The reason is that an increase in r_i will improve carrier i's marginal profitability, owing to the multi-output complementarity between passenger flights and concession consumption. Furthermore, an increase in r_i increases, not affects, and decreases carrier j's output if the carriers offer complementary, independent, and substitutable services, respectively. For the case of substitutes, since that ensures a downward-sloping 'best reply function' for each carrier (defined by (2.5) in the output space), an increase in r_i will, by increasing carrier i's marginal profit, shift its best-reply function outward. This will move the equilibrium quantities downward along j's best-reply function, thereby increasing q^*_i and decreasing q^*_j. For complements, on the other hand, that ensures an upward-sloping best-reply function for each carrier. An increase in r_i will again shift i's best-reply function outward, moving the equilibrium quantities upward along j's best-reply function, thereby increasing both q^*_i and q^*_j. Finally, if the services are independent, then an increase in r_i does not affect q^*_j, as expected.

[9] This assumption implies that the Cournot equilibrium exists and is unique (e.g. Friedman, 1997). Note that if carriers face linear demands, then all these conditions will be satisfied.

Stage one: revenue-sharing structures therefore influence subsequent airline quantities, which in turn will affect the airport's profit. Assume, for simplicity, that the airport's fixed cost is zero and its marginal cost is constant and normalized to zero. The airport's profit is then given by:

$$\Pi = w \cdot (q_1^* + q_2^*) + [(1 - r_1)hq_1^* + (1 - r_2)hq_2^*] + f_1 + f_2, \tag{2.7}$$

where the second-stage equilibrium outputs are taken into account. (Throughout the paper, we use capital letter Π to denote airport profit, while lower case π denoting airline profit.) There are three components in Π: (i) the aeronautical revenue (profit) given by $w \cdot (q_1^* + q_2^*)$; (ii) the residual concession revenue given by the bracketed term in (2.7); and (iii) the fixed payment collected from carriers, $f_1 + f_2$.

The airport chooses (r_i, f_i), $i = 1, 2$, to maximize Π. While f_i will not, as indicated above, affect the second-stage equilibrium outputs, $\partial \Pi / \partial f_i = 1$ by (2.7). Consequently, the airport should, given its Stackelberg leader's role, charge the airlines a fee as high as possible subject to their participation constraints $\pi^i \geq \pi_0^i$, with π_0^i being carrier i's reservation profit. Assume, without loss of generality, that each carrier receives its reservation profit.[10] This participation constraint implies, using (2.4), that

$$f_i = R^i(q_1^*, q_2^*) - C_i(q_i^*) - wq_i^* + r_i hq_i^* - \pi_0^i, \qquad i = 1, 2, \tag{2.8}$$

where equilibrium outputs q_i^* are functions of r_1 and r_2. With (2.8), airport profit (2.7) becomes:

$$\Pi(r_1, r_2) = \sum_i [R^i(q_1^*, q_2^*) - C_i(q_i^*) + hq_i^* - \pi_0^i] \equiv v(q_1^*(r_1, r_2), q_2^*(r_1, r_2)). \tag{2.9}$$

[10]The assumption that the airport chooses the fees as high as possible subject to carriers' participation constraints implies that all the benefits from improvements in performance go to the airport. This is due to our airport-airlines relationship with the airport being a Stackelberg leader. Such a 'vertical structure' has been a standard set-up in the recent literature on airport pricing and capacity investment that incorporates imperfect competition of airlines at an airport (see, e.g., Basso and Zhang, 2008, for a survey). As pointed out by an anonymous referee, Bowley (1928) has this idea (not the expression) for a two firms' game in a vertical context (with one buyer and one seller, when the seller has more market power). In the present context, maybe a single airport ('monopolist') fits the set-up better than multiple airports: since the airport has more market power than airlines, its first mover advantage in choosing the fees may be due to its monopolist position. We discuss the issue further in the concluding remarks.

Thus, the revenue-sharing equilibrium is characterized by the first-order conditions,

$$\frac{\partial \Pi}{\partial r_i} = v_i \cdot \frac{\partial q_i^*}{\partial r_i} + v_j \cdot \frac{\partial q_j^*}{\partial r_i} = 0, \qquad i = 1, 2, \tag{2.10}$$

where $v_i (\equiv \partial v / \partial q_i) = R_i^i(q_1^*, q_2^*) - C_i'(q_i^*) + h + R_i^j(q_1^*, q_2^*)$. By (2.5), v_i can be rewritten as:

$$v_i = w + (1 - r_i)h + R_i^j(q_1^*, q_2^*). \tag{2.11}$$

Consider first the case where carriers' services are independent. It can be easily seen from (2.10), (2.11), (2.2) and Lemma 2.1 that the equilibrium sharing proportions are given by (superscript I for 'independent services'):

$$r_i^I = 1 + \frac{w}{h}, \qquad i = 1, 2, \tag{2.12}$$

which are strictly positive. Revenue sharing therefore improves the airport's profit – here, the profit gain is due to the internalization of a demand complementarity between the flights and concession consumption. Further, even when $r_i = 1$, the profit will rise with r_i going beyond the 'full' share. Basically, the two-part revenue sharing resolves the well-known 'double marginalization' problem in a vertical structure (e.g. Tirole, 1988).

The independent-services case turns out to be a useful benchmark for the cases of substitutes and complements. By first-order conditions (2.10) it follows:

$$v_1 \cdot \frac{\partial q_1^*}{\partial r_1} + v_2 \cdot \frac{\partial q_2^*}{\partial r_1} = 0, \tag{2.13}$$

$$v_1 \cdot \frac{\partial q_1^*}{\partial r_2} + v_2 \cdot \frac{\partial q_2^*}{\partial r_2} = 0, \tag{2.14}$$

which give rise to $v_2 \cdot [\partial q_1^* / \partial r_2 \partial q_2^* / \partial r_1 - \partial q_1^* / \partial r_1 \partial q_2^* / \partial r_2] = 0$. This equation, by (2.6), reduces further to $v_2 h^2 (\pi_{12}^1 \pi_{21}^2 - \pi_{11}^1 \pi_{22}^2)/J = 0 \Rightarrow -v_2 h^2 = 0 \Rightarrow v_2 = 0$. Substituting $v_2 = 0$ into (2.13) we immediately have $v_1 = 0$. It follows from (2.11) that

$$r_i = 1 + \frac{w}{h} + \frac{R_i^j}{h}, \qquad i = 1, 2. \tag{2.15}$$

If airline services are complements, then $R_i^j > 0$; consequently (superscript C for

'complements'),

$$r_i^C > 1 + \frac{w}{h} = r_i^I, \qquad i = 1,2. \tag{2.16}$$

If airline services are substitutes, then $R_i^j < 0$ and so equation (3.14) yields (superscript S for 'substitutes')

$$r_i^S < 1 + \frac{w}{h} = r_i^I, \qquad i = 1,2, \tag{2.17}$$

leading, therefore, to:

Proposition 2.1 *At the revenue-sharing equilibrium with a single airport, the sharing proportions are $r_i^I = 1 + w/h$ when airlines' services are independent, $i = 1,2$. The sharing proportions are greater (smaller, respectively) than r_i^I when airlines provide complementary (substitutable, respectively) services to each other.*

The explanations for the deviations from the independent-services benchmark are as follows. When services are complementary to each other, both carriers are interested in increasing passengers' numbers but are unable to internalize such complementarity by themselves. The airport, as a first mover, can achieve this by manipulating revenue-sharing proportions – here, by increasing the sharing proportions beyond r_i^I – and this in turn will increase the airport's profit. Conversely, substitutability between airlines' services will lead to a failure of coordination between competing airlines, resulting in their providing too much service with respect to what would be best for them as a whole. Anticipating this, the airport uses revenue sharing as a device to coordinate airline competition downstream. In particular, a smaller sharing proportion than the independent-services benchmark will, by Lemma 2.1, reduce industry output, thus lessening 'excessive' services by carriers.[11]

It is important to point out that for the substitutes case, the sharing proportions might become negative (i.e. $r_i^S < 0$). This is because airline-service substitutability works in an opposite direction of the flights-concessions demand complementarity discussed above, in terms of the amount of airline services the airport would like to induce. The optimal level of revenue sharing, r_i^S, is set to balance these two effects. Thus, r_i^S depends on the degree of substitutability between carriers' services. Numer-

[11] An alternative explanation for the substitutes case is that substitutability increases one carrier's passengers at the expense of another carrier's passengers. The airport must balance this trade-off and will not allow for a very high r_i.

ical examples are constructed at the end of this section, in which airline-service substitutability is so strong that r_i^S becomes negative. Such a 'negative revenue sharing' allows the airport to penalize the over-competing airlines so as to support prices in the output market and improve the profit of ('coordinate') the whole airport-airlines chain.

2.2.3 Comparison with the no-sharing regime

Our concern now is to compare the revenue-sharing equilibrium with the situation where airport-airline revenue sharing is not allowed, characterized by $r_i = f_i = 0$. First, for the cases of complements and independent services, it is clear from Lemma 2.1, Proposition 2.1, (2.10) and (2.11) that revenue sharing will increase airline output and improve airport profit. Define social welfare as the sum of the airport-airline profit and consumer (passenger) surplus:

$$W(r_1, r_2) = U(q_1^*, q_2^*) - C_1(q_1^*) - C_2(q_2^*) + hq_1^* + hq_2^* \equiv \psi(q_1^*, q_2^*), \tag{2.18}$$

where $U(q_1, q_2)$ is the consumer utility function in the usual industry (partial equilibrium) analysis, with $\partial U/\partial q_i = p^i$. Although passengers may derive surplus also from their concession consumption, such surplus per passenger is assumed constant and further normalized to zero, thus giving rise to formulation (3.18). Differentiating W with respect to r_i yields:

$$\frac{\partial W}{\partial r_i} = (p^i - C_i' + h)\frac{\partial q_i^*}{\partial r_i} + (p^j - C_j' + h)\frac{\partial q_j^*}{\partial r_i}. \tag{2.19}$$

Since $p^i - C_i' > 0$ (positive markups in oligopoly), the output expansion identified above leads immediately to $\partial W/\partial r_i > 0$ and thus, revenue sharing improves welfare.

As for prices, it can be easily seen (from below) that they will fall if carriers' services are independent. For the complements case, the effect is not as straightforward. Differentiating $p^i(q_1^*, q_2^*)$ with respect to r_i and r_j yields

$$\frac{\partial p^i}{\partial r_i} = p_i^i \cdot \frac{\partial q_i^*}{\partial r_i} + p_j^i \cdot \frac{\partial q_j^*}{\partial r_i}, \tag{2.20}$$

$$\frac{\partial p^i}{\partial r_j} = p_i^i \cdot \frac{\partial q_i^*}{\partial r_j} + p_j^i \cdot \frac{\partial q_j^*}{\partial r_j}, \tag{2.21}$$

respectively. With carriers' services being complementary, the first term on the right-hand side (RHS) of (2.20) is negative (recall $p_i^i < 0$ and Lemma 2.1) whilst the second term is positive. Similarly, the first term on the RHS of (2.21) is negative whilst the second term is positive. Under 'symmetry' however, the overall effects will be negative for both (2.20) and (2.21), as is shown below (Proposition 2.2). By 'symmetry' we mean (i) carriers have identical cost functions and face symmetric demands, and (ii) at the equilibrium, carriers have the same sharing contract (i.e. $r_1 = r_2,\ f_1 = f_2$). The symmetry condition will also be used in the comparison for the substitutes case (see Proposition 2.2).

Proposition 2.2 *At the revenue-sharing equilibrium with a single airport,*

1. *when airlines provide independent or complementary services to each other, (i) outputs and welfare are greater and (ii) under symmetry, prices are lower, than in the absence of revenue sharing;*

2. *when airlines provide substitutable services to each other and are symmetric, (i) outputs and welfare are greater (smaller, respectively) and (ii) prices are lower (higher, respectively), than in the absence of revenue sharing if $r_i^S > 0$ ($r_i^S < 0$, respectively).*

Note that all the proofs in this chapter are provided in Appendix A.

Three comments about Proposition 2.2 are worth making. First, although the proposition does not say anything about airport-airlines profits, the joint profits of the airport and airlines are always higher at the revenue sharing equilibrium when carriers' services are independent, as expected. When carriers provide substitutable and complementary services, the joint profits are higher at the revenue sharing equilibrium for linear demand and cost functions, but we are unable to prove the result for general demand and cost functions.[12] Second, although some of the comparisons in Proposition 2 are carried out under 'perfect' symmetry between airlines, a closer look at the proof of Proposition 2.2 indicates that small asymmetries will not undermine the results. Third, Proposition 2.2 shows that when carriers offer complementary and unrelated services to each other, revenue sharing between an airport and its airlines improves welfare. The welfare improvement arises because prices exceed

[12] A similar comment about the profit comparison applies to Proposition prop 6 below.

marginal costs in the oligopolistic airline market and revenue sharing reduces prices (or equivalently, expands outputs).

When carriers provide substitutable services to each other, revenue sharing may or may not improve welfare, depending on the sign of equilibrium sharing proportions r_i^S. As indicated above, the sign of r_i^S will in turn depend on the degree of substitutability between carriers' services. To capture such an impact, we need to impose more structure on the model.[13] Specifically, a linear (inverse) demand is specified:

$$p^i = 1 - bq_i - kq_j,$$

with $b > 0$ and $k \in (-b, b)$, which ensure downward-sloping demands and the property of 'own-price effects' dominating 'cross-price effects.' It is clear that carriers' services are complements, independent and substitutes when $k < 0, = 0$ and > 0, respectively. Carriers' marginal costs c_1 and c_2 are constant and $c_1 = c_2$. In the simulation, parameters are chosen to ensure positive outputs and marginal revenues.

Figure 2.1 reports the effects of airline-service substitutability, where we define $k = m \cdot b$ with $m \in (-0.1, 1)$. Thus, negative m indicates complementarity between airlines' services, whilst for positive m, larger m's mean increasingly substitutable services. As expected, for complementary services ($m < 0$), the airport shares a high percentage of concession revenue with airlines ($r_i > 1$) so as to internalize airline-service complementarity. On the other hand, the (equilibrium) sharing proportions r_i^S fall when airline services become increasingly substitutable. When airline-service substitutability becomes sufficiently strong, r_i^S turns into a negative value, implying carriers pay a higher price (than airport charge w) per unit of output. The figure shows that the fixed fees become negative in this case, indicating carriers are compensated for with fixed payments from the airport.[14] In such a case, the output and welfare

[13]Examining how equilibrium results change with substitutability (i.e. when airline services become more substitutable to each other) is also important, since there are situations in which airports or policy makers can 'moderate' such substitutability. For example, only a few Asian cities are served by multiple airports and as a result, low-cost carriers (LCCs) are often forced to use the same airport as competing full-service airlines (FSAs). Recently, airports in, e.g. Kuala Lumpur and Singapore, chose to build separate LCC terminals which offer lower quality of airport service with less charge (Zhang et al., 2009). Such a measure would make LCCs' services less substitutable to the services provided by FSAs.

[14]The combination of 'negative sharing' and airports' transfer payments to airlines may also be observed in practice. There are cases, for instance, where airports may make one-shot investments (for carriers) to offset high airport charges. For example, Federal Express (FedEx) had been planning to move its Asia Pacific operating center from Subic Bay in the Philippines to Guangzhou in China

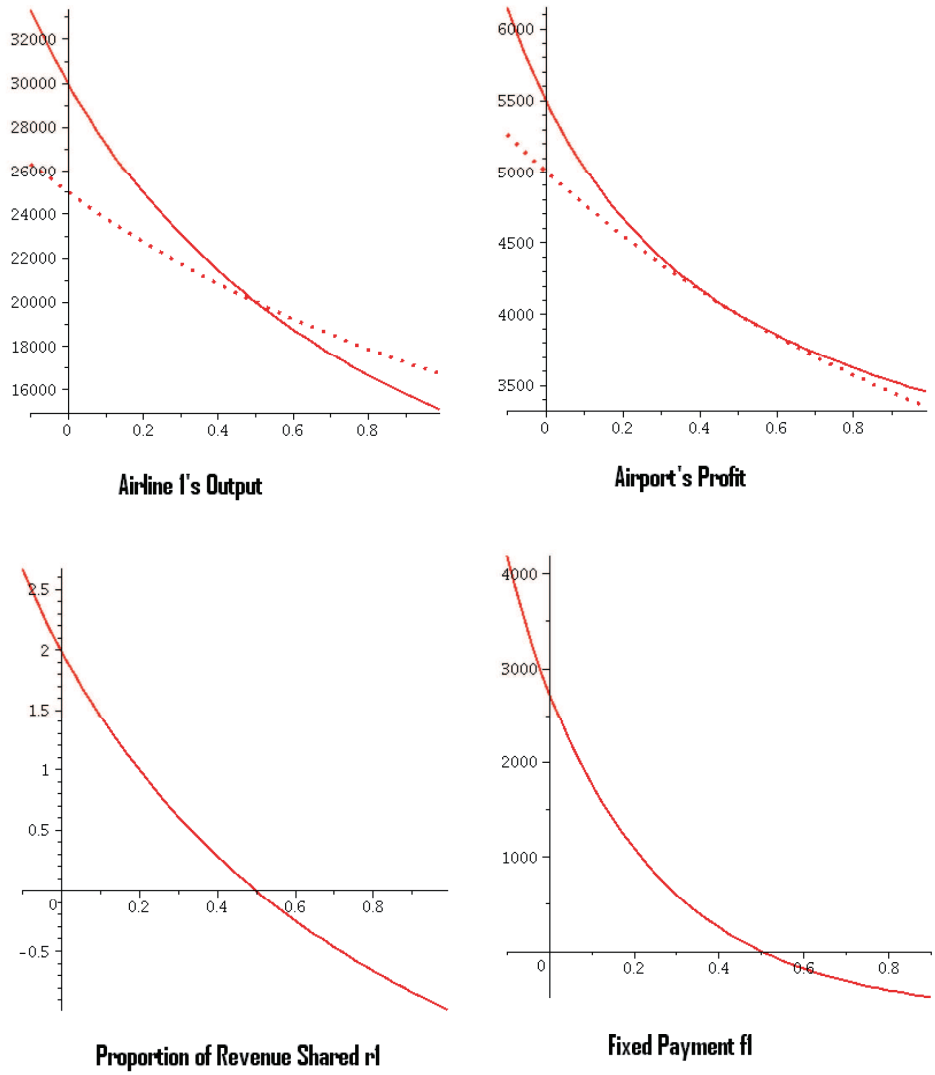

Figure 2.1: Revenue sharing vs. no sharing: Single airport with two carriers. The horizontal axis corresponds to substitutability parameter m, with $k = m \cdot b, m \in (-0.1, 1)$. Parameter values are: $b = 0.00001, c_1 = c_2 = 0.45, w = 0.05, h = 0.05$.
—- Solid Line: Results with share revenue.
..... Dotted Line: Results without revenue sharing.

(not shown in Figure 2.1) with revenue sharing (the solid line in the figure) are less than those in the no-sharing case (the dotted line), as predicted by Proposition 2.2. Here, while revenue sharing improves the total channel profit (see the figure), it might reduce social welfare.

2.3 Competing airports

2.3.1 Strategic revenue sharing

We now consider two airports, represented by $i = 1, 2$, beginning with a situation of one carrier at each airport. (The case of multiple airlines will be considered in Section 2.3.2.) To save notation we continue to use $p^i(q_1, q_2)$ for the inverse demands faced by carriers, with i denoting the ith airport's carrier (and its output). The two airports compete with each other in the sense that their airlines' services are substitutes in the eyes of passenger: thus airlines compete with each other even if they operate at different airports. More specifically, airline revenue functions $R^i(q_1, q_2)(= p^i(q_1, q_2)q_i)$ satisfy the substitutes condition (2.3).

Airport-airline behavior is modeled again as a two-stage game: In the first stage, each airport offers its carrier to share proportion r_i of concession revenue hq_i in exchange for fixed fee f_i, subject to the carrier's participation constraint. In the second stage, airlines compete in Cournot fashion with their profits given by (2.4). This airport-airline vertical structure has also been assumed in other analytical studies on competing airports mentioned in the introduction. Given this set-up, the second-stage equilibrium is characterized by (2.5), the same condition as in the single-airport

since 2003. However, FedEx was concerned about the high operating costs in Guangzhou airport due to its high charges for fuel, airport and ATC (air traffic control) services which are regulated by the central government. To offset these high service charges and attract FedEx, the airport agreed to invest US$300 million on infrastructures including exclusive aircraft parking space and taxi runways for the usage of FedEx. FedEx opened its Asia Pacific operating center in Guangzhou in February 2009, and within half a year it operates 136 flights per week at the airport. Notice, here, a negative relationship between airport charge w and revenue sharing proportion r_i. For instance, the value of r_i, for independent airline services, is equal to $1 + w/h$; consequently, $dw/dr_i < 0$: i.e. the higher w is, the smaller will r_i be. A smaller or negative sharing would then be compensated with higher fixed payments which, in the present example, are represented by the investments that the airport made to attract carriers (i.e. airport quality is in a sense interpreted as negative fees offered to airlines). Our results also suggest that when the downstream airline market is extremely competitive, the airport may prefer similar 'negative sharing' strategy to the choice of encouraging additional outputs via positive revenue sharing, in order to coordinate the airport-airlines chain. We discuss the issue further in the concluding remarks.

case. Further, the equilibrium quantities – denoted again as $q_i^*(r_1, r_2)$ – have the comparative-static properties of Lemma 2.1: i.e. an increase in the sharing proportion by airport i will increase its carrier's output while reducing output of the competing airport's carrier.

Taking the second-stage equilibrium outputs into account, each airport's profit in stage one is expressed as

$$\Pi^i = wq_i^* + (1 - r_i)hq_i^* + f_i, \qquad i = 1, 2. \tag{2.22}$$

The subgame perfect equilibrium then arises when each airport chooses its sharing contract (r_i, f_i) to maximize Π^i, taking its rival's sharing contract at the equilibrium values. This revenue-sharing equilibrium with airport competition will be referred to as the 'rivalry (revenue sharing) equilibrium,' where 'rivalry' refers to 'airport rivalry.' Without loss of generality the carriers are again assumed to receive their reservation profits $\pi_0^i, i = 1, 2$; consequently, each airport's profit can be rewritten as:

$$\Pi^i(r_1, r_2) = R^i(q_1^*, q_2^*) - C_i(q_i^*) + hq_i^* - \pi_0^i \equiv v^i(q_1^*(r_1, r_2), q_2^*(r_1, r_2)). \tag{2.23}$$

The rivalry equilibrium is characterized by the first-order conditions,

$$\Pi_i^i = v_i^i \cdot \frac{\partial q_i^*}{\partial r_i} + v_j^i \cdot \frac{\partial q_j^*}{\partial r_i}, \qquad i = 1, 2, \tag{2.24}$$

where subscripts again denote partial derivatives (e.g. $\Pi_i^i = \partial \Pi^i / \partial r_i, v_i^i = \partial v^i / \partial q_i$, and $v_j^i = \partial v^i / \partial q_j$). From (3.23), $v_i^i = R_i^i(q_1^*, q_2^*) - C_i'(q_i^*) + h$ which can by (2.5) be rewritten as:

$$v_i^i = w + (1 - r_i)h. \tag{2.25}$$

For the rivalry equilibrium, since $v_j^i = R_j^i < 0, \partial q_i^* / \partial r_i > 0$ and $\partial q_j^* / \partial r_i < 0$, it follows by (3.24) that $v_i^i < 0$. Thus by (3.25), the equilibrium sharing proportions satisfy (superscript R for 'rivalry equilibrium'),

$$r_i^R > 1 + \frac{w}{h}, \qquad i = 1, 2. \tag{2.26}$$

It is interesting to compare this rivalry equilibrium with the 'non-rivalry (revenue sharing) solution,' which is obtained when the two airports were perceived as inde-

pendent in the sense that $p_j^i(q_1, q_2) = 0$. It can be easily seen from (3.24) and (3.25) that the non-rivalry sharing proportions are given by (superscript N for 'non-rivalry solution'):

$$r_i^N = 1 + \frac{w}{h}, \qquad i = 1, 2. \tag{2.27}$$

Comparing (3.27) with (3.26) leads to:

Proposition 2.3 *The revenue-sharing proportions are greater at the rivalry revenue-sharing equilibrium than under the non-rivalry revenue-sharing solution, i.e.* $r_i^R > r_i^N$ *for* $i = 1, 2$.

The non-rivalry regime is, from (3.27) and (3.12), similar to the case of a single (monopoly) airport examined in Section 2.2, as expected: Like a monopoly airport, each airport in the non-rivalry regime shares positive proportion $r_i^N = 1 + w/h$ of concession revenue with its carrier. While r_i^N internalizes the flights-concessions demand complementarity, the rivalry revenue sharing involves an additional term δ_i – i.e. $r_i^R = r_i^N + \delta_i$ – which is unique to the case of competing airports. Since this additional effect works by indirectly influencing the behavior of the rival airport-airline pair – which in turn will improve profit of the airport-airline pair in question – the rivalry revenue sharing may be referred to as the 'strategic revenue sharing.' Proposition 2.3 therefore shows that airport competition will, owing to this strategic effect, result in a higher degree of revenue sharing than would be had in the case of single airports.

Next, the rivalry equilibrium is compared to the non-rivalry solution in terms of output, price, profit and social welfare. Here, welfare is the sum of passenger surplus and profits of the two airport-airline pairs; hence, it takes the same form as (3.18). The comparison results are stated as follows:

Proposition 2.4 *Under symmetry, at the rivalry revenue-sharing equilibrium, (i) outputs are greater, (ii) prices are lower, (iii) airport profits are lower, and (iv) social welfare is higher, than at the non-rivalry revenue-sharing solution.*

Perhaps the most surprising result from Proposition 2.4 (especially as compared to the single-airport case) is related to profit comparison: both airport-airline pairs will derive lower profits through this revenue-sharing rivalry. In effect, the airport-airline pairs are trapped by the incentive structure of the environment. If one airport-airline pair ignores the possibility of strategic use of revenue-sharing contracts while

the other pair shares revenue strategically, the first pair loses while the second pair gains relative to the non-strategic sharing arrangement. Here the situation is similar to the classic Prisoner's Dilemma. As the pairs move further away from their joint profit maximum through such a revenue-sharing rivalry, social welfare nevertheless rises beyond the level achievable by single airports.

2.3.2 Multiple airlines

Section 2.3.1 studies the case of one carrier per airport. We now extend the analysis to a situation where there may be multiple competing airlines at each airport. Our second objective in this section is to show that the general demand structure used in Section 2.3.1 can be generated through explicit considerations of passenger behavior.

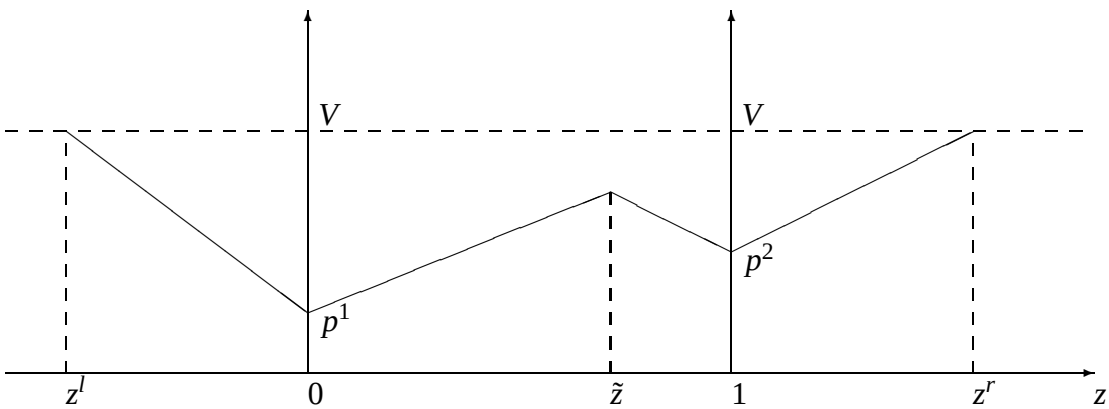

Figure 2.2: Consumer distribution and airports' catchment areas (adapted from Basso and Zhang, 2007).

More specifically, our demand derivation follows Basso and Zhang (2007) by considering an infinite linear city, where potential consumers are distributed uniformly with a density of one consumer per unit of length. Two competing airports are located at 0 (airport 1) and 1 (airport 2) and there are n_i carriers at airport i, (see Figure 2.2). At each airport, carriers provide homogeneous output, with total output $Q_i = \sum_{k=1}^{n_i} q_{ik}$ and market price p^i.

The 'full price' faced by a consumer located at $0 \leq z \leq 1$ and who goes to airport 1 is given by $p^1 + (4t) \cdot z$, where $4t(>0)$ represents the consumer's transportation cost from z to location 0. By choosing airport 1 or airport 2 (but not both) the consumer

derives the following respective net utilities:

$$U_1 = V - p^1 - (4t)\cdot z, \qquad U_2 = V - p^2 - (4t)\cdot(1-z), \tag{2.28}$$

where V denotes (gross) benefit from air travel.[15] Assuming everyone in the $[0,1]$ interval consumes, then the indifferent passenger $\tilde{z} \in (0,1)$ is determined by setting $U_1 = U_2$, or

$$\tilde{z} = \frac{1}{2} + \frac{p^2 - p^1}{8t}. \tag{2.29}$$

Given that airport 1 also captures consumers at its immediate left side, define z^l as the last passenger on the left side of the city who goes to airport 1. Similarly, define z^r as the last passenger on the right side of the city who goes to airport 2. With the uniformity and unit density of consumers, z^l and z^r are computed as:

$$z^l = -\frac{V - p^1}{4t}, \qquad z^r = 1 + \frac{V - p^2}{4t}. \tag{2.30}$$

The airports' catchment areas are shown in Figure 2.2, and their demands are computed as:

$$Q_1 = \tilde{z} + |z^l| = \frac{1}{2} + \frac{p^2 - p^1}{8t} + \frac{V - p^1}{4t}, \tag{2.31}$$

$$Q_2 = (1 - \tilde{z}) + (z^r - 1) = \frac{1}{2} - \frac{p^2 - p^1}{8t} + \frac{V - p^2}{4t}. \tag{2.32}$$

From (2.31) the inverse demands are given by

$$p^i(Q_1, Q_2) = (2t + V) - 3tQ_1 - tQ_2, \qquad i, j = 1, 2, \tag{2.33}$$

which take the linear functional forms. This demand system has the properties of $p^i_i = -3t < 0, p^1_1 p^2_2 - p^1_2 p^2_1 = 8t^2 > 0$, and substitutes condition (2.3).

[15] This is an 'address model' with positive linear transportation costs, and the differentiation of the two airports is captured by consumer transportation cost. Within a multi-airport region, passengers may not necessarily choose an airport with cheaper airfare, but may go to a nearer airport – see the empirical studies by, e.g., Pels et al. (2001); Fournier et al. (2007) and Ishii et al. (2009). In addition to distance, other aspects of airport differentiation may be captured by extending the present formulation. For instance, Pels et al. (2000, 2001, 2003) have shown, using a hypothetical example and later the San Francisco Bay Area case study, that ground accessibility of an airport is the most important factor in affecting airport choices in a multi-airport market. Such differential ground access costs could be addressed by introducing a new parameter to the net-benefit functions (3.28).

To solve the two-stage airport competition game, we begin with an analysis of the second stage when airlines engage in intra- and inter-airport competition. Suppose for simplicity that carriers have linear costs $C(q) = F + cq$. Consider first that the two airports have the same number of carriers, i.e. $n_1 = n_2 = n$. Then airline profits can be written as:

$$\pi^{ik}(Q_1, Q_2, q_{ik}) = p^i(Q_1, Q_2) \cdot q_{ik} - F - cq_{ik} - wq_{ik} + r_i h q_{ik} - f_i. \tag{2.34}$$

The Cournot-Nash equilibrium is characterized by first-order conditions,

$$\frac{\partial \pi^{ik}(Q_1, Q_2, q_{ik})}{\partial q_{ik}} = p^i - 3tq_{ik} - c - w + r_i h = 0, \qquad k = 1, \ldots, n, \qquad i = 1, 2, \tag{2.35}$$

(and the corresponding second-order conditions, which hold as $\partial^2 \pi^{ik} / \partial q_{ik}^2 = -6t < 0$). Given the underlying symmetry of this set-up, the equilibrium quantities are easily obtained:

$$q_{ik}^*(r_1, r_2) = \frac{[3(n+1)r_i - nr_j]h}{(2n+3)(4n+3)t} + \frac{2t + V - c - w}{(4n+3)t}, \qquad k = 1, \ldots, n, \qquad i = 1, 2. \tag{2.36}$$

Back to the first stage of the game, each airport's profit is:

$$\Pi^i = wQ_i^* + (1 - r_i)hQ_i^* + nf_i, \qquad i = 1, 2. \tag{2.37}$$

With the airline participation constraints, these profits can be rewritten as,

$$\Pi^i(r_1, r_2) = [p^i(Q_1^*, Q_2^*) - c + h]Q_i^* - n \cdot (F + \pi_0^i). \tag{2.38}$$

Hence the rivalry equilibrium is characterized by first-order conditions,

$$\Pi_i^i = [w + (1 - r_i)h - 3t(Q_i^* - q_{ik}^*)] \cdot \frac{\partial Q_i^*}{\partial r_i} - tQ_i^* \cdot \frac{\partial Q_j^*}{\partial r_i} = 0, \qquad i = 1, 2. \tag{2.39}$$

From (3.38) the equilibrium sharing proportions are obtained as,

$$r_i^R(n) = 1 + \frac{w}{h} - \frac{(8n^2 - 9)(2t + V + h - c)}{n(20n + 21)h}, \qquad i = 1, 2. \tag{2.40}$$

Notice from (3.39) that if $n = 1$ (each airport has one carrier) then $r_i^R > 1 + w/h = r_i^N$, a result obtained in Section 2.3.1 (see Proposition 2.3).[16] Further, it follows from (3.39) that $dr_i^R/dn < 0, i = 1,2$: i.e. the sharing proportions decrease in the number of carriers serving the airports.

For the general case where airports 1 and 2 have n_1 and n_2 carriers respectively, the inverse demands are given by (3.32), where $Q_i = \sum_{k=1}^{n_i} q_{ik}$ is the aggregate demand at airport i. Solving the two-stage game yields:

$$r_i^R = 1 + \frac{w}{h} - \frac{[(8n_j+9)n_i - 9n_j - 9](14n_i+15)(2t+V+h-c)}{n_i(280n_in_j+297n_i+297n_j+315)h}, \qquad i = 1,2. \tag{2.41}$$

Note that when $n_1 = n_2 = n$, the above expression reduces to expression (3.39). From (3.40) it is straightforward to show that $dr_i^R/dn_i < 0$ and $dr_i^R/dn_j > 0$, leading to:

Proposition 2.5 *At the rivalry equilibrium with n_1 and n_2 carriers at airports 1 and 2 respectively, $dr_i^R/dn_i < 0$ and $dr_i^R/dn_j > 0$: i.e. the revenue-sharing proportion of an airport-airlines chain decreases in the number of carriers at its airport, and increases in the number of carriers at the competing airport. If $n_1 = n_2 = n$, then $dr_i^R/dn < 0$.*

The intuition behind $dr_i^R/dn_i < 0$ is similar to that of Proposition 2.1 (the substitutes case): As n_i rises (while holding n_j constant) and airline competition intensifies, total output becomes increasingly 'excessive' (relative to profit maximization) for the ith airport-airlines chain. Anticipating this, airport i will have a greater incentive to discourage such competition, which can be achieved by a smaller sharing proportion.[17] While this result is largely expected, the other result, $dr_i^R/dn_j > 0$, is not obvious. Here, the explanation is related to the 'number of competitors' effect: An increase in the number of airlines serving at airport j, while holding n_i unchanged, would increase airport j's output share in the two-airport market.[18] To

[16]This result can also be shown using demand functions (3.32) and the property of their associated revenue functions $R_j^i = p_j^i q_i = -tq_i < 0$.

[17]While the two results have similar intuitions, the present result is nevertheless obtained in an environment of competing airports.

[18]This 'number of competitors' effect is related to a well-known result found by Salant et al. (1983): in a Cournot market, a merger of two firms into one entity reduces the merger partners' profit (unless the merger leads to a monopoly). By internalizing part of the effect that a firm's quantity decision has

counter the effect, airport i strategically raises the sharing proportion so as to induce its carriers to commit to greater output. This would credibly deter airport j's carriers from providing more service, which in turn improves profit of the ith airport-airline chain.[19] Finally, $dr_i^R/dn < 0$ for $n_1 = n_2 = n$, indicating that as n rises, the (negative) excessive-output effect dominates the number-of-competitors effect.

Like Section 2.3.1 (which considers one carrier at each airport) we can compare the rivalry equilibrium with the non-rivalry solution – in the present case however, each airport has multiple carriers. It can be easily calculated that the non-rivalry sharing proportions are equal to:

$$r_i^N = 1 + \frac{w}{h} - \frac{(n_i - 1)(2t + V + h - c)}{2n_i h}, \qquad i = 1, 2. \tag{2.42}$$

Note, first, that if $n_i = 1$, (3.41) reduces to (3.27) and so it extends formula (3.27) to the case of multiple airlines. Second, using (3.41) we obtain:

$$\frac{dr_i^N}{dn_i} < 0, \qquad i = 1, 2, \tag{2.43}$$

that is, as the number of airlines at a single airport increases and hence (uncoordinated) output gets increasingly excessive for the carriers' joint-profit maximization, the airport then has a greater incentive to curb output by using a smaller sharing proportion.[20] This result is a clear extension of Proposition 2.1 which considers the effect of moving from one carrier to two carriers. Finally, comparing (3.41) with (3.40) yields that $r_i^R > r_i^N$ for any n_i and n_j (n_i and n_j can take different values, $i, j = 1, 2$): i.e. the revenue-sharing proportions are greater at the rivalry revenue-sharing equilibrium than under the non-rivalry revenue-sharing solution. This extends Proposi-

on the rivals' profit, the merged entity sets its quantity too low, thereby yielding market share to the non-participating firms.

[19] As noted by an anonymous referee, Proposition 2.5 is rather interesting in that it recalls the case of some LCCs (for instance, Ryanair) at some secondary airports an LCC dominates. While competing with main airports with many airlines, the LCC will ask for a higher r_i and the airport will be interested in this.

[20] An alternative explanation for the intuition behind this result, suggested by an anonymous referee, is the following: As the number of airlines in an airport increases, the airport has more market power and may raise its share $1 - r_i$. Moreover, the competition effect (or the increase of the output, recalling that w is fixed, so that wq increases with q) is done in the downstream market by a more intense competition amongst airlines. Then the airport may increase $1 - r_i$ without decreasing much the output.

tion 2.3 of Section 2.3.1 to the general case of multiple airports with each having an arbitrary number of carriers.[21]

2.4 Pure revenue-sharing contract

So far our approach to revenue sharing has focused on a 'two part' scheme under which an airport chooses both a sharing proportion and a lump-sum fee on its carriers for the right to share concession revenue. In this section we consider a 'pure' sharing contract under which the fixed fee is constrained to zero, while keeping the rest of the model unchanged. Using 'hat' to denote the pure revenue-sharing equilibrium – i.e. $(\hat{r}_1, \hat{r}_2)$ – these sharing proportions are constrained by the carriers' participation constraints. Unlike the two-part sharing scheme, therefore, 'negative sharing' is not possible since these carriers cannot be compensated for with any fixed payments by the airport, indicating $\hat{r}_i \geq 0$. Given these observations, the effects of the pure revenue-sharing contract will be compared to those of the two-part scheme as well as the no-sharing regime.

2.4.1 Single airport

Consider first a single airport served by two carriers, which provide complementary, independent or substitutable services to each other. The airport offers carrier i a pure sharing contract with sharing proportion r_i, and the carriers compete by choosing quantities q_i. We can show

Proposition 2.6 *At the pure revenue-sharing equilibrium with a single airport,*

1. *when carriers provide independent and complementary services (assuming symmetric carriers in the case of complements) to each other, both the sharing proportions and social welfare are smaller than at the two-part revenue-sharing equilibrium;*

2. *when carriers provide substitutable services to each other, both the sharing proportions and social welfare may be higher or smaller than at the two-part revenue-sharing equilibrium.*

[21] Similarly, Proposition 2.4 (including the Prisoners' Dilemma result) can be extended to the n-carrier case. The derivation is available upon request.

For the cases of independent or complementary services, the airport, being unable to charge the fixed fee under the pure revenue sharing, shares less concession revenue with its carriers than would be under the two-part revenue sharing. This result follows directly from comparing (A.5) and (A.6) with the sharing proportions (3.12) and (3.15). This reduction in sharing will, by similar arguments used in the proof of Proposition 2.2, reduce welfare. For the substitutes case however, although the equilibrium sharing proportions are, by (A.5) and (3.17), less than $1+w/h$ for both types of revenue sharing, the sharing-proportions comparison between the two types is in general ambiguous. In particular, while negative sharing is ruled out under the pure revenue sharing, it is possible under the two-part revenue sharing. In such situations, it can be shown that the pure revenue sharing results in not only a higher sharing proportion, but also a higher welfare level if carriers are sufficiently symmetric, than the two-part revenue sharing.[22]

Finally, the pure revenue sharing can also be compared to the no-sharing regime. It can be shown that at the pure revenue-sharing equilibrium, prices are lower, and both outputs and welfare are greater, than in the absence of revenue sharing. These results hold irrespective of the carriers' offering complementary, unrelated or substitutable services. The proofs are analogous to the proofs of Proposition 2.2, with some of the results requiring that carriers be reasonably symmetric.

2.4.2 Competing airports

Next consider two competing airports, each served by one carrier. The stage-two equilibrium quantities are again characterized by (2.5) and are given by $q_i^*(r_1,r_2)$, which have comparative-static property $\partial q_i^*/\partial r_i > 0, i = 1,2$. Then each airport's profit in stage one is $\Pi^i(r_1,r_2) = wq_i^*(r_1,r_2)+(1-r_i)hq_i^*(r_1,r_2)$, and the pure revenue-sharing equilibrium is characterized by first-order conditions,

$$\Pi_i^i = [w+(1-r_i)h]\frac{\partial q_i^*}{\partial r_i} - hq_i^* = 0, \qquad i = 1,2. \tag{2.44}$$

[22]When competing carriers are asymmetric, however, there is an interesting twist introduced in the sharing-proportions and welfare comparison between the pure and two-part sharing arrangements. Numerical simulations can be constructed (available upon request) to show that an airport with the two-part revenue sharing tends to share more revenue with a more efficient carrier, whilst an airport under the pure revenue sharing may share less with a carrier as it becomes more efficient. As a result, carrier asymmetry tends to favor the two-part revenue sharing, in terms of enhancing welfare, over the pure revenue sharing.

From (2.44) and $\partial q_i^*/\partial r_i > 0$, it follows that $w + (1 - r_i)h > 0$ and so

$$0 \leq \hat{r}_i < 1 + \frac{w}{h} = r_i^N < r_i^R, \qquad i = 1, 2. \tag{2.45}$$

The following results are then obtained (part 2's proof is analogous to Proposition 2.2's):

Proposition 2.7 *At the pure revenue-sharing equilibrium with competing airports,*

1. *the sharing proportions are smaller (greater, respectively); and*
2. *under symmetry, (i) outputs and welfare are smaller (greater, respectively) and (ii) prices are higher (lower, respectively)*

than at the two-part revenue-sharing equilibrium (the no-sharing equilibrium, respectively).

Proposition 2.7 indicates that under airport competition, the pure revenue sharing improves welfare relative to the no-sharing regime, albeit less effective than the two-part revenue sharing. In general, in terms of airfare, traffic volume and social welfare, the pure revenue sharing with competing airports lies in between the no-sharing and two-part revenue sharing regimes. It is also worth noting that unlike the ambiguous result for the single airport, the two-part revenue sharing unambiguously entails a higher sharing proportion than the pure revenue sharing. The reason that competition between airports plays a decisive role in pushing up the sharing proportions under the two-part sharing is related to the result $dr_i^R/dn_j > 0$ of Proposition 2.5: an airport needs to raise its two-part sharing proportions in the presence of a competing airport.

2.5 Concluding remarks

This paper has investigated the implications of concession revenue sharing between an airport and its airlines. Earlier studies show that such sharing allows an airport to internalize the demand complementarity between flights and concessions, and may improve both profits and welfare. We found that the degree of sharing will be further affected by how carriers' services are related (complements, independent, or substitutes). In particular, when carriers provide substitutable services to each other, the sharing proportions might become negative if substitutability between airlines'

services is sufficiently strong and the fixed (transfer) payments between the airport and carriers are feasible (the two-part revenue sharing). The negative sharing allows the airport to penalize the over-competing airlines so as to support airfares. In these situations, while revenue sharing improves the total airport-airlines channel profit, it reduces social welfare. If the fixed payments are not feasible, under the resulting pure revenue sharing the airport will, for the cases of independent or complementary services, share less concession revenue with its carriers than would be under the two-part revenue sharing. For the substitutes case however, the sharing-proportions comparison between the two types is in general ambiguous. In the special case of negative sharing, the pure revenue sharing results in not only a higher sharing proportion, but also a higher welfare level if carriers are sufficiently symmetric, than the two-part revenue sharing.

Our second objective in writing this paper is to extend the existing literature on airport-airline vertical cooperation to the general case of multiple competing airports with each having an arbitrary number of carriers. We found that airport competition will result in a higher degree of vertical cooperation between an airport and its home carriers, in forms such as the revenue sharing modeled in our paper, than would be had in the case of single airports. Nevertheless, the airport-airline chains may derive lower profits through this revenue-sharing rivalry: in effect, the airports are trapped by the incentive structure of the environment, and the situation is similar to a classic Prisoners' Dilemma. As the airport-airline chains move further away from their joint profit maximum, social welfare rises beyond the level achievable by single airports. Our analysis also showed that the (equilibrium) revenue-sharing proportion at an airport decreases in the number of its carriers, and increases in the number of carriers at the competing airport. Airline market structure will therefore influence revenue sharing arrangements not only at the airport in question, but also at the competing airports.

Overall, our results indicate that when airport-airline vertical cooperation is allowed, an airport has a strategic interest in influencing competition in the downstream airline market. Airport competition further induces airports to strengthen their cooperation with airlines, although such cooperation might actually reduce joint profits. In terms of the welfare consequences of alternative revenue sharing arrangements, whether an airport is subject to competition is critical: for competing airports, 'no sharing' is worse than 'pure sharing' which is in turn worse than the two-part sharing.

For single airports, on the other hand, while no-sharing is worse than pure-sharing, both no-sharing and pure-sharing might be better than the two-part sharing when airlines provide substitutable services to each other.

The paper has also raised several other issues and avenues for future research. First, we assumed that the airport chooses the fees as high as possible subject to carriers' participation constraints. An alternative, and perhaps more realistic, structure is to have the airport and airlines bargain over the fees, which may be modeled as the result of a Nash-bargaining process, with the division capturing the degree of bargaining power of the airport with respect to the airlines involved. Second, we assumed that the aeronautical fare, w, is regulated and cannot be changed. This assumption does not allow for analyzing the effects of changes in revenue-sharing systems on price w. It would be interesting to further study the implications of allowing w to vary, perhaps along with the contract variables examined in the present paper. For instance, the value of r_i is, for independent services, equal to $1 + w/h$; consequently, $dw/dr_i < 0$: i.e. the higher w is, the smaller will r_i be. Airport deregulation or a loosened cap on the aeronautical price may mean a rise in w and hence a fall in r_i. Also, the game in Section 2.3.1 would become a three-stage game if airports would also compete in w. We see these analyses as natural extensions of the analysis presented here, although beyond the scope of the present article.

Chapter 3

Price-cap Regulation of Congested Airports[1]

3.1 Introduction

Airports have traditionally been owned and managed by governments. Starting with the privatization of airports in the UK in the late 1980s, more and more airports have been privatized (or partially privatized) around the world, including Europe, Oceania, Asia, South America and Africa (e.g. Oum et al., 2004; Winston and de Rus, 2008). As the ownership of airports changes from public to private, the goal of airports is expected to be profit maximization instead of the traditional concern with social welfare maximization. As a result, price regulations may thus be called upon to contain potential market power of an airport, which has the potential to be a "local monopoly" candidate (e.g. Fu et al., 2006; Basso, 2008).[2]

[1]A version of this chapter has been accepted by the *Journal of Regulatory Economics*. We are very grateful to the two anonymous referees and the editor (Michael Crew) for their constructive and perceptive comments which have significantly improved the paper. We also thank Juergen Mueller, Andrew Yuen, seminar participants at the Workshop on Aviation Economics, University of British Columbia, and especially Achim Czerny, for helpful comments on an earlier version of the paper. Financial support from the Social Science and Humanities Research Council of Canada (SSHRC) is gratefully acknowledged.

[2]On the other hand, as noted in Barbot (2009c) and Bel and Fageda (2010), oligopolistic airlines may have market power that can counter the market power of private airports, especially at congested hub airports. Brueckner (2002) points out that hub airports are typically dominated by one, two or three major carriers. In addition, private airports may have incentives to lower aeronautical charges so as to attract more traffic and thereby increase concession revenues (Starkie, 2001). The threat of re-regulation can also help mitigate the potential exploitation of market power by private airports

The exact form of price regulation appears to vary both across countries and over time. For example, a number of countries - including Germany and Canada - have adopted cost-based regulation, while price-cap regulation has been popular in countries such as the UK, Denmark, Ireland and Australia. Price-cap regulation adjusts the operator's prices according to a price-cap index that reflects the overall rate of inflation in the economy, the ability of the operator to gain efficiencies relative to the average firm in the economy, and the inflation in the operator's input prices relative to the average firm in the economy. Since price-cap regulation gives firms incentives to be cost efficient, it is often referred to as "incentive regulation". For example, while German airports have traditionally been regulated by cost-based regulation, price-cap regulation has been in place since 2000 for the airports of Hamburg, Hanover and Dusseldorf (Mueller et al., 2010). Niemeier (2002) argues that such a change improves the economic efficiency of airports.

Our analysis in this paper focuses on price-cap regulation of airports. We consider two versions of price-cap regulation: the single-till approach and the dual-till approach. The distinction between the two approaches concerns how an airport generates revenue. Airport revenue is derived from two facets of its business: the traditional aeronautical operation and the commercial (concession) operation. The former refers to aviation activities associated with runways, aircraft parking and terminals, whereas the latter refers to non-aeronautical activities that occur within terminals and on airport land, including terminal concessions (duty-free shops, restaurants, etc.), car rental and car parking. For the last two decades, commercial revenues have grown faster than aeronautical revenues and, as a result, have become the main income source of many airports.[3] Furthermore, commercial operations tend to be more profitable than aeronautical operations (e.g. Jones et al., 1993; Starkie, 2001; Francis et al., 2004) owing in part to prevailing regulations and charging mechanisms (e.g. Starkie, 2001). Under single-till price-cap regulation, revenues from both the aeronautical and commercial operations are considered in the determination of a price

(Forsyth, 2008).

[3]In a recent study, Van Dender (2007) investigated 55 large US airports from 1998 to 2002, and found that although its share dropped with the slump in travel in 2001 and 2002, concession revenue still represents more than half of the total airport revenue. ATRS (2008) studied 142 airports worldwide and found a majority of these airports derived 40-75% of their revenues from non-aviation services, a major part of which is revenue from concession services (with large hub airports relying, on average, even more on concession income). For earlier studies on the importance of commercial services, see Doganis (1992) and Zhang and Zhang (1997).

cap on aeronautical charges. By contrast, under the dual-till price-cap approach the aeronautical charges are determined based solely on aeronautical activities.

More specifically, we investigate price-cap regulation of an airport where the airport facility (e.g. runway) is congested and air carriers have market power. The single-till and the dual-till price-cap regulations are compared in terms of social welfare. We show that when the airport is not able to cover its fixed costs with an efficient aeronautical charge and its concession profit, then the single-till price-cap dominates the dual-till price-cap approach. When the efficient aeronautical charge covers the airport cost associated with aeronautical services and airport congestion is significant, then dual-till regulation performs better. Otherwise, the comparison depends on whether the efficient aeronautical charge is greater than the average of the aeronautical charges under single-till and dual-till regulation. If so, then dual-till regulation dominates single-till regulation; otherwise, single-till regulation is better.

Our paper extends the recent analytical work by Czerny (2006) who shows that single-till price-cap regulation dominates dual-till price-cap regulation with respect to social welfare at a non-congested airport. For the last decade or so, airport congestion and delays have become a major public policy issue in many countries, owing mainly to the fact that traffic growth has outpaced increases in airport capacity (e.g. Brueckner, 2002; Zhang and Zhang, 2006; Basso, 2008). A major critique of the single-till approach is that the aeronautical (e.g. runway) charges are set too low at congested airports. More specifically, when the single-till approach is applied to a capacity-constrained airport, the aeronautical charges must be lowered - as more profits are made from commercial activities - so that the airport remains under the single-till price cap. Under single-till price-cap regulation, therefore, the aeronautical charges are lowered at congested airports when economic efficiency requires them to be raised (e.g. Beesley, 1999; Starkie, 2001; Gillen, 2011).[4] It is generally believed that dual-till price-cap regulation seems more desirable at a congested airport. Nevertheless, no rigorous theoretical work has compared the single-till approach with the

[4]Control and management of airport slots, including slot auctions and slot trading, alleviates this concern, at least partly. In Europe, in particular, single-till price-cap regulation normally comes along with slots. Brueckner (2009) shows that slot auctions or slot trading would, under certain conditions, lead to an efficient outcome. With slot auctions or slot trading, therefore, the reduced aeronautical charges under the single-till approach may not be a serious issue. To focus on the comparison between the single-till and dual-till schemes, we do not consider the role of slots in this paper. For further discussion on the economics of airport slots, see e.g. Jones et al. (1993), Forsyth and Niemeier (2008), Czerny (2010), and Basso and Zhang (2010).

dual-till approach at congested airports.[5]

The paper is organized as follows. Section 3.2 sets up the basic model and examines airline competition. Section 3.3 investigates the airport behavior in choosing aeronautical charge and concession price. Section 3.4 compares single-till regulation with dual-till regulation, and Section 3.5 contains the concluding remarks.

3.2 Model

Consider a model with a single airport and n competing airlines. Let ρ_i be the passengers' perceived "full price" of airline i. The carriers provide horizontally differentiated outputs and for analytical tractability, we assume linear demand functions:

$$\rho_i = a - bq_i - \sum_{j \neq i} q_j, \tag{3.1}$$

where $a > 0, b \geq 1$, and q_i is airline i's output (number of passengers).

Let $\tilde{q}_i$ be the number of flights of airline i. Assuming, as is common in the airport pricing literature, that all the flights use identical aircraft and have the same load factor (e.g. Brueckner, 2002), then each flight has an equal number of passengers. Denoting the number by S, we then have $\tilde{q}_i = q_i/S$. Letting $\tilde{Q} = \sum \tilde{q}_i$ and $Q = \sum q_i$ be, respectively, the number of flights and the number of passengers of all airlines, then $\tilde{Q} = Q/S$.

Following Zhang and Zhang (2006), Basso (2008), and Czerny and Zhang (2010), the full price ρ_i is treated to be the sum of ticket price and congestion cost:

$$\rho_i = p_i + \alpha D(\tilde{Q}, K), \tag{3.2}$$

where p_i is airline i's ticket price, D is the congestion delay time and α denotes

[5]While a number of studies have qualitatively compared the relative merits of single-till and dual-till regulations, there have been only a few theoretical studies on this debate. To the best of our knowledge, Czerny (2006) and Crew and Kleindorfer (2000) are the only analytical papers that show single-till price-cap regulation is socially more desirable than dual-till price-cap at non-congested airports. Although several authors, e.g. Lu and Pagliari (2004), intuitively argue that the single-till scheme is more desirable at non-congested airports, while the dual-till scheme dominates at congested airports, they do not show the results analytically. Our paper also extends these papers in that their airline market, namely perfect competition, can be a special (limiting) case of our market structure (i.e. when the number of airlines at the airport approaches infinity). Oum et al. (2004) show empirically that the dual-till price-cap regulation provides stronger incentives for capacity investments and cost reductions than no regulation.

the passengers' value of time. The congestion delay depends on the total number of flights $\tilde{Q}$ and the airport's (runway) capacity K. We shall use the same linear delay function as the one in De Borger and Van Dender (2006) and Basso and Zhang (2007):

$$D(\tilde{Q},K) = \theta\frac{\tilde{Q}}{K} = \theta\frac{Q}{KS}, \tag{3.3}$$

where θ is a positive parameter. Without loss of generality, we normalize $KS = 1$. From (3.2)-(3.3), it follows that

$$p_i = \rho_i - \alpha D(\tilde{Q},K) = a - bq_i - \sum_{j\neq i} q_j - \alpha\theta Q. \tag{3.4}$$

Next, we specify the passengers' demand for concessions. Suppose that the passengers' valuation for the commercial good has a positive support on the interval $[0,u]$, where u is the largest valuation for the good. Let $G(\cdot), g(\cdot)$ be the cumulative distribution function and probability density function of the passengers' valuation, respectively. Assume the passengers' valuation has the property of "non-decreasing failure rate", that is, $g(x)/\bar{G}(x)$ is non-decreasing in x, where $\bar{G}(x) = 1 - G(x)$. This property guarantees the uniqueness and existence of the optimal concession price. Many common distribution functions satisfy the property, including uniform, exponential, truncated Normal, etc. A passenger will consume the concession good if his/her valuation is greater than the concession price p_c.

It is worth noting that our treatment of concession demand is different from Oum et al. (2004) and Zhang and Zhang (2010) where the price of concession good is exogenously given and the concession demand is taken simply as a fixed proportion of the aeronautical demand. Our modeling of interaction between aeronautical demand and concession demand is related to, but different from, Czerny (2006). Czerny assumes that (potential) consumers make decisions simultaneously on buying flight tickets and concessions. In other words, he assumes that consumers will buy a flight ticket as long as the joint surplus from consuming the flight and commercial services is positive. However, it is perhaps more reasonable, we believe, to assume that consumers make these two decisions sequentially: Consumers first decide whether to fly; if they decide flying, they then decide whether to purchase the commercial services provided at the airport.[6] Therefore, the concession demand depends on both the con-

[6] A similar argument was also made in Currier (2008).

cession price and the number of passengers, which in turn depends on the air ticket price. As a result, the concession demand depends on the air ticket price as well.

The airport regulation is modeled as a three-stage game: In stage 1, the regulator chooses the price-cap on aeronautical charge (per passenger) p_a, subject to the airport's cost recovery constraint. In stage 2, the airport decides on both the aeronautical charge (within the given cap) and concession price p_c. In stage 3, each airline chooses its output q_i to maximize profit (i.e. airlines compete in Cournot fashion).[7] Note that we do not include the concession price in the price-cap regulation to reflect the prevailing regulations (e.g. Starkie, 2001) - concession prices are generally not regulated in practice.

We solve the subgame perfect equilibrium of the regulatory game through backward induction. More specifically, in stage 3, airline i's profit function is

$$\pi_i = [p_i - c - p_a - \beta D(\tilde{Q}, K)]q_i, \tag{3.5}$$

where c is airlines' unit operating cost and β denotes their value of time per passenger.[8] Using (3.4) and the chain rule, we obtain the first-order condition of (3.5):

$$\frac{d\pi_i}{dq_i} = p_i - c - p_a - \beta\theta Q - q_i(b + \alpha\theta + \beta\theta) = 0. \tag{3.6}$$

It is easy to see that the second-order condition $d\pi_i^2/dq_i^2 < 0$ holds. Imposing symmetry we obtain the Cournot-Nash equilibrium output as:

$$q_i^* = \frac{a - c - p_a}{(n+1)(\alpha+\beta)\theta + 2b + n - 1}. \tag{3.7}$$

Notice that $(\alpha+\beta)\theta$ is the total (adjusted) per-passenger value of time taking both the passengers and airlines as a whole. For notational simplicity, we denote it by v: $v \equiv (\alpha+\beta)\theta$. Equation (3.7) shows, intuitively, that the (equilibrium) number of passengers decreases in both airport charge and value of time v.

[7]Earlier studies that have incorporated imperfect competition of carriers at a congestible airport (e.g. Brueckner, 2002, 2005; Pels and Verhoef, 2004; Basso and Zhang, 2007) have assumed Cournot behavior. Brander and Zhang (1990, 1993), for example, find some empirical evidence that rivalry between duopoly airlines is consistent with Cournot behavior.

[8]By the assumption that each flight has an equal number of passengers, value of time per passenger and value of time per flight are equivalent by a constant.

3.3 Airport pricing

Back to stage 2, the airport decides on aeronautical charge p_a and concession price p_c. We first consider a public welfare-maximizing airport in Section 3.3.1. This is followed, in Section 3.3.2, by examination of a private profit-maximizing airport.

3.3.1 Welfare-maximizing airport

Consider first a public airport whose objective is to maximize social welfare (SW), which is defined as the sum of consumer surplus and producer surplus. Consumer surplus consists of two parts, namely aeronautical services (CS_a) and concession services (CS_c), which are given by:

$$\begin{aligned} CS_a &= \sum_{i=1}^{n}\left(\int_0^{q_i^*}(a-bq_i-\sum_{j>i}q_j^*)dq_i-(a-bq_i-\sum_{j\neq i}q_j^*)q_i^*\right) \\ &= \frac{b+n-1}{2n}Q^{*2}, \qquad (3.8) \\ CS_c &= \int_{p_c}^{u}Q^*\bar{G}(x)dx, \qquad (3.9) \end{aligned}$$

where, by (3.7),

$$Q^* = \frac{n(a-c-p_a)}{(n+1)v+2b+n-1}. \qquad (3.10)$$

Producer surplus is the joint profit of the airport and the n airlines. Taking the stage-3 airline rivalry into account, the airport's profit is

$$\Pi = (p_a-c_a)Q^* + (p_c-c_c)Q^*\bar{G}(p_c) - F, \qquad (3.11)$$

where c_a is the airport's operating cost per passenger, c_c is the unit cost of the commercial good, and F is the fixed cost of the airport. To guarantee positive outputs, we must have

$$a-c-c_a > 0. \qquad (3.12)$$

For simplicity, let $H(p_c) \equiv \bar{G}(p_c)(p_c-c_c)$ be the per-passenger airport profit from concession operations, and $I(p_c) \equiv \int_{p_c}^{u}\bar{G}(x)dx$ be the per-passenger consumer surplus from concession consumption. From (3.5), (3.8)-(3.9), and (3.11), it follows

that

$$\begin{aligned} SW &= CS_a + CS_c + \Pi + \sum_{i=1}^{n} \pi_i \\ &= \frac{b+n-1}{2n} Q^{*2} + I(p_c)Q^* + (p_a - c_a)Q^* + H(p_c)Q^* - F \\ &\quad + \left(a - c - p_a - \frac{b+n-1}{n} Q^* - vQ^* \right) Q^* \\ &= \left(a - c - c_a + H(p_c) + I(p_c) \right) Q^* - \frac{2nv+b+n-1}{2n} Q^{*2} - F. \end{aligned} \tag{3.13}$$

It is worth pointing out that SW depends on p_a, p_c and v since by (3.10), Q^* depends on p_a and v. Here, the public airport maximizes social welfare by choosing p_a and p_c simultaneously. Notice that Q^* does not depend on p_c and that $a - c - c_a > 0$ as assumed in (3.12). Given p_a, therefore, maximizing SW over p_c is equivalent to maximizing $H(p_c) + I(p_c)$ over p_c. We obtain the following result:

Proposition 3.1 *For a public, welfare-maximizing airport, the optimal concession price is $p_c^w = c_c$, and the optimal aeronautical charge is*

$$p_a^w = c_a + \frac{(a-c-c_a)[(n-1)v - b] - I(c_c)[(n+1)v + 2b + n - 1]}{2nv + b + n - 1}, \tag{3.14}$$

where superscript w stands for welfare maximization.

The proof of Proposition 3.1 is relatively straightforward and is given in Appendix B. As expected, the first-best concession price is set at unit concession cost. To better interpret the first-best aeronautical charge, we rewrite p_a^w in (3.14) as

$$p_a^w = c_a - I(c_c) + \left(1 - \frac{1}{n}\right) vQ^w - \frac{1}{n} bQ^w, \tag{3.15}$$

where Q^w is the total number of passengers under welfare maximization, and is given by

$$Q^w = \frac{n(a - c - p_a^w)}{(n+1)v + 2b + n - 1}. \tag{3.16}$$

Similar to Zhang and Zhang (2010), equation (3.15) has a clear interpretation: The first-best aeronautical charge is equal to the airport's unit operating cost, minus concession surplus per passenger, plus a charge for uninternalized congestion, and mi-

nus a subsidy to correct airline exploitation of market power. The charge for un-internalized congestion is the "congestion toll" component of the airport charges (Brueckner, 2002, 2005) whereas the last term in (3.15) is the "market power" component (Pels and Verhoef, 2004).

3.3.2 Profit-maximizing airport

A private airport chooses p_a and p_c to maximize its profit. Note that given p_a, maximizing Π over p_c is equivalent to maximizing $H(p_c)$ over p_c. The following proposition shows that the optimal concession price chosen by a private airport depends not only on the unit cost but also on the distribution function G.

Proposition 3.2 *For a private, profit-maximizing airport, there exists a unique optimal concession price, $p_c^\pi > c_c$, which is determined by the following equation,*

$$\bar{G}(p_c^\pi) - g(p_c^\pi)(p_c^\pi - c_c) = 0, \tag{3.17}$$

where superscript π is for "profit maximization". The privately optimal aeronautical charge is

$$p_a^\pi = c_a + \frac{a - c - c_a - H(p_c^\pi)}{2}. \tag{3.18}$$

The proof of Proposition 3.2 is given in Appendix B. It is quite intuitive that the privately optimal concession price is greater than the unit cost. As for aeronautical charge, we write p_a^π in Proposition 3.2 alternatively as

$$p_a^\pi = c_a - H(p_c^\pi) + \left(1 + \frac{1}{n}\right) vQ^\pi + \left(1 + \frac{2b-1}{n}\right) Q^\pi, \tag{3.19}$$

where Q^π is the total number of passengers under profit maximization, and is given by

$$Q^\pi = \frac{n(a - c - p_a^\pi)}{(n+1)v + 2b + n - 1}. \tag{3.20}$$

Thus, the privately optimal aeronautical charge is equal to the airport's unit operating cost, minus per-passenger concession profit, plus an (overcharged) congestion toll, and plus a markup owing to the airport's monopoly market power. Insights derived from comparing equation (3.19) with equation (3.15) are similar to those given in

earlier work (e.g. Basso, 2008). Finally, we note that p_a^π is independent of the time value. This property is useful for the analysis in Section 3.4.

3.4 Price-cap regulation

In Section 3.4.1, we define the efficient aeronautical charge, which will be used for the comparison in Section 3.4.4. Then we will give definitions of single-till and dual-till price-cap regulation in Sections 3.4.2 and 3.4.3, respectively. Finally, we will compare the single-till approach with the dual-till approach in Section 3.4.4.

3.4.1 Efficient aeronautical charge

By the analysis in Section 3.3 we know that for any given aeronautical charge p_a, a profit-maximizing airport will always set concession price at p_c^π. In this section, thereafter, the concession price is fixed at p_c^π unless otherwise specified. Given $p_c = p_c^\pi$, the aeronautical charge a welfare-maximizing regulator will choose is determined by

$$\begin{aligned} \max_{p_a} \quad & SW \\ s.t. \quad & p_c = p_c^\pi. \end{aligned} \tag{3.21}$$

In what follows we shall refer to the solution to problem (3.21) as the "efficient" aeronautical charge. To simplify expressions, we denote $H(p_c^\pi)$ by H, and $I(p_c^\pi)$ by I. By (3.13) and (3.7), we know that the welfare function is a quadratic and concave function of the aeronautical charge. It follows that the efficient aeronautical charge is:

$$p_a^e = c_a + \frac{(a-c-c_a)[(n-1)v-b] - (H+I)[(n+1)v+2b+n-1]}{2nv+b+n-1}, \tag{3.22}$$

where superscript e stands for efficient charge. By comparing (3.22) with (3.14), it is straightforward to show that $p_a^e > p_a^w$. This is expected as while p_a^w is the first-best charge, the efficient charge p_a^e may be considered as the second-best charge - note that the difference between (3.22) and (3.14) comes from the constraint in problem (3.21).

Furthermore, subtracting (3.22) from (3.18) yields

$$p_a^\pi - p_a^e = \frac{(a-c-c_a+H)(2v+3b+n-1)+2I[(n+1)v+2b+n-1]}{2(2nv+b+n-1)} > 0. \tag{3.23}$$

In other words, the efficient aeronautical charge is smaller than the profit-maximizing aeronautical charge, as expected. Taking the first and second derivatives of p_a^e with respect to v, we obtain

$$\frac{dp_a^e}{dv} = \frac{(a-c-c_a+H+I)[(n+1)^2+(3n-1)b]}{(2nv+b+n-1)^2} > 0, \tag{3.24}$$

$$\frac{d^2p_a^e}{dv^2} = -\frac{2n(a-c-c_a+H+I)[(n+1)^2+(3n-1)b]}{(2nv+b+n-1)^3} < 0. \tag{3.25}$$

That is, the efficient aeronautical charge is increasing and concave in the value of time.

3.4.2 Single-till price-cap regulation

Under price-cap regulation, the optimization problem faced by the profit-maximizing airport is as follows:

$$\begin{aligned} \max_{p_a,p_c} \quad & \Pi \\ s.t. \quad & p_a \leq \bar{p}_a, \end{aligned} \tag{3.26}$$

where $\bar{p}_a$ is the price cap being chosen by the regulator to maximize social welfare subject to the airport's cost recovery constraint.

Under single-till price-cap regulation, $\bar{p}_a = p_a^s$, where superscript s represents single-till, and p_a^s is the smallest root of $\Pi(p_a, p_c^\pi) = 0$.[9] It follows that

$$p_a^s = c_a + \frac{a-c-c_a-H-\sqrt{(a-c-c_a+H)^2-4F[(n+1)v+2b+n-1]/n}}{2}. \tag{3.27}$$

To ensure that the single-till price cap is well defined, i.e. the expression under the

[9] In the present paper, we follow the common definition of single-till and dual-till price-cap regulations in the literature, e.g. Oum et al. (2004), Czerny (2006), and Zhang and Zhang (2010). This definition might be considered as a "strict" interpretation of price-cap regulation, and we discuss the issue further in the concluding remarks.

square root in (3.27) is non-negative, we must have

$$v \leq v_s \equiv \frac{n(a-c-c_a+H)^2}{4(n+1)F} - \frac{2b+n-1}{n+1}. \tag{3.28}$$

Since the airport profit $\Pi(p_a, p_c^\pi)$ is concave in p_a, we have $p_a^s < p_a^\pi$, i.e. the singe-till price cap is smaller than the profit-maximizing aeronautical charge. Therefore, under single-till price-cap regulation, the price-cap constraint will be binding. That is, the profit-maximizing airport will choose p_a^s as the aeronautical charge.

Taking the first and second derivatives of p_a^s with respect to v yields

$$\frac{dp_a^s}{dv} = 2F(n+1)\left((a-c-c_a+H)^2 - 4F[(n+1)v+2b+n-1]/n\right)^{-\frac{1}{2}} > 0, \tag{3.29}$$

$$\frac{d^2p_a^s}{dv^2} = 4F^2(n+1)^2\left((a-c-c_a+H)^2 - 4F[(n+1)v+2b+n-1]/n\right)^{-\frac{3}{2}} > 0. \tag{3.30}$$

Similar to the efficient aeronautical charge, the single-till price cap is also increasing in the value of time. But it is convex (rather than concave as for the efficient aeronautical charge) in the time value.

3.4.3 Dual-till price-cap regulation

We now examine dual-till price-cap regulation. Following Czerny (2006), we rewrite the airport's profit as

$$\Pi = \Pi_a + \Pi_c, \tag{3.31}$$

where $\Pi_a = (p_a - c_a)Q^* - \lambda F$ and $\Pi_c = Q^*H(p_c) - (1-\lambda)F$ are the aeronautical profit and the commercial profit, respectively. The fixed cost of the airport is F, of which a fraction $\lambda \in (0,1)$ is attributed to aeronautical services, with the remaining fraction to concession activities.

Under dual-till price-cap regulation, $\bar{p}_a = p_a^d$, where superscript d represents dual-till, and p_a^d is the smallest root of $\Pi_a(p_a) = 0$. Solving $\Pi_a(p_a) = 0$ yields

$$p_a^d = c_a + \frac{a-c-c_a-\sqrt{(a-c-c_a)^2 - 4\lambda F[(n+1)v+2b+n-1]/n}}{2}. \tag{3.32}$$

Analogous to the single-till price cap, to ensure that the dual-till price cap is well

defined we must have

$$v \leq v_d \equiv \frac{n(a-c-c_a)^2}{4(n+1)\lambda F} - \frac{2b+n-1}{n+1}. \tag{3.33}$$

It is not difficult to verify that the dual-till price cap is also increasing and convex in the value of time.

In order to make sure that under dual-till price-cap regulation, the private profit-maximizing airport makes non-negative profit from concession activities, we assume that $\Pi_c(p_a^d, p_c^\pi) \geq 0$. Otherwise, the private airport will not provide concession services. The non-negative concession profit implies

$$v \leq v_c \equiv \frac{nH(a-c-c_a+H)}{2(n+1)(1-\lambda)F} - \frac{2b+n-1}{n+1}. \tag{3.34}$$

Thereafter, we assume

$$v \leq \bar{v} \equiv \min\{v_c, v_s, v_d\}, \tag{3.35}$$

which ensures that the single-till and dual-till price caps are well-defined, and the concession profit is non-negative under the dual-till scheme.

Notice that

$$\Pi(p_a^d, p_c^\pi) = \Pi_a(p_a^d) + \Pi_c(p_a^d, p_c^\pi) = \Pi_c(p_a^d, p_c^\pi) \geq 0 = \Pi(p_a^s, p_c^\pi), \tag{3.36}$$

where the second equality follows from the property that $\Pi_a(p_a^d) = 0$. Since $\Pi(p_a, p_c^\pi)$ is concave in p_a and p_a^s is the smallest root, it follows, by (3.36), that

$$p_a^s \leq p_a^d. \tag{3.37}$$

Solving $p_a^d = p_a^\pi$ yields

$$v = v_0 \equiv \frac{n[(a-c-c_a)^2 - H^2]}{4(n+1)\lambda F} - \frac{2b+n-1}{n+1}. \tag{3.38}$$

Recall that p_a^d is increasing in v, and p_a^π is, by Proposition 2.2, independent of v. If $v_0 \geq \bar{v}$, then $p_a^d \leq p_a^\pi$ for any $v \leq \bar{v}$, and so dual-till price-cap regulation will be binding. If $v_0 < \bar{v}$, then $p_a^d \leq p_a^\pi$ for $v \leq v_0$, and $p_a^d > p_a^\pi$ for $v_0 < v \leq \bar{v}$. Note that dual-till price-cap regulation will not be binding when $p_a^d > p_a^\pi$: The profit-maximizing

airport will choose p_a^π as the aeronautical charge. Let p_a^D be the aeronautical charge chosen by the profit-maximizing airport under dual-till price-cap regulation. Then we must have

$$p_a^D = \min\{p_a^d, p_a^\pi\}. \tag{3.39}$$

It follows that $p_a^D = p_a^d$ when $v \leq \min\{v_0, \overline{v}\}$, and $p_a^D = p_a^\pi$ when $\min\{v_0, \overline{v}\} < v \leq \overline{v}$. Given $p_a^s \leq p_a^d$ and $p_a^s \leq p_a^\pi$, (3.39) then indicates that

$$p_a^s \leq p_a^D. \tag{3.40}$$

Inequality (3.40) verifies the commonly held belief that the aeronautical charge under single-till price-cap regulation is smaller than that under dual-till price-cap regulation (see, e.g. Bilotkach et al., 2010 for empirical evidence).

Before comparing single-till and dual-till price-cap regulations, we summarize the above results:

Proposition 3.3 *(i) The efficient aeronautical charge, p_a^e, is increasing and concave in time value v.*

(ii) The aeronautical charge under single-till price-cap regulation, p_a^s, is increasing and convex in v.

(iii) The aeronautical charge under dual-till price-cap regulation, p_a^D, is increasing and convex in v when $v \leq \min\{v_0, \overline{v}\}$, and remains constant when $\min\{v_0, \overline{v}\} < v \leq \overline{v}$.

(iv) The aeronautical charge under single-till price-cap regulation is less than that under dual-till price-cap regulation, i.e. $p_a^s \leq p_a^D$.

3.4.4 Single-till vs. dual-till price-cap regulation

A privatized airport needs to be financially self-sufficient. Hence, a natural regulation benchmark is that the regulator maximizes social welfare by setting the aeronautical charge, subject to the airport's cost recovery constraint:

$$\begin{aligned} \max_{p_a} \quad & SW \\ s.t. \quad & \Pi \geq 0, \\ & p_c = p_c^\pi. \end{aligned} \tag{3.41}$$

Notice that the only difference between the benchmark problem (3.41) and the welfare-maximizing problem (3.21) is the airport's cost recovery constraint. If the efficient aeronautical charge p_a^e satisfies the airport's cost recovery constraint, then p_a^e is the "benchmark aeronautical charge", i.e. the optimal solution to (3.41). Otherwise, the benchmark aeronautical charge must be greater than p_a^e to make the airport break even. Below, we will derive the benchmark aeronautical charge "case by case". Recall that SW is a quadratic and concave function of p_a. Therefore, whether single-till or dual-till regulation yields higher welfare depends on whether the aeronautical charge under single-till or dual-till regulation is closer to the benchmark aeronautical charge.

In order to compare single-till and dual-till price-cap regulations, we plot the efficient aeronautical charge (p_a^e), the aeronautical charges under the single-till and dual-till schemes (p_a^s and p_a^D), and the privately optimal aeronautical charge (p_a^π) against the value of time (v). There are three scenarios.

<u>Scenario 1</u>: The efficient aeronautical charge curve is always below the aeronautical charge curve under single-till price-cap regulation. See Figure 3.1.[10]

As shown in Figure 3.1, we have $p_a^e < p_a^s < p_a^D \leq p_a^\pi$. By the definition of the single-till scheme, to achieve cost recovery the minimum aeronautical charge is p_a^s. Setting the aeronautical charge at p_a^e will lead to negative airport profit. Since SW is a quadratic and concave function of p_a, then p_a^s is the benchmark aeronautical charge. This implies that single-till regulation dominates dual-till regulation with respect to welfare maximization.

<u>Scenario 2</u>: The efficient aeronautical charge curve intersects with the aeronautical charge curves under both single-till and dual-till price-cap regulations. See Figure 3.2.

Scenario 2 is much more complicated than scenario 1. The curve p_a^e intersects with both p_a^s and p_a^D. Let v_1, v_2, v_3, and v_4 be the intersection points (shown in Figure 3.2) where v_1 and v_2 are the zeros of $\Pi(p_a^e, p_c^\pi) = 0$, while v_3 and v_4 are the zeros of $\Pi_a(p_a^e) = 0$. There are three possible cases here:

Case 1: When $v < v_1$ or $v > v_2$, we have $\Pi(p_a^e, p_c^\pi) < 0$, i.e. with the efficient aeronautical charge and its concession profit, the airport is not able to cover the fixed airport cost. In this case, we have $p_a^e < p_a^s < p_a^D \leq p_a^\pi$. Hence, analogous to scenario

[10] In Figures 3.1, 3.2 and 3.4, we assume that $v_0 < \bar{v}$. If $v_0 \geq \bar{v}$, then $p_a^D = p_a^d$, and so the analysis will be similar but simpler.

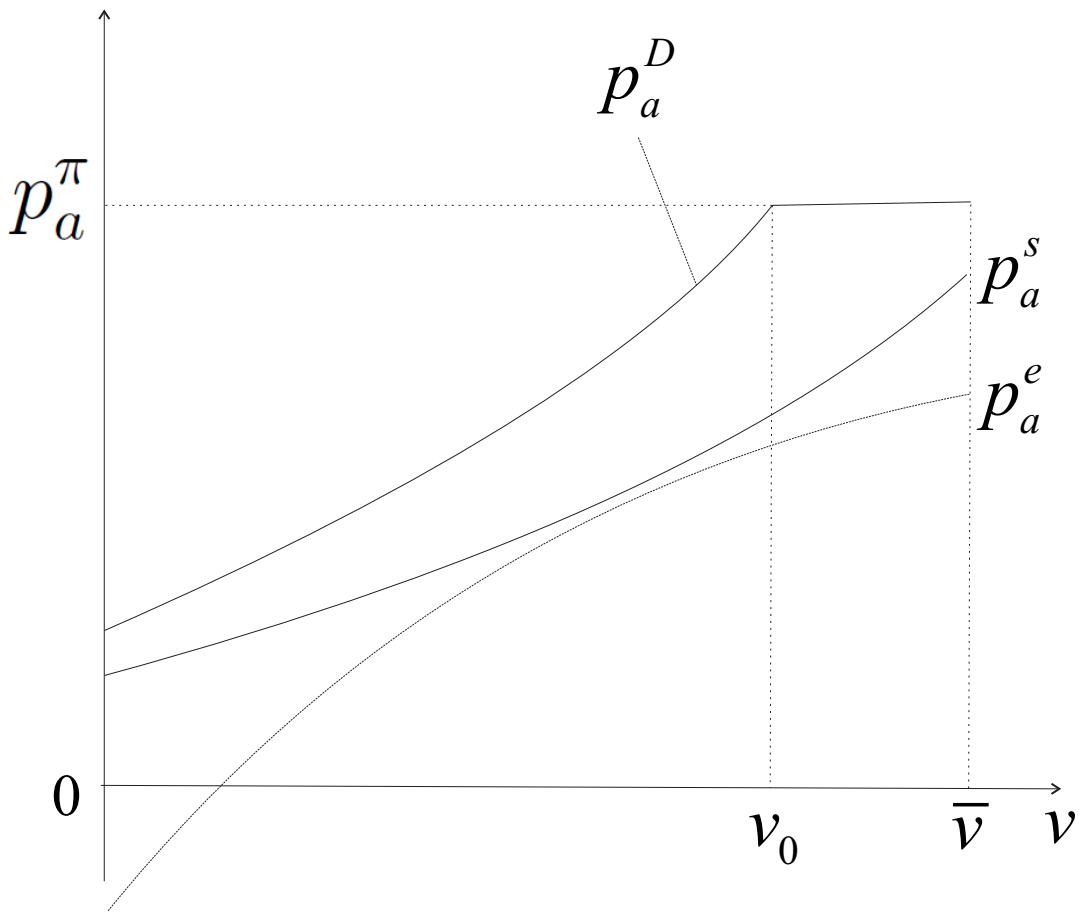

Figure 3.1: The efficient aeronautical charge curve is below the aeronautical charge curve under the single-till regulation

1, single-till regulation performs better than dual-till regulation.

Case 2: When $v_3 \leq v \leq v_4$, we have $\Pi_a(p_a^e) \geq 0$, i.e. with the efficient aeronautical charge only, the airport covers the airport cost associated with aeronautical services. As depicted in Figure 3.2, $p_a^s < p_a^D \leq p_a^e < p_a^\pi$. By the definition of the single-till scheme, to achieve cost recovery the minimum aeronautical charge is p_a^s. Hence, the efficient aeronautical charge p_a^e satisfies the airport's cost recovery constraint, and so p_a^e is the benchmark aeronautical charge. Since $p_a^s < p_a^D \leq p_a^e$, dual-till regulation then dominates single-till regulation.

Case 3: When $v_1 \leq v < v_3$, or $v_4 < v \leq v_2$, we have $\Pi_a(p_a^e) < 0$ and $\Pi(p_a^e, p_c^\pi) \geq 0$. Figure 3.2 shows that in this case. Following the same reasoning as in case 2, is the benchmark aeronautical charge. In this case, we need to compare $SW(p_a^s, p_c^\pi)$ and $SW(p_a^D, p_c^\pi)$. Since SW is a quadratic and concave function of p_a, we only need to

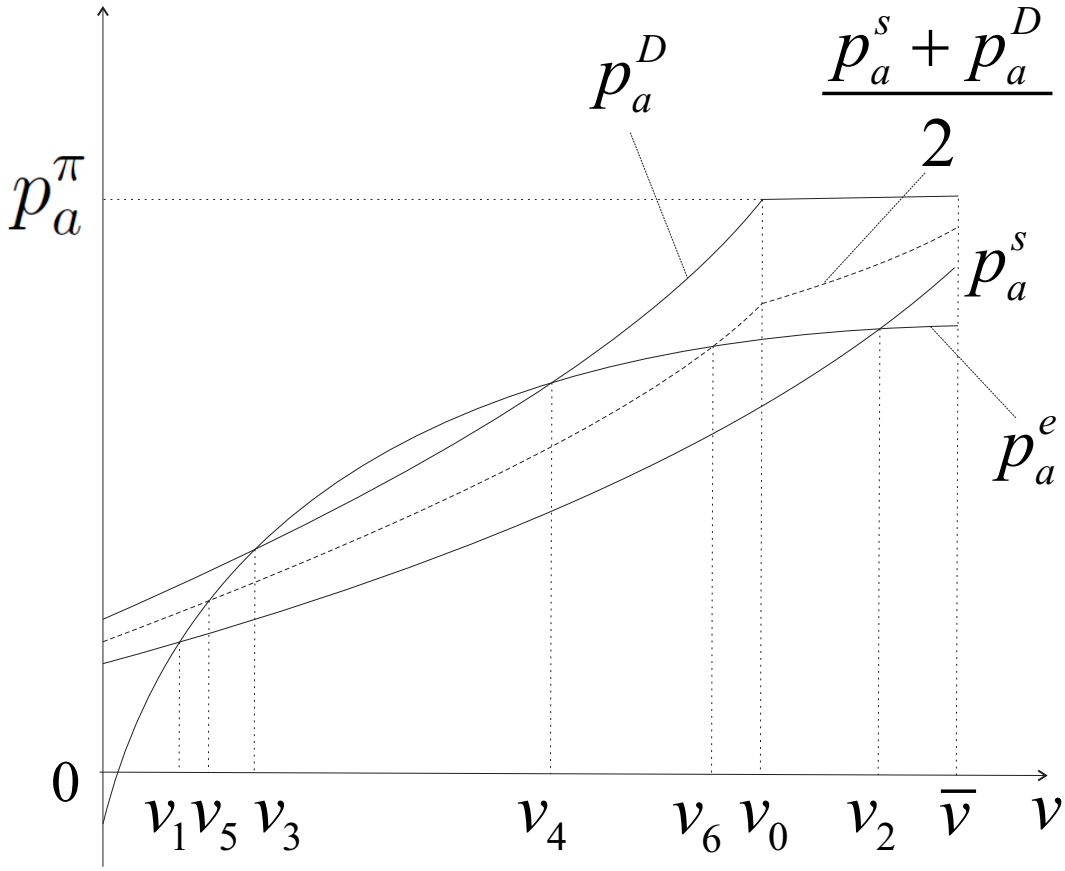

Figure 3.2: The efficient aeronautical charge curve intersects with the aeronautical charge curves under both the single-till and dual-till regulations

compare $p_a^e - p_a^s$ with $p_a^D - p_a^e$. Equating $p_a^e - p_a^s$ with $p_a^D - p_a^e$ yields

$$p_a^e = \frac{p_a^s + p_a^D}{2}. \tag{3.42}$$

Therefore, if $p_a^e > \frac{p_a^s + p_a^D}{2}$, then dual-till regulation yields higher social welfare. Otherwise, single-till regulation dominates. From Figure 3.2 it is easy to see that equation (3.42) has two roots, v_5 and v_6.

Let $\Delta SW = SW(p_a^s, p_c^\pi) - SW(p_a^D, p_c^\pi)$. We can plot ΔSW as a function of v. Figure 3.3 depicts that from the perspective of welfare maximization, single-till regulation dominates dual-till regulation when the value of time is sufficiently small ($v < v_5$) or sufficiently large ($v > v_6$); while the dual-till regulation is better when the value of time is intermediate ($v_5 < v < v_6$).

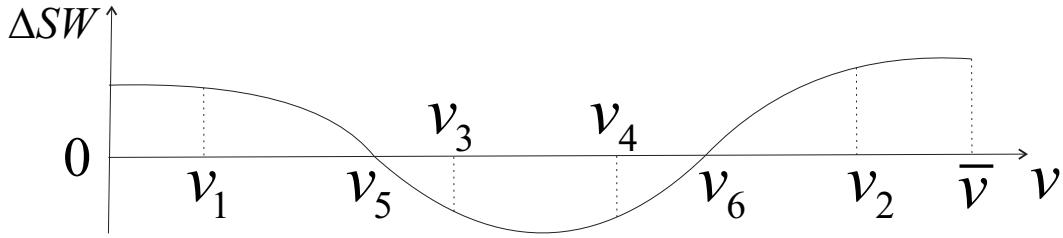

Figure 3.3: The welfare difference between single-till and dual-till regulations under Scenario 2: $\Delta SW > 0$ implies single-till regulation yields higher welfare, while $\Delta SW < 0$ implies dual-till regulation yields higher welfare

The intuition of Figure 3.3 can be explained as follows. When the value of time is sufficiently small, both passengers and airlines do not care about congestion delays and behave as if there were no airport congestion. As a consequence, airport congestion is not a problem. This result is consistent with Czerny (2006): At an airport with no congestion, single-till price-cap regulation dominates dual-till price-cap regulation with respect to welfare maximization. When the value of time is sufficiently large, the number of passengers will be very small, though airfares may be low. As a result, the level of congestion and hence absolute delays will, in equilibrium, be very low. However, the low equilibrium quantities are due to the fact that passengers and airlines are very sensitive to congestion delays. In this sense, airport congestion is a major problem. When the value of time is intermediate, airport congestion exists and matters to passengers and airlines as they do care about congestion delays. In particular, Figure 3.3 shows that when the value of time is intermediate, dual-till regulation performs better than single-till regulation.

<u>Scenario 3</u>: The efficient aeronautical charge curve intersects with the aeronautical charge curve under single-till price-cap regulation, but it is always below that under dual-till price-cap regulation. See Figure 3.4.

Scenario 3 is similar to scenario 2 except that the efficient aeronautical charge is always below the aeronautical charge under dual-till price-cap regulation. As a result, we have two cases. To save notations, we continue to use the same v_i's as in scenario 2.

Case 1: When $v < v_1$ or $v > v_2$: Same as case 1 of scenario 2, single-till price-cap regulation dominates dual-till price-cap regulation.

Case 2: When $v_1 \leq v \leq v_2$, we have $\Pi_a(p_a^e) < 0$ and $\Pi(p_a^e, p_c^\pi) \geq 0$. Analogous to case 3 of scenario 2, if $p_a^e > \frac{p_a^s + p_a^D}{2}$, then dual-till price-cap regulation yields

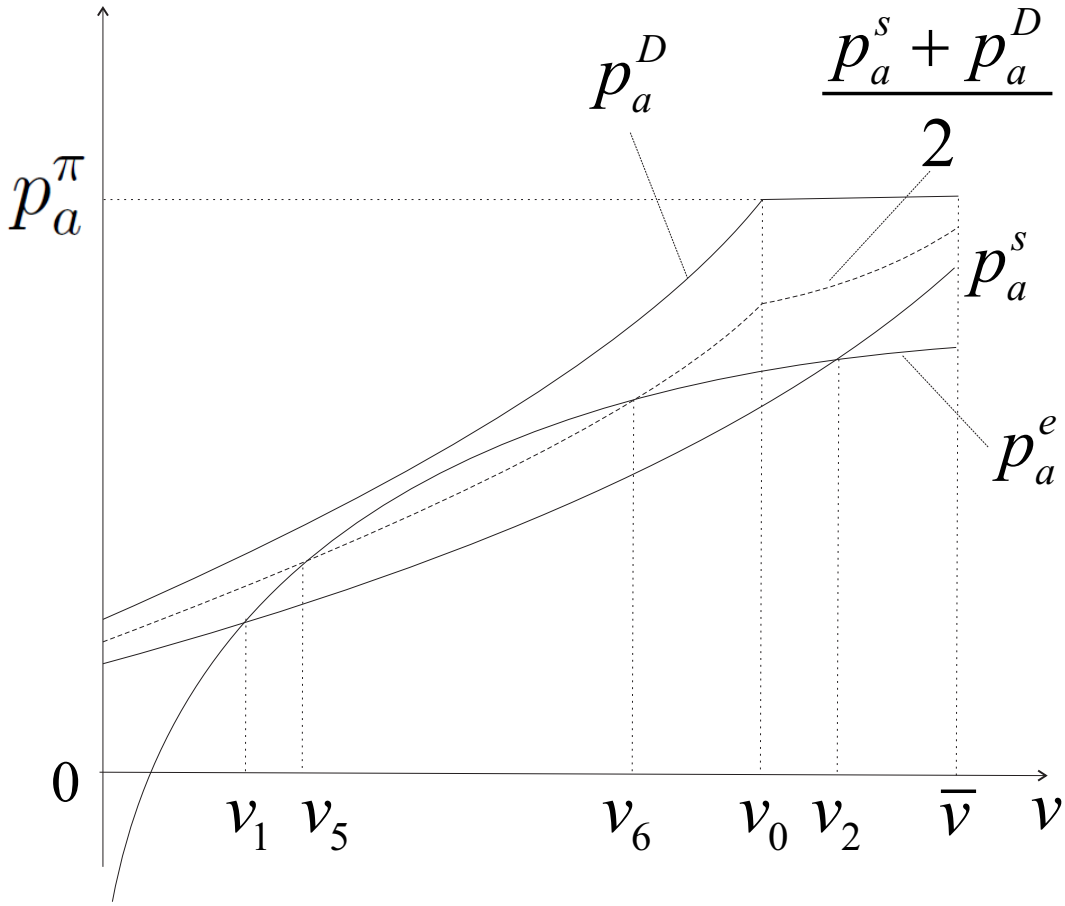

Figure 3.4: The efficient aeronautical charge curve intersects with the aeronautical charge curve under single-till regulation, but is below that under dual-till regulation

higher welfare than single-till price-cap regulation. Otherwise, single-till price-cap regulation dominates. Note that it is possible that equation (3.42) has no roots in this case.

Proposition 3.4 summarizes the comparisons between single-till and dual-till price-cap regulations:

Proposition 3.4 *From the perspective of welfare maximization,*

(i) If the airport is not able to cover the fixed airport cost with the efficient aeronautical charge and its concession profit, i.e. $\Pi(p_a^e, p_c^\pi) < 0$*, then single-till price-cap regulation dominates dual-till price-cap regulation.*

(ii) If with only the efficient aeronautical charge the airport covers the airport cost associated with aeronautical services, i.e. $\Pi_a(p_a^e) > 0$*, then dual-till price-cap regulation performs better.*

(iii) Otherwise, the comparison depends on whether the efficient aeronautical charge is greater than the average of the aeronautical charges under single-till and dual-till regulations, i.e. $p_a^e > \frac{p_a^s + p_a^D}{2}$*. If so, then dual-till regulation dominates single-till regulation. Otherwise, single-till regulation is better.*[11]

Proposition 3.4 shows that neither single-till regulation nor dual-till regulation always yields higher social welfare. From scenarios 1 to 3, we may conclude that single-till regulation dominates dual-till regulation when the value of time is sufficiently small or sufficiently large. However, when the value of time is intermediate, dual-till regulation can perform better than single-till regulation under scenarios 2 and 3. In particular, dual-till regulation is better when the conditions in Proposition 3.4(ii) and 3.4(iii) are satisfied.

3.5 Concluding remarks

Our main objective in writing this paper is to contribute to a better understanding of airport regulation by comparing single-till price-cap regulation with dual-till price-cap regulation. We have extended Czerny (2006)'s work by introducing congestion delays and oligopoly airlines at an airport. We showed that when airport congestion is not a significant problem, single-till price-cap regulation dominates dual-till price-cap regulation in terms of social welfare. Furthermore, when airport congestion is significant, we find conditions under which dual-till regulation performs better than single-till regulation. A sufficient condition is that the efficient aeronautical charge raises enough revenue to cover the airport cost associated with aeronautical services.

The paper has also raised several issues and avenues for future research. First, for analytical tractability we have assumed the linear demand and the linear congestion delay functions. It would be interesting to see whether the results are robust in

[11] Proposition 3.4(iii) is a direct consequence of the assumptions of linear demands and linear congestion delays. Due to these assumptions, the welfare function is quadratic and concave in the aeronautical charge. In general, the critical point is not necessarily the average of the aeronautical charges under single-till and dual-till price-cap regulations. However, there must be some critical point as long as the welfare function is concave in the aeronautical charge. We discuss the issue of functional forms further in the concluding remarks.

a more general setting. Second, we have assumed that the airport capacity is fixed. Incorporating airport capacity as a decision variable is an important direction for future research. Third, we focus on a static model. In practice, price-cap regulations on airport charges are usually adjusted every (say) five years. It is therefore practically relevant to explore the dynamic nature of price-cap regulations. Fourth, following the literature on airport regulation, we do not consider regulatory costs, which can be significant. Incorporating regulatory costs into our framework would be an interesting research direction. Fifth, following the literature on price-cap regulation, we have adopted the "strict" interpretation of single-till and dual-till price-cap regulation. Alternatively, one might consider a more "flexible" interpretation of single-till and dual-till price-cap regulation. More specifically, define the flexible single-till (dual-till, respectively) price cap as the maximum of the welfare-maximizing airport charge and the strict single-till (dual-till, respectively) price cap. Given these interpretations, it would be interesting to compare the performance of the flexible single-till and dual-till schemes.

Finally, a number of airports in the world are contemplating to switch from their existing rate-of-return (ROR) regulation to price-cap regulation. Under ROR regulation, the regulated firm is allowed to charge the price that would prevail in a competitive market, which is equal to efficient costs of production plus a market-determined rate of return on capital. A major limitation of the ROR approach is the well-known Averch-Johnson effect: i.e. if the allowable rate of return is set too high, the regulated firm can increase its profit by increasing capital assets and consequently, it has an over-investment tendency (Averch and Johnson, 1962). Concerns also exist regarding productive inefficiency: in particular, the cost-based nature of ROR regulation suggests that airports would not benefit from cost reduction. While recent empirical studies by Bel and Fageda (2010) and Bilotkach et al. (2010) find no significant difference between these two types of regulation in terms of airport charges, it is important to compare the two analytically in terms of prices, profits and social welfare.

Chapter 4

Impact of Discounting and Competition on Benefit of Decentralization with Strategic Customers [1]

4.1 Introduction

Accustomed to frequent sales and promotions, many consumers will wait for better prices even if their willingness-to-pay is higher than the current retail price. Strategic or forward-looking customers anticipate future price reductions, and optimize their purchase timing to maximize their expected payoffs. There is much evidence of strategic customer behavior in practice. For example, the Wall Street Journal (McWilliams, 2004) reported that Best Buy found that around 20% of its customers were not profitable, and labeled them as "devils". Due to these customers' behavior of waiting for sales, applying for refunds and rebates, etc., they represent a loss in profit for Best Buy. Melnikov (2001) provides evidence from the US printer market that supports the hypothesis of forward-looking behavior among customers. The author finds that customer discounting has a significant impact on demand. Song and Chintagunta (2003) show that empirical data from the digital camera

[1] A version of this chapter has been submitted for publication. We thank Chris Ryan, Yehuda Bassok, Harish Krishnan, Mahesh Nagarajan, Maurice Queyranne, Yunzeng Wang, Ralph Winter, Anming Zhang, and Fuqiang Zhang for their constructive comments on earlier versions of this paper.

category are consistent with the presence of strategic customer behavior. In the videogame industry, Nair (2007) finds similar evidence of consumer forward-looking behavior. In that study, simulations reveal a profit loss of nearly 30% when strategic customer behavior is ignored, and demonstrate that increased information about consumer discounting is valuable. Even in the specialized market of college textbooks, Chevalier and Goolsbee (2005) find strong evidence that students are strategic and have rational expectations of publishers' revision behavior.

We develop a dynamic two-period model consisting of one manufacturer who sells a product through multiple retailers under linear wholesale price contracts. The manufacturer produces each unit of product at a constant marginal cost. Customers are strategic and heterogeneous in their valuations of the product. Both customers and firms discount their future payoffs, but with different discount factors. We assume that the manufacturer acts as a Stackelberg leader. At the beginning of the first period, the manufacturer announces a wholesale price to the retailers. Then the retailers simultaneously decide how much to order from the manufacturer. Observing the first period supply, customers rationally anticipate the second period supply, and make purchase decisions. The same sequence occurs for the second period except customers do not need to form rational expectations of future supply. We emphasize that the manufacturer and retailers cannot make credible commitments to future prices or quantities, either internally (manufacturer to retailers) or externally (manufacturer and retailers to customers). We derive retail prices through the underlying utility model.

With strategic customers, we find that there exists a wide range of customer and firm discount factors under which a decentralized channel has higher profit than a centralized channel in our model. The message that a centralized channel is not always the best has already been discovered in the existing literature. The key driving force identified in this literature is that double marginalization can reduce the time inconsistency problem (Coase, 1972), and so may improve the decentralized channel profit. We find that different customer and firm discount factors are essential in making the decentralized channel profit higher. Indeed, we show that without discounting, the double marginalization effect is not enough to make the profit of a decentralized channel exceed that of a centralized channel in our setting. Interestingly, we also find that the range of discount factors under which the decentralized channel profit is higher is much wider with two competing retailers than with one

single retailer.

We also explore the impact of demand uncertainty. Roughly speaking, we find that demand uncertainty reduces the extent to which strategic customers wait. In addition to customer discounting, it provides customers an incentive to purchase early. The finding confirms that customer and firm discounting is indispensable for the phenomenon that a decentralized channel earns higher profit than a centralized channel.

One of the earliest papers which studies strategic customer behavior is Coase (1972), who argues that without customer and firm discounting, facing strategic consumers, a durable goods monopolist loses monopoly power, and the only subgame perfect equilibrium pricing strategy is a uniform price which equals to the marginal cost. The "no discounting" assumption is essential for the Coase outcome. von der Fehr et al. (1995) prove that if the firm discount factor is significantly larger than the customer discount factor (i.e. the firm is much more patient than the customers), the Coase outcome is not sustainable.

Three recent papers study the benefit of decentralization when customers are strategic, and find that the profit of a decentralized channel may exceed that of a centralized channel. Arya and Mittendorf (2006), and Su and Zhang (2008) assume no customer and firm discounting, and claim that adding customer and firm discounting will not alter their conclusion, which is easily verified. Desai et al. (2004) assume a common discount factor for both customers and firms. It is not difficult to verify that considering different customer and firm discount factors will not affect their main results. However, we show that different customer and firm discount factors are essential in making the decentralized channel profit higher in our model. Indeed, we find that without discounting, the double marginalization effect is not enough to make the profit of a decentralized channel higher than that of a centralized channel. Thus, our paper focuses interest on the impact of discounting, whilst others consider models where discounting is not a major feature. Our results indicate that discounting does play a pivotal role in the qualitative outcomes discussed in the paper, which is our highlighted point of contrast with existing literature.

The strategic behavior of consumers has been widely recognized in the consumer behavior literature: Bell et al. (2002), Krishna et al. (1991), Ho et al. (1998), Guo and Villas-Boas (2007). The literature focuses mainly on the consumable products like groceries. One important phenomenon is that consumers stockpile for future consumption to take advantage of low prices during price promotions or sales.

Recently, strategic customer behavior has attracted a lot of attention in operations management. The following list of papers is only a representative list. Aviv and Pazgal (2008) investigate the optimal pricing of selling a finite quantity of a fashion-like seasonal good, in the presence of forward-looking customers. Elmalghraby et al. (2008) study optimal markdown mechanisms in the presence of rational customers with multi-unit demands. Liu and van Ryzin (2008) study whether it is optimal for a firm to create rationing risk by deliberately understocking products. Levin et al. (2010) present a dynamic pricing model of a monopolist selling perishable products. Levin et al. (2009) consider dynamic pricing for oligopolistic firms selling differentiated perishable products to strategic consumers. Jerath et al. (2010) use the Hotelling model to explain and compare the benefit of last-minute sales directly to consumers vs. through an opaque intermediary. Cachon and Swinney (2009) study purchasing and pricing decisions of a monopolist facing bargain-hunters, myopic and strategic consumers. Su (2007) considers a heterogenous population of strategic as well as nonstrategic customers, and shows that depending on the customer market composition, optimal price paths can involve either markdowns or markups. Yin et al. (2008) compare two inventory display formats (Display All and Display One) for a retailer who sells a limited inventory of a product over a finite selling season. Lai et al. (2010) investigate the impact of posterior price matching on profit with strategic consumers. Dasu and Tong (2010) study dynamic policies for a monopolist selling perishable products over a finite horizon to strategic consumers. Su and Zhang (2009) study the role of product availability in attracting consumer demand. Shen and Su (2007) offer a nice review on customer behavior modeling in revenue management and auctions.

All the papers in the above list do not consider strategic customer behavior in a supply chain setting. Moreover, they all focus on monopolist setting except Levin et al. (2009). In contrast, we study strategic customer behavior in a supply chain. Furthermore, we investigate the impact of retailer competition in a decentralized channel.

The remainder of this paper is organized as follows. In Section 4.2, we present the basic model and derive retail prices from the underlying utility model. In Section 4.3, we first analyze the benchmark case: a centralized channel with the ability to commit. Then we consider a centralized channel without commitment, and compare the results with the benchmark case. Next, we solve the decentralized channel case under dynamic linear wholesale price contracts. Then we analyze the impact of demand uncertainty. We conclude in Section 4.4.

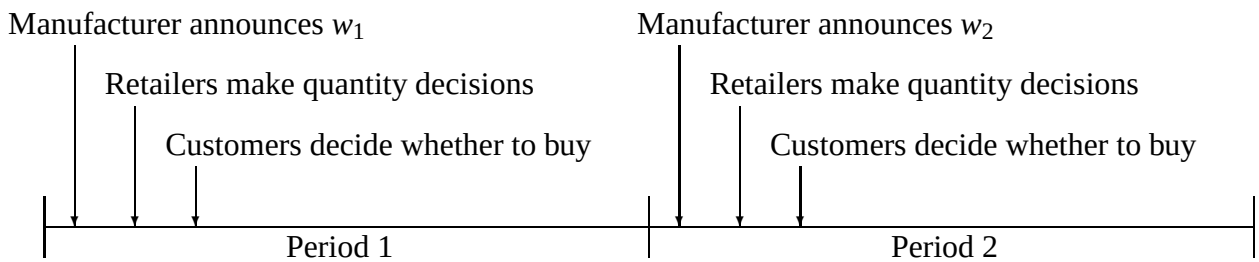

Figure 4.1: The sequence of the two-period model

4.2 Basic model

We consider a dynamic two-period model consisting of one manufacturer who sells a product through n symmetric retailers who are engaged in Cournot competition. The manufacturer produces each unit of product at constant marginal cost c, and sells to downstream retailers through linear wholesale price contracts. Customers are strategic, i.e., they compare current surplus with future surplus, and choose when to buy to maximize the present value of their payoffs. We assume customers buy at most one unit of the product in the two-period horizon. Customers are heterogeneous in their valuations of the product. The valuation can be interpreted as the lifetime utility a consumer obtains from consuming the product. For example, the valuation of a pair of shoes can be considered as the total value of using it until it wears out. Their willingness-to-pay is assumed to be uniformly distributed in the interval $[0,1]$. Many papers on strategic customer behavior assume uniformly distributed valuations, e.g., Besanko and Winston (1990); Desai et al. (2004, 2007); Liu and van Ryzin (2008); Cachon and Swinney (2009).

We assume both customers and firms are risk neutral. Customers discount future payoffs at factor $\delta_c \in [0,1]$, which can be interpreted as how much they value future consumption. Alternatively, the value of δ_c measures the degree of patience of a customer. If $\delta_c = 1$, then we say that the customer is "fully strategic". At the other extreme, a customer with discount factor $\delta_c = 0$ is not strategic, in other words, myopic. The manufacturer and the retailers have a common discount factor $\delta_f \in [0,1]$, which can be interpreted as how much they value future profits.

We assume all the customers arrive at the beginning of the first period. In the basic model, the total market size, denoted by N, is deterministic. In Section 4.3.4, we explore the impact of demand uncertainty. The customer valuation distribution, the customer and firm discount factors, as well as the total market size are common

knowledge. Recall that firms cannot make credible commitments to future actions. In other words, firms make decisions sequentially to maximize their own profits.

The sequence of the game is illustrated in Figure 4.1. At the beginning of period t, the manufacturer announces a linear wholesale price contract w_t to the retailers ($t = 1, 2$). The retailers simultaneously choose the quantities to sell in the market. Customers make their purchasing decisions. Customers do not observe the wholesale price and the retailers' quantity decisions in either period. Let q_{it} be the order quantities of retailer i in period t, where $i = 1, 2, \cdots, n$, and $t = 1, 2$. For notational convenience, denote the total supply in period t by $Q_t := \sum_{i=1}^{n} q_{it}$. Let Q_t^* be the optimal total supply in period t, and let Q_t^e be customers' rational expectations of the total supply in period t. In equilibrium, Q_t^e should be equal to Q_t^*. Note that retail prices clear the market in each period. However, because customers are strategic, retail prices in both periods depend on both the first period supply and the second period supply. Let p_t be the resulting retail price in period t. We derive the retail prices through the underlying utility model.

Depending on when and whether to purchase the product, in equilibrium, there are three strategies that a customer can choose:

(i) do not buy in the first period, and buy in the second period (denoted by 'NB');

(ii) buy in the first period, and do not buy in the second period (denoted by 'BN');

(iii) do not buy in both periods (denoted by 'NN').

First, let us look at the lowest valuation customer who adopts the 'NB' strategy in equilibrium. Let v_2 be the valuation of this customer. Since customers' valuations are uniformly distributed over the interval $[0, 1]$ then we have $N(1 - v_2)/(1 - 0) = Q_1^* + Q_2^*$. It follows that $v_2 = 1 - (Q_1^* + Q_2^*)/N$. This customer must be indifferent between the 'NB' strategy and the 'NN' strategy. The net utility from following the 'NB' strategy is $v_2 - p_2$, and the net utility from adopting the 'NN' strategy is 0. Then $v_2 - p_2 = 0$, and so

$$p_2 = 1 - (Q_1^* + Q_2^*)/N. \tag{4.1}$$

Now consider the lowest valuation customer who chooses the 'BN' strategy in equilibrium. Denote the valuation of this customer by v_1. Then $N(1 - v_1) = Q_1^*$, and so $v_1 = 1 - Q_1^*/N$. This customer has to be indifferent between the 'BN' strategy and the 'NB' strategy. The net utility from following the 'BN' strategy is $v_1 - p_1$, and

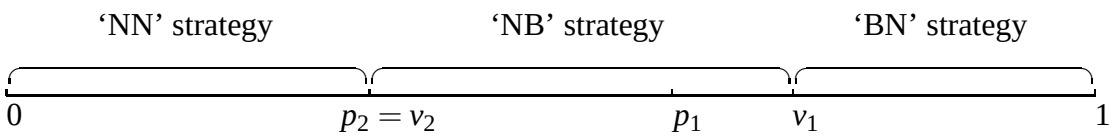

Figure 4.2: Customers' equilibrium purchasing strategies

the net utility from adopting the 'NB' strategy is $\delta_c(v_1 - p_2)$. Then we must have $v_1 - p_1 = \delta_c(v_1 - p_2)$. It follows that

$$p_1 = 1 - (Q_1^* + \delta_c Q_2^*)/N. \tag{4.2}$$

Figure 4.2 illustrates customers' purchasing strategies in equilibrium. Note also that the strategic customer behavior in our model is captured in equation (4.2) through the term $\delta_c Q_2^*$. Setting $\delta_c = 0$ in equation (4.2) yields that $p_1 = v_1 = 1 - Q_1^*/N$. In other words, if customers are myopic, then customers with valuations above p_1 will buy in the first period, and the first period price depends only on the first period supply.

4.3 Analysis

4.3.1 Benchmark

Let us first solve the the benchmark case: a centralized channel with the ability to credibly commit to future production decisions. We use the superscript 'CC' to represent the optimal values chosen by a centralized channel with commitment, where the first 'C' stands for centralized channel, and the second 'C' stands for commitment. The optimization problem faced by the centralized seller with commitment is:

$$\max_{Q_1,Q_2} \Pi = \max_{Q_1,Q_2} \{(p_1 - c)Q_1 + \delta_f (p_2 - c)Q_2\},$$

where p_1 and p_2 are given in equations (4.1) and (4.2).

Proposition 4.1 *Depending on whether the firm discount factor δ_f is larger than customer discount factor δ_c, we have the following two cases.*

(a) If $\delta_f > \delta_c$, then the optimal quantities and profit are

$$\begin{aligned} Q_1^{CC} &= N(1-c)(2-\delta_c-\delta_f)\delta_f/(4\delta_f-2\delta_c\delta_f-\delta_c^2-\delta_f^2), \\ Q_2^{CC} &= N(1-c)(\delta_f-\delta_c)/(4\delta_f-2\delta_c\delta_f-\delta_c^2-\delta_f^2), \\ \Pi^{CC} &= N(1-c)^2(1-\delta_c)\delta_f/(4\delta_f-2\delta_c\delta_f-\delta_c^2-\delta_f^2). \end{aligned}$$

(b) If $\delta_f \leq \delta_c$, then the optimal quantities and profit are

$$\begin{aligned} Q_1^{CC} &= N(1-c)/2, \\ Q_2^{CC} &= 0, \\ \Pi^{CC} &= N(1-c)^2/4. \end{aligned}$$

Note that all the proofs in this chapter are provided in Appendix C.

When the seller is more patient than the customers (customers discount future payoffs more than the seller), then the seller will produce positive quantities in each period. As expected, the channel profit decreases in customer discount factor δ_c, and increases in firm discount factor δ_f. The maximum profit $N(1-c)^2/3$ is achieved at $\delta_c = 0$ and $\delta_f = 1$. When customers are at least as patient as the seller, then the seller produces nothing in the second period, and makes a constant profit $N(1-c)^2/4$. Note that Desai et al. (2004) and Arya and Mittendorf (2006) consider a special case of Proposition 4.1(b) by by assuming customers and firms have a common discount factor, and conclude that there is no production in the second period under commitment.

4.3.2 Centralized channel

Now we consider a centralized channel without commitment. We begin solving the problem by finding a subgame-perfect equilibrium between the seller and the strategic customers in the second period. The seller chooses Q_2 to maximize his second-period profit:

$$\Pi_2 = (p_2 - c)Q_2.$$

This yields $Q_2^C = ((1-c)N - Q_1)/2$, where the superscript 'C' stands for the optimal values chosen by a centralized channel without commitment. Returning to the first

period, the seller selects Q_1 to maximize his two-period total profit:

$$\Pi = (p_1 - c)Q_1 + \delta_f \Pi_2^C,$$

where $\Pi_2^C = \Pi_2(Q_2^C)$.

Lemma 4.1 *An integrated channel's optimal quantities and profit are*

$$\begin{aligned} Q_1^C &= N(1-c)(2-\delta_c-\delta_f)/(4-2\delta_c-\delta_f), \\ Q_2^C &= N(1-c)(2-\delta_c)/(2(4-2\delta_c-\delta_f)), \\ \Pi^C &= N(1-c)^2(2-\delta_c)^2/(4(4-2\delta_c-\delta_f)). \end{aligned}$$

Note that Lemma 4.1 is consistent with Proposition 4.1 in Besanko and Winston (1990) who investigate optimal price skimming by a monopolist facing strategic customers. They study a finite horizon problem and assume customers and firms have a common discount factor, while we consider a two-period model and assume customers and firms have different discount factors. Note that by Lemma 4.1, the seller makes positive productions in both periods except when both customers and firms do not discount future payoffs. In that case, the seller produces nothing in the first period.

Comparing Proposition 4.1 and Lemma 4.1 yields:

Proposition 4.2 *With strategic customers ($\delta_c > 0$),*

(a) The second period production quantity of a centralized channel without commitment is greater than with commitment, i.e., $Q_2^C > Q_2^{CC}$.

(b) The centralized channel profit without commitment is no greater than with commitment, i.e., $\Pi^C \leq \Pi^{CC}$, where equality holds if and only if both the seller and the customers do not discount their future payoffs ($\delta_c = \delta_f = 1$).

Compared with a seller with ability to commit, a seller without ability to commit always has incentive to produce and sell more at lower prices in the second period. Recall this is the time inconsistency problem. Note also that there is no time inconsistency problem when customers are myopic. Together with Proposition 4.2(b), we may conclude that the ability to commit has no value for a channel in our model when either customers are myopic ($\delta_c = 0$), or when the seller and the customers

do not discount future payoffs ($\delta_c = \delta_f = 1$). This conclusion is in contrast with Arya and Mittendorf (2006), and Desai et al. (2004). They show that the ability to commit has positive value for a channel with $\delta_c = \delta_f = 1$. Following the literature on durable products with used markets (e.g. Bulow, 1982, 1986), they assume that a durable product provides finite periods of service, and customers value the service provided by the product period by period. For example, in a two-period model, let v be the valuation of the service provided by the product in each period. If a customer purchases the product in the first period, then he receives gross utility $2v$ from consuming the product in the first and second periods. If a customer buys the product in the second period, he only gets gross utility v from consuming the product in the second period. Essentially, customers discount future consumption in their models even when $\delta_c = 1$. In contrast, following the operation management literature (e.g. newsvendor-type models), we interpret the valuation as the lifetime utility a consumer obtains from consuming the product. A customer who buys the product in the first period receives the same gross utility as he buys the product in the second period.

4.3.3 Decentralized channel

In this subsection, we study the case of a decentralized channel. Again, we solve the game backwards to derive the symmetric subgame-perfect equilibrium among the manufacturer, the downstream competing retailers, and the strategic customers. In the second period, the wholesale prices w_1 and w_2, and the first period supply Q_1 are given, and retailer i orders q_{i2} to maximize his second-period profit:

$$\pi_{i2} = (p_2 - w_2)q_{i2},$$

where $i = 1, 2, \cdots, n$. Assuming retailers are symmetric, this yields $q_{i2}^D = ((1 - w_2)N - Q_1)/(n+1)$, where the superscript 'D' represents optimal values of a decentralized channel without commitment. Using the best response functions of the retailers, the manufacturer chooses w_2 to maximize his second-period profit:

$$\pi_{m2} = (w_2 - c)Q_2^D.$$

Solving the optimization problem, we obtain $w_2^D = (1+c)/2 - Q_1/N$. Back to the first period, retailer i chooses order quantities q_{i1} to maximize his two-period profit:

$$\pi_i = (p_1 - w_1)q_{i1} + \delta_f \pi_{i2}^D.$$

This yields

$$q_{i1}^D = \frac{\big(2(n+1)^2(1-w_1) - (\delta_c n^2 + \delta_c n + \delta_f)(1-c)\big)N}{(2-\delta_c)n^3 + (6-2\delta_c)n^2 + (6-\delta_c-\delta_f)n + 2}.$$

At the beginning of the first period, the manufacturer chooses w_1 to maximize his total two-period profit:

$$\pi_m = (w_1 - c)Q_1^D + \delta_f \pi_{m2}^D.$$

Solving the maximization problem yields the subgame-perfect equilibrium. The equilibrium values are provided in Appendix C.

Conventional wisdom suggests that the profit of a decentralized supply chain cannot exceed that of a centralized supply chain. They are equal if and only if the decentralized channel is coordinated. However, this conventional wisdom assumes that customers are myopic. Is a centralized channel always the best even in the presence of strategic customer behavior? The following proposition gives a negative answer.

Proposition 4.3 *In a two-period model with dynamic linear wholesale price contracts, facing strategic customers, a decentralized channel has higher profit than a centralized channel if and only if the function $F_n(\delta_c, \delta_f) > 0$, where $F_n(\delta_c, \delta_f)$ is given in Appendix C. In particular, we have $F_n(1,1) < 0$, i.e., with no customer and firm discounting, the centralized channel profit is the highest.*

As we mentioned in the Introduction, the message that a centralized channel is not always the best has already been discovered in Desai et al. (2004), Arya and Mittendorf (2006), and Su and Zhang (2008). Double marginalization is identified as the key driving force in these papers. With strategic customers, double marginalization reduces the time inconsistency problem, and so may improve the decentralized channel profit. Arya and Mittendorf (2006) assume no customer and firm discounting, and claim that adding customer and firm discounting will not alter their conclusion,

which is easily verified. Su and Zhang (2008) also assume no customer and firm discounting. The authors discuss the effect of customer discounting at the end of their paper, and conclude that adding customer discounting will not change their main results. Desai et al. (2004) assume a common discount factor for both customers and firms. Considering different customer and firm discount factors will not alter their conclusion. However, we show that different customer and firm discount factors are essential the phenomenon that a higher profit is earned in a decentralized channel. Indeed, we find that without discounting, the double marginalization effect is not enough to make the decentralized channel profit higher in our model.

We can gain more insight into why a decentralized channel may have higher profit than a centralized channel by investigating the behavior of the second period production quantities.

Lemma 4.2 *With strategic customers,*

(a) The second period total order quantity of a decentralized channel is less than a centralized channel ($Q_2^D < Q_2^C$).

(b) Q_2^D is increasing in the number of retailers, n. Moreover, $\lim_{n\to\infty} Q_2^D = Q_2^C$.

Lemma 4.2(a) says that a decentralized channel without commitment will produce less than a centralized channel without commitment in the second period. Recall Proposition 4.2(a) states that a centralized channel with commitment will also produce less than a centralized channel without commitment in period 2 ($Q_2^{CC} < Q_2^C$). This implies that, compared with a centralized channel without commitment, a decentralized channel without commitment actually has some "implicit" commitment power. Facing strategic customers, a decentralized channel will benefit from this commitment power. Lemma 4.2(b) shows that the downstream retailer competition increases the second period supply. As expected, under perfect retailer competition, the second period supply in a decentralized channel equals that in a centralized channel.

Single retailer

Double marginalization occurs when both the upstream manufacturer and the downstream retailer set positive margins to maximize their individual profits. These

self-profit maximizing objectives create channel inefficiency. This is the cost of double marginalization. On the other hand, in the presence of strategic customers, double marginalization yields the production pattern for second period supply to which a decentralized channel would like to commit. Observing a decentralized channel, strategic customers rationally expect that the second period price will be kept high due to the reduced supply in the second period ($Q_2^D < Q_2^C$). They are willing to buy the product at a high price in the first period. We call this the commitment benefit of decentralization/double marginalization, or the commitment benefit for the sake of brevity.

By Proposition 4.3, customer and firm discounting is essential in making the profit of a decentralized channel higher than that of a centralized channel. First, we investigate the effect of firm discounting by assuming customers do not discount future payoffs, i.e. $\delta_c = 1$. We find that the decentralized channel profit is higher than a centralized channel for a wide range of firm discount factors. Lower firm discount factor makes the commitment benefit more salient. When the firm discount factor is less than 0.821, the commitment benefit outweighs the cost of double marginalization.

Second, we check the impact of customer discounting by fixing the firm discount factor $\delta_f = 1$. When firms do not discount future profits, the cost of double marginalization dominates the commitment benefit.

Finally, we study the joint effect of firm and customer discounting. As long as customers are sufficiently more patient than firms, the decentralized channel profit is higher. The condition is graphically shown in Figure 4.3(a). Higher customer discount factor makes the cost of double marginalization less severe. And lower firm discount factor increases the commitment benefit. Proposition 4.4 summarizes the impact of different customer and firm discounting with a single retailer.

Proposition 4.4 *With a single retailer,*

(a) When customers do not discount their future payoffs, i.e., $\delta_c = 1$, the decentralized channel profit is higher if and only if $0 \leq \delta_f < 0.821$.

(b) When firms do not discount their future payoffs, i.e., $\delta_f = 1$, the centralized channel profit is higher for any customer discount factor.

(c) The decentralized channel profit is higher than the centralized channel profit if

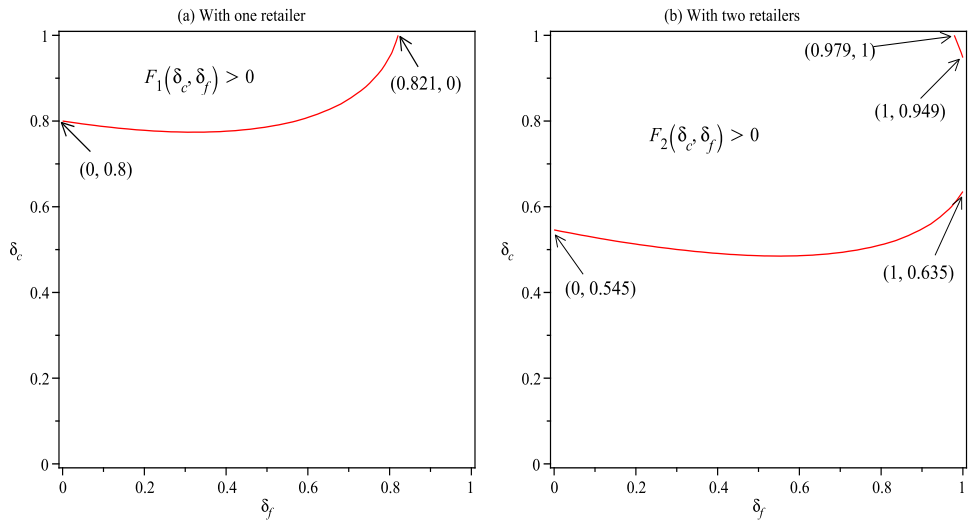

Figure 4.3: With only one retailer, the decentralized channel profit is higher if and only if $F_1(\delta_c, \delta_f) > 0$. With two competing retailers, the decentralized channel profit is higher if and only if $F_2(\delta_c, \delta_f) > 0$. Note that $F_2(\delta_c, \delta_f) > 0$ on the dashed line in Figure 4.3(b).

and only if the function $F_1(\delta_c, \delta_f) > 0$, where $F_1(\delta_c, \delta_f)$ is given in Appendix C.

Many studies have found that identical managerial insights and implications hold with or without discounting, e.g., Arya and Mittendorf (2006), Su and Zhang (2008), Liu and van Ryzin (2008). This has led to a belief that discounting only makes quantitative changes but will not change results qualitatively. However, this belief is not true in general. As pointed out in the Introduction, discount factors are essential in the Coase outcome. In this paper, we find that discounting plays a significant role in understanding the benefit of decentralization with strategic customers. Without discounting, the profit of a centralized channel is higher than a decentralized channel (Proposition 4.3); with certain ranges of customer and firm discount factors, the profit of a decentralized channel can exceed that of a centralized channel (Propositions 4.4 and 4.5).

Multiple retailers

Lemma 4.2(b) shows that the second period total order quantity increases in the number of competing retailers. When there are infinitely many retailers, the decen-

tralized channel is equivalent to a centralized channel: the production quantities and profits are the same in both channels. So, retailer competition reduces the cost of double marginalization. On the other hand, because retailer competition increases the second period supply, customers become less willing to buy the product at a high price in the first period. In short, retailer competition reduces both the cost of double marginalization and the commitment benefit. However, the magnitudes of the decreases can be different.

In order to quantify the effect of downstream retailer competition, we consider a two-retailer decentralized channel, and then compare the results with those in the single-retailer channel. Analogously, we investigate the impact of firm discount factor δ_f under retailer competition by fixing $\delta_c = 1$. As the number of retailers increases from one to two, the decrease in the cost of double marginalization is larger than the decrease in the commitment benefit. Compared with the one-retailer case ($0 \leq \delta_f < 0.821$), the range of firm discount factor ($0 \leq \delta_f < 0.979$) is wider under which the profit of a decentralized channel with two retailers is higher than a centralized channel.

Next, we check the effect of customer discounting with retailer competition by fixing $\delta_f = 1$. Recall that the ability to commit has no value for a channel when either customers are myopic ($\delta_c = 0$), or no customer and firm discounting ($\delta_c = \delta_f = 1$). So, if the commitment benefit were greater than the cost of double marginalization, then δ_c must be neither too small nor too large. Indeed, we show that the decentralized channel profit is higher for an intermediate range of customer discount factors ($0.635 < \delta_c < 0.949$).

Finally, we study the joint impact of firm and customer discounting under retailer competition. Figure 4.3 graphically compares the one-retailer case and the two-retailer case. With two competing retailers, the decentralized channel profit can be higher for a much wider range of parameter values. Proposition 4.5 summarizes the results with two competing retailers.

Proposition 4.5 *With two competing retailers,*

(a) When customers do not discount their future payoffs, i.e., $\delta_c = 1$, the decentralized channel profit is higher if and only if $0 \leq \delta_f < 0.979$.

(b) When firms do not discount their future payoffs, i.e., $\delta_f = 1$, the decentralized channel profit is higher if and only if $0.635 < \delta_c < 0.949$.

(c) *The decentralized channel profit is higher than the centralized channel profit if and only if the function $F_2(\delta_c, \delta_f) > 0$, where $F_2(\delta_c, \delta_f)$ is presented in Appendix C.*

Table 4.1 summarizes the comparisons between Propositions 4.4 and 4.5, which deliver a message that downstream retailer competition plays an important role in making the profit of a decentralized channel higher than that of a centralized channel, and interacts in a compelling way with the impact of customer and firm discounting.

Discount factors	With one retailer $n = 1$	With two retailers $n = 2$
$\delta_f = 1, \delta_c \in [0,1]$	$\Pi^D < \Pi^C$	$\Pi^D > \Pi^C \Leftrightarrow 0.635 < \delta_c < 0.949$
$\delta_f \in [0,1], \delta_c = 1$	$\Pi^D > \Pi^C \Leftrightarrow 0 \leq \delta_f < 0.821$	$\Pi^D > \Pi^C \Leftrightarrow 0 \leq \delta_f < 0.979$
$\delta_f, \delta_c \in [0,1]$	$\Pi^D > \Pi^C \Leftrightarrow F_1(\delta_c, \delta_f) > 0$	$\Pi^D > \Pi^C \Leftrightarrow F_2(\delta_c, \delta_f) > 0$

Table 4.1: The effect of downstream retailer competition. Π^D is the decentralized channel profit with dynamic wholesale price contracts, and Π^C is the centralized channel profit.

It seems that we can increase the decentralized channel profit by adding more retailers downstream. This is not true in general because with infinitely many retailers, the decentralized channel profit equals the centralized channel profit. Numerical examples show that with a few retailers, the reduction in the cost of double marginalization is larger than the reduction in the commitment benefit. Hence, the decentralized channel profit is increasing in n when n is small (see Figure 4.4). However, as n becomes larger, the decentralized channel behaves closer to a centralized channel, and so the decrease in the cost of double marginalization becomes smaller than the decrease in the commitment benefit. In summary, the impact of n on the decentralized channel profit is not monotone.

However, the dependence of decentralized channel profit on n is also affected by customer and firm discounting, as demonstrated in Figure 4.4. Since cash flow discount rates are relatively small (usually less than 10%), high firm discount factors are expected. Hence, we will focus on high firm discount factors in the numerical examples. We have also done numerical experiments with low firm discount factors, and the results are similar. Depending on how customers value future consumption, the customer discount factor may vary a lot. If a customer values new arrivals much

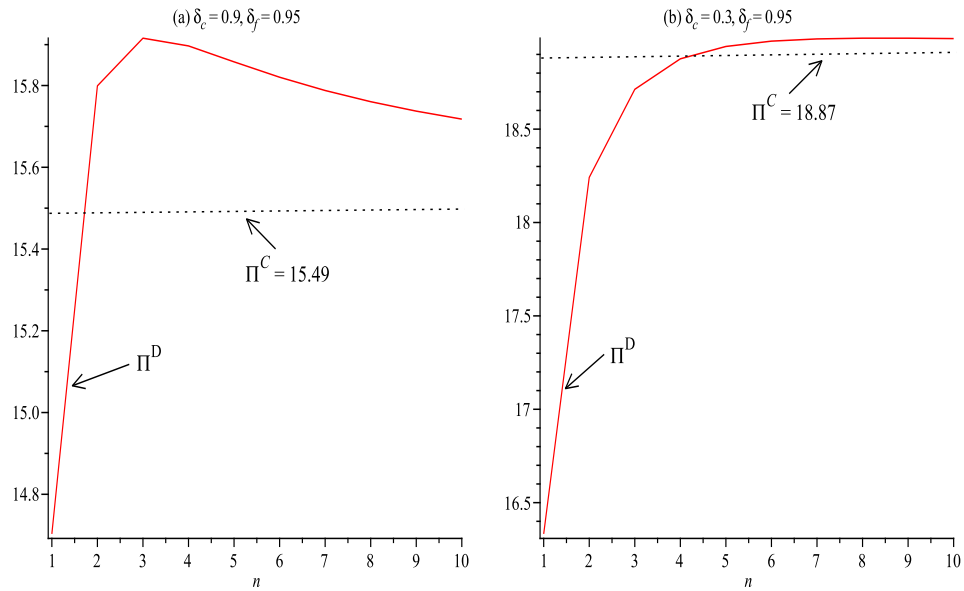

Figure 4.4: The decentralized channel profits Π^D change as the number of retailers n increases. The centralized channel profits Π^C are shown in dashed lines for comparison. The parameter values are $N = 100$, and $c = 0.2$.

more than old items, then we should adopt a low customer discount factor. Otherwise, a high customer discount factor is more appropriate. Figure 4.4(a) displays that when both customers and firms have high discount factors ($\delta_c = 0.9, \delta_f = 0.95$), the decentralized channel profit is higher except in the single retailer case. Figure 4.4(b) shows the case of low customer discount factor ($\delta_c = 0.3, \delta_f = 0.95$). In this case, we need more retailers in the downstream to make the decentralized channel profit to surpass the centralized channel profit.

4.3.4 Uncertain demand

The above analysis assumes deterministic demand. We will explore the impact of demand uncertainty in this section. We model demand uncertainty by assuming that the market size N can be either high, N_h, with probability θ, or low, N_l, with probability $1-\theta$. At the beginning of the first period, the manufacturer and the retailers only know the distribution of the demand, and need to make decisions before the realization of the demand. The demand uncertainty is resolved during the first period. So, there is no uncertainty in the second period, and the firms will make

decisions based on the realized demand state from the first period.

Comparing the decentralized channel profit with the centralized channel profit yields similar results of Propositions 4.4 and 4.5. All the details and the proofs are given in Appendix C.

Proposition 4.6 *Under demand uncertainty,*

- *With a single retailer,*
  - *(a) When customers do not discount their future payoffs ($\delta_c = 1$), there exists a critical value $\delta_{f1} \in (0, 0.821)$ under which the decentralized channel profit is higher if $0 \leq \delta_f < \delta_{f1}$.*
  - *(b) When firms do not discount their future payoffs ($\delta_f = 1$), the centralized channel profit is higher for any level of demand uncertainty and customer discount factor.*
- *With two competing retailers,*
  - *(a) When customers do not discount their future payoffs ($\delta_c = 1$), there exists a critical value $\delta_{f2} \in (0, 0.979)$ such that the decentralized channel profit is higher if $0 \leq \delta_f < \delta_{f2}$.*
  - *(b) When firms do not discount their future payoffs ($\delta_f = 1$), there are two cases. If $(N_h - N_l)^2\theta(1-\theta) \leq 0.754 N_h N_l$ (demand uncertainty is sufficiently small), then there exist critical values δ_{c1}, δ_{c2} with $0.635 < \delta_{c1} < \delta_{c2} < 0.949$ under which the decentralized channel profit is higher if and only if $\delta_{c1} < \delta_c < \delta_{c2}$. Otherwise, the centralized channel profit is higher.*

Comparing Proposition 4.6 with Propositions 4.4 and 4.5, we see that the range of discount factors under which the profit of a decentralized channel exceeds that of a centralized channel is narrower. The intuition is that demand uncertainty limits strategic customer behavior. Facing uncertain demand, strategic customers are more willing to buy the product in the first period. Nevertheless, Proposition 4.6 confirms that customer and firm discounting is indispensable for the phenomenon that a decentralized channel earns higher profit than a centralized channel.

4.4 Conclusion

Although the literature on strategic customer behavior is rich in marketing, economics and operations management, only a few articles examine strategic customer behavior in a decentralized channel, especially with downstream retailer competition. We develop a dynamic two-period model in which one manufacturer sells high-tech products, e.g. digital cameras and printers, through multiple competing retailers. With strategic customers, we find that there exists a wide range of customer and firm discount factors under which a decentralized channel has higher profit than a centralized channel in our model. The message that a centralized channel is not always the best has already been discovered in the existing literature. The key driving force identified in this literature is that double marginalization can reduce the time inconsistency problem, and so may improve the decentralized channel profit (Arya and Mittendorf, 2006; Desai et al., 2004; Su and Zhang, 2008). We demonstrate that different customer and firm discount factors are essential for the phenomenon that a higher profit is earned in a decentralized channel. Indeed, we show that without discounting, the double marginalization effect is not enough to make the profit of a decentralized channel exceed that of a centralized channel in our setting.

By modeling multiple retailers in the downstream, we are able to investigate the effect of retail competition on the benefit of decentralization. We find that it reduces both the cost of double marginalization and the commitment benefit. Interestingly, we show that the range of discount factors under which the decentralized channel profit is higher is much wider with two competing retailers than with one single retailer. Through numerical examples, we also find that the impact of the level of retailer competition on the decentralized channel profit is not monotone. We explore the impact of demand uncertainty in Section 3.4. Intuitively, we find that the demand uncertainty reduces the extent to which strategic customers wait. In addition to customer discounting, it provides customers another incentive to purchase early. The finding confirms that customer and firm discounting is essential for the phenomenon that the profit of a decentralized channel is higher than that of a centralized channel.

This paper has also raised several issues for future research. First, when making purchasing decisions, customers decide *whether to buy, when to buy, and where to buy*. Following the operation management literature on strategic customers, we focus on the first two aspects, and do not consider the last one by assuming a homogeneous

product. Note that most papers in the literature on strategic customers consider a monopolist seller. This homogeneous-product assumption allows us to use quantity competition to investigate the effect of retailer competition on the benefit of decentralization when customers are strategic. To examine the *where to buy* aspect is an important direction for future research, but is beyond the scope of this paper. Second, although it is common in the literature on strategic customers to assume that customer valuations are uniformly distributed, it would be interesting to consider more general customer valuations. Third, we may investigate the importance of customer and firm discounting in other commonly used channel coordination contracts, e.g. revenue sharing contracts, quantity discount contracts, etc.

Chapter 5

Conclusions

5.1 Summary

Three essays are covered in this dissertation. Chapter 2 investigates concession revenue sharing between airlines and airports. We first consider the case of a single airport and multiple downstream competing airlines. We find that the degree of revenue sharing will be affected by how airlines' services are related to each other. In particular, the degree of revenue sharing, i.e., the revenue sharing proportion, is smaller as the level of airline competition increases. The basic intuition is that as the level of airline competition increases, as a first mover the airport reduces the sharing proportion to decrease competition among airlines. We also investigate the case of two competing airports where each airport serves many airlines. It is found that airport competition results in a higher degree of revenue sharing than in the case of single airports. In the case of competing airports, each airport wants to get more market share. Hence, each airport increases the degree of revenue sharing to induce its airlines to reduce airfare so as to attract more passengers.

Chapter 3 studies price-cap regulation of an airport where the airport facility (e.g., its runway) is congested and air carriers have market power. We consider two forms of price-cap regulation: the single-till scheme and the dual-till scheme. We show that single-till price-cap regulation dominates dual-till price-cap regulation in terms of social welfare when airport congestion is ignored. This finding is consistent with Czerny (2006) and Crew and Kleindorfer (2000). However, when airport congestion becomes significant, we find that dual-till price-cap regulation may perform better

than single-till price-cap regulation with respect to welfare. The basic economic intuition can be explained as follows. Given the concession profit is positive, the airport charge is always lower under the single-till approach than under the dual-till approach, and so in equilibrium, the airfares are also lower under the single-till approach. As a result, passenger demand is higher under single-till price-cap regulation. Intuitively, social welfare is higher under the single-till approach than that under the dual-till approach when airport congestion is negligible. However, when airport congestion is a significant problem, lower airfares and higher passenger volume do not necessarily lead to higher social welfare due to the negative effect of congestion. It turns out that the overall welfare may be higher under dual-till regulation than under single-till regulation. Our results have important policy implications for airport authorities since many major airports are congested all over the world. Many airport authorities are considering whether single-till or dual-till price-cap regulation should be adopted.

Suppose now when the regulator chooses the right type of price-cap regulation, he takes into account concession revenue sharing between airports and airlines. As shown in Chapter 2, concession revenue sharing always improves the concession profit and the total profit of an airport. However, its impact on passenger volume is ambiguous, so is on the airport's aeronautical profit. Therefore, single-till price-cap is lower with concession revenue sharing than without; whilst dual-till price-cap might be lower or higher depending on whether outputs are greater or lower. However, since the total profit equals the sum of the aeronautical profit and the concession profit, the reduction in single-till price-cap should always be larger than the reduction in dual-till price-cap. Given the major critique of single-till price-cap regulation is that airport charges are set too low at congested airports, dual-till price-cap regulation will be more desirable at congested airports if the regulator takes into account concession revenue sharing between airports and airlines.

Chapter 4 investigates the impact of discounting and competition on the benefits of decentralization when customers are strategic. Conventional wisdom suggests that a centralized channel eliminates the incentive conflicts between channel members, and achieves the most efficient outcome. However, in the presence of strategic customer behavior, we show that a centralized channel is not always the first-best, i.e., a decentralized channel may have higher profit than that of a centralized channel. With strategic customers, the double marginalization effect could be desirable since

it yields the production pattern for late sales to which the decentralization channel would like to commit. In addition to the double marginalization effect, we also find that both customer and firm discounting and downstream retailer competition are also driving factors of the phenomenon that higher profit can be earned in a decentralized channel.

5.2 Related on-going work

5.2.1 Price-cap versus rate-of-return regulation

As mentioned in the Introduction, price-cap (PC) and rate-of-return (ROR) regulation are widely used in many industries all over the world. Under PC regulation, the regulator puts a ceiling on the price that the regulated firm can choose. In contrast, under ROR regulation, the regulator specifies an allowed rate of return that the regulated firm can achieve. A major critique of ROR regulation is the Averch-Johnson effect (Averch and Johnson, 1962): the regulated firm tends to make excessive investment in capacity but lacks incentives to be cost efficient. PC regulation is not perfect either: while the regulated firm has an incentive to be cost efficient, service quality may be downgraded in the process (e.g. Spence, 1975; Rovizzi and Thompson, 1992; Armstrong et al., 1994; Forsyth, 1997). Using data from the US telecommunications industry, Uri (2004) found empirically that service quality, measured by the average installation interval, the percent of commitments met, total trouble reports, and the average repair interval for both switched access service and special access service, had fallen after adopting price-cap regulation. More recently, Ter-Martirosyan and Kwoka (2010) examined the US electricity distribution utilities for the 1993-1999 period. Their data and model indicated that incentive regulation is indeed associated with significantly longer service outages. They also found that by incorporating service quality standards, incentive regulation may achieve cost savings without quality degradation. On the other hand, Tardiff and Taylor (2003) and Ai et al. (2004) find no evidence of service quality degradation under PC regulation in the telecommunications industry. As summarized by Sappington (2005), the findings regarding the impact of PC regulation on the levels of service quality are not consistent in the empirical literature.

Our objective in this work-in-progress is to develop a model to compare PC reg-

ulation and ROR regulation analytically. We compare the effects of the two types of regulation on capacity, capacity utilization and service quality as well as social welfare. In particular, a three-stage game is investigated. In stage 1, the regulator announces a regulation type, PC or ROR regulation, for an infrastructure supplier. In stage 2, the regulated infrastructure supplier announces both the capacity and the facility charge to downstream firms who will use the infrastructure facility. In stage 3, these downstream firms decide whether to participate. If so, they pay the facility charge and choose output to maximize their individual profits.

This three-stage structure can be found in a number of industries. Taking the airline industry as an example, we can consider an airport as the infrastructure, and airlines using the airport as the competing downstream firms. Both PC and ROR regulations have been adopted in the industry: A number of countries (e.g. Germany, the US and Canada) have adopted ROR regulation, while PC regulation has been popular in such countries as the UK, Denmark, Ireland and Australia. Another example is the ocean shipping industry, with seaport as the infrastructure and shipping liners as the competing firms. It is worth pointing out that most papers on regulation do not have this third stage. But this stage must be considered for the airline and ocean shipping industries since these industries are characterized typically as oligopolies (rather than perfect competition) and strategic rivalry among the firms must be explicitly analyzed.

Our analysis shows that for a profit-maximizing infrastructure, the capacity is larger under ROR regulation than under PC regulation. Furthermore, capacity utilization is higher under PC regulation, whilst service quality (measured by the degree of congestion delay) is better under ROR regulation. Through numerical examples, we observe that PC regulation dominates ROR regulation in terms of overall social welfare.

Few papers in the literature have examined the impact of PC and ROR regulation on efficiency and quality analytically. Sappington and Weisman (2010) have reviewed the key features of PC, ROR and earnings sharing regulation as well as the 25 years of experience of PC regulation in the telecommunications industry. Although many studies have compared PC regulation with ROR regulation, e.g. Braeutigam and Panzar (1993) and Liston (1993), most of them used arguments based on empirical evidence or economic intuition. There have been few theoretical papers comparing PC and ROR regulation. Pint (1992) compares PC with ROR regulation in

a stochastic cost model, and finds that both forms of regulation lead to overinvestment in capital but they differ in the timing of hearings and in the use of cost information. Kidokoro (2002) studies the effects of the regulatory shift from cost-of-service to PC regulation on service quality. The author finds that in the case of investment-related service quality, the regulatory shift lowers service quality and social welfare. In the case of effort-related service quality, the regulatory shift increases service quality and social welfare. Our paper is similar in spirit but differs from Kidokoro (2002) in several perspectives. First, cost-of-service regulation considered in Kidokoro does not include allowed rate of return. Hence, strictly speaking, it is not a ROR regulation. Second, Kidokoro does not consider the capacity decision, which is essential in our model. Third, rate of return and price cap are endogenous variables in our paper but they are treated as exogenous in Kidokoro (2002).

5.2.2 Empirical analysis of airport revenue sharing

In Zhang et al. (2010), the authors model revenue sharing as a two-stage game where in the first stage, the airport offers a carrier a sharing contract subject to the carrier's participation constraint. Thus, any gain from the revenue-sharing contract goes to the airport, which is portrayed as a Stackelberg leader. While this might be the case at certain airports, in general both airports and airlines may possess some power over sharing arrangements. In this work, we consider a bargaining game between one airport and n competing airlines in the determination of their sharing contacts.

Through the bargaining framework, we show that the revenue sharing proportions by the airport increase in airlines' bargain power and aeronautical charge, but decrease in the number of airlines as well as in the total market size. Higher proportions of revenue sharing in our model provide the airport with greater incentives to strengthen its cooperation with downstream airlines; therefore, there is an increasing likelihood that the airport and airlines will formalize such vertical relationships.

Great efforts have been made to ensure the applicability of our analytical investigation. Still, to make the model tractable, we made routine simplifications such as symmetric airlines and constant marginal costs. In addition, while our theoretical conclusions indicated qualitative effects of airport-airline bargaining, it is not clear how significant these effects are in practice. Therefore, empirical tests are of great importance: they allow one to verify the analytical conclusions, and to quantify the

actual impacts of airport-airline vertical relationships.

However, most airport-airline contracts / agreements are not publicly available. Such data limitations make it difficult to test the effects of revenue sharing directly. A few recent airport competition and regulation cases provide good samples for researchers to study. Making statistical inference from such a small and special sample, however, would be difficult and likely be biased. Therefore, we choose to test our conclusions against general practices of airport - airline vertical cooperation. There are both pros and cons for such an approach: on the one hand, this allows us to conduct rigorous empirical tests over a larger representative sample, thus more general conclusions can be obtained; on the other hand, such tests may introduce an implied assumption that revenue sharing would have similar effects as other forms of airline - airport cooperation. The degree of revenue sharing between the airport and airlines may not be empirically identified.

5.3 Future research plans

5.3.1 Airport congestion

Traffic growth has outpaced capacity increases at major airports around the world. For the last several years, airlines and passengers have increasingly been suffering from flight delays. Not surprisingly, congestion delays have become a major public policy issue. However, airport congestion is a very challenging problem. Although many suggestions and improvements have been made, there still exist many potential research opportunities to study the issue and make useful contributions. I am interested in developing research projects with airlines and airport authorities in the near future. My aim is to provide guidance on policy development, capacity increases, route structures, flight schedules, etc.

5.3.2 High-speed rail vs. air transport

The Ministry of Railways of China (MORC) is creating what will be by far the biggest high-speed network in the world. In 2003, MORC's Mid to Long-Range Network Plan (MLRNP) was approved by the Government of China. The Plan originally targeted a 12,000 route-kms high-speed passenger network by 2020, based on four north-south and four east-west corridors. The stimulus package launched by China

in 2008 to mitigate the impact of the global financial crisis has more than doubled the investment funds available for railways for the years 2008 to 2010, enabling MORC to accelerate the construction of the high-speed rail network. Now, the total investment in the high-speed rail network of China is around CNY 2 trillion (or USD 300 billion). As a result, the completion dates of several projects were brought forward, and it is now planned to complete construction of 42 high-speed rail lines by 2012, amounting to 13,000 kms.[1] China will have more high-speed railway than the rest of the world put together.

As train speeds get faster and rail fares become lower, competition from high-speed trains on air transport (especially for short and medium routes) will become significant. For example, the high-speed trains connecting Wuhan, the capital of Hubei province in Central China, and Nanjing, the capital of Jiangsu province in East China, were opened in 2009. After operating airlines struggled for about 2 years, the General Administration of Civil Aviation of China (CAAC) announced that all the flights between Wuhan and Nanjing were suspended starting from March 27, 2011. On the other hand, according to a recent report by Goldman Sachs (Lam et al., 2010), total traffic may be stimulated after the entry of high-speed rail, so the diversion effect to airlines will be compensated by this stimulation effect (or might even be outweighed so airlines benefit) in the distance range when the two modes compete. Relating this to our modeling, this feature may be reflected by the "outside option" or by the elastic total demand. Also, it might be useful to compare the situations with and without high-speed rail.

Based mainly on ticket prices and total travel time, passengers decide to use which transport mode. Roughly speaking, passengers can be divided into two groups: business and leisure travelers. Each group of passengers have different benefits of travel and different value of time. Business travelers are expected to have significant higher benefits of travel and value of time. We want to use a game theoretic setting to model the competition between air transport and high-speed rail. There are at least two models can be adopted for this purpose. One is the linear city Hotelling line model, where two ends of the Hotelling line represent air transport and high-speed rail respectively. Passengers' value of time can be considered as the "transporta-

[1] According to a recent report by the World Bank (Amos et al., 2010), of the 13,000 route-kms, 8,000 kms will have a maximum speed of 350 km/h while 5,000 kms will have a maximum speed of 250 km/h.

tion cost". As airlines often use dynamic pricing to price discriminate business and leisure travelers, we may use two separate Hotelling lines to model the two passenger groups. Another alternative is the multinomial logit model (MNL). A traveler's choice among air transport and high-speed rail is based on the discrete choice theory of product differentiation. A passenger chooses the travel model which yields the highest utility. The main advantage of the MNL model is that in addition to air transport and high-speed rail, we may also consider no travel option or other road alternatives, e.g. car and regular train. The major limitation of the MNL model is the analytical tractability. It is even not easy to get results on comparative statics. However, it would be very useful for computational case studies to evaluate high-speed rail projects and air routes.

In a deregulated market, not surprisingly, airlines are profit maximizers. Due to the huge capital requirement, high-speed rail networks around the world are typically invested or co-invested by the government. Because of the significant capital costs, rail companies or authorities need to earn a lot of profits to make it break even. As a result, the objective of high-speed rails is likely to a weighted sum of profit and social welfare. This is a distinct feature of the competition between high-speed rail and air transport. In a typical competition model, players are typically profit maximizers. Back to the high-speed rail network in China, the central government of China might have the power or the influence to coordinate high-speed rail (MORC) and air transport (CAAC). This can be considered as the benchmark for the competition model.

Bibliography

Ai, C., S. Martinez, D. Sappington. 2004. Incentive regulation and telecommunications service quality. *Journal of Regulatory Economics* **26**(3) 263–285. → pages 77

Amos, P., D. Bullock, J. Sondhi. 2010. High-speed rail: the fast track to economic development? Report, World Bank. → pages 81

Armstrong, M., S. Cowan, J. Vickers. 1994. *Regulatory reform: Economic analysis and British experience*. MIT Press, Cambridge, MA. → pages 77

Arya, A., B. Mittendorf. 2006. Benefits of channel discord in the sale of durable goods. *Marketing Science* **25**(1) 91–96. → pages 4, 57, 62, 64, 65, 68, 73

ATRS (Air Transport Research Society). 2008. The atrs airport performance benchmarking report: Global standards for airport excellence, 3-volume report. Report, The Centre for Transportation Studies, University of British Columbia, Vancouver, BC. → pages 6, 35

Auerbach, S., B. Koch. 2007. Cooperative approaches to managing air traffic efficiently – the airline perspective. *Journal of Air Transport Management* **13** 37–44. → pages 8

Averch, H., L. Johnson. 1962. Behavior of the firm under regulatory constraint. *American Economic Review* **52** 1052–1069. → pages 3, 54, 77

Aviv, Y., A. Pazgal. 2008. Optimal pricing of seasonal products in the presence of forward-looking consumers. *Manufacturing & Service Operations Management* **10**(3) 339–359. → pages 58

Barbot, C. 2006. Low-cost airlines, secondary airports, and state aid: An economic assessment of the ryanair-charleroi airport agreement. *Journal of Air Transport Management* **12** 197–203. → pages 8

Barbot, C. 2009a. Airport and airline competition: Incentives for vertical collusion. *Transportation Research Part B* **43**(10) 952–965. → pages 8, 9

Barbot, C. 2009b. Vertical contracts between airports and airlines: Is there a trade-off between welfare and competitiveness? Working paper, CETE, Faculty of Economics of Porto, Porto, Portugal. → pages 8

Barbot, C. 2009c. Vertical contracts between airports and airlines: Is there a trade-off between welfare and competitiveness? Working paper, CETE, Faculty of Economics of Porto, Porto, Portugal. → pages 34

Basso, L.J. 2008. Airport deregulation: Effects on pricing and capacity. *International Journal of Industrial Organization* **26**(4) 1015–1031. → pages 12, 34, 36, 37, 43

Basso, L.J., A. Zhang. 2007. Congestible facility rivalry in vertical structures. *Journal of Urban Economics* **61**(2) 218–237. → pages ix, 9, 24, 38, 39

Basso, L.J., A. Zhang. 2008. On the relationship between airport pricing models. *Transportation Research Part B* **42**(9) 725–735. → pages 14

Basso, L.J., A. Zhang. 2010. Pricing vs. slot policies when airport profits matter. *Transportation Research Part B* **44**(3) 381–391. → pages 36

Beesley, M. E. 1999. Airport regulation. M. E. Beesley, ed., *Regulating utilities: A new era? Institute of Economic Affairs*. London. → pages 36

Bel, G., X. Fageda. 2010. Factors explaining charges in european airports: Competition, market size, private ownership and regulation. *Journal of Regulatory Economics* **37**(2) 142–161. → pages 34, 54

Bell, D.R., G. Iyer, V. Padmanabhan. 2002. Price competition under stockpiling and flexible consumption. *Journal of Marketing Research* **39** 292–303. → pages 57

Besanko, D., W.L. Winston. 1990. Optimal price skimming by a monopolist facing rational consumers. *Management Science* **36**(5) 555–567. → pages 59

Bilotkach, V., J.A. Clougherty, J. Mueller, A. Zhang. 2010. Regulation, privatization, and aeronautical charges: Panel data evidence from european airports. Working paper, Department of Economics, University of California, Irvine. → pages 47, 54

Bowley, A.L. 1928. Bilateral monopoly. *The Economic Journal* **38**(152) 651–659. → pages 14

Braeutigam, R., J. Panzar. 1993. Effects of the change from rate-of-return to price cap regulation. *American Economic Review* **83**(2) 191–198. → pages 78

Brander, J.A., A. Zhang. 1990. Market conduct in the airline industry: An empirical investigation. *Rand Journal of Economics* **21**(4) 567–583. → pages 12, 39

Brander, J.A., A. Zhang. 1993. Dynamic behaviour in the airline industry. *International Journal of Industrial Organization* **11**(3) 407–435. → pages 12, 39

Brueckner, J.K. 2001. The economics of international codesharing: An analysis of airline alliances. *International Journal of Industrial Organization* **19**(10) 1475–1498. → pages 11

Brueckner, J.K. 2002. Airport congestion when carriers have market power. *American Economic Review* **92**(5) 1357–1375. → pages 12, 34, 36, 37, 39, 42

Brueckner, J.K. 2005. Internalization of airport congestion: A network analysis. *International Journal of Industrial Organization* **23** 599–614. → pages 39, 42

Brueckner, J.K. 2009. Price vs. quantity-based approaches to airport congestion management. *Journal of Public Economics* **93** 681–690. → pages 36

Brueckner, J.K., W.T. Whalen. 2000. The price effects of international airline alliancess. *Journal of Law and Economics* **43**(2) 503–545. → pages 11

Bulow, J.I. 1982. Durable-goods monopolists. *Journal of Political Economy* **90**(2) 314–332. → pages 64

Bulow, J.I. 1986. An economic theory of planned obsolescence. *Quartely Journal of Economics* **101**(4) 729–779. → pages 64

Bulow, J.I., J.D. Geanakoplos, P.D. Klemperer. 1985. Multimarket oligopoly: Strategic substitutes and complementss. *Journal of Political Economy* **93**(2) 488–511. → pages 11

Cachon, G.P., R. Swinney. 2009. Purchasing, pricing and quick response in the presence of strategic consumers. *Management Science* **55**(3) 497–511. → pages 58, 59

Chevalier, J., A. Goolsbee. 2005. Are durable-good consumers forward-looking? evidence from college textbooks. Working paper, NBER Working Papers 11421, National Bureau of Economic Research, Inc. → pages 4, 56

Coase, R.H. 1972. Durability and monopoly. *J. Law & Econ.* **15**(1) 143–149. → pages 56, 57

Crew, M.A., P.R. Kleindorfer. 2000. Regulation for priviated airports: single-till versus multi-till pricing methodologies for syndey airport. Unpublished manuscript, Rutgers Univesity. → pages 3, 37, 75

Currier, K. 2008. Price cap regulation of airports: a new approach. *Economics Bulletin* **12**(8) 1–7. → pages 38

Czerny, A. I. 2010. Airport congestion management under uncertainty. *Transportation Research Part B* **44**(3) 371–380. → pages 36

Czerny, A. I., A. Zhang. 2010. Airport congestion pricing and passenger types. *Transportation Research Part B* Forthcoming. → pages 37

Czerny, A.I. 2006. Price-cap regulation of airports: Single-till versus dual-till. *Journal of Regulatory Economy* **30**(1) 85–97. → pages 3, 11, 36, 37, 38, 44, 45, 51, 53, 75

Dasu, S., C. Tong. 2010. Dynamic pricing when consumers are strategic: Analysis of posted and contingent pricing schemes. *European Journal of Operational Research* **204**(3) 662–671. → pages 58

De Borger, B., K. Van Dender. 2006. Prices, capacities and service levels in a congestible bertrand duopoly. *Journal of Urban Economics* **60**(2) 264–283. → pages 38

Desai, P., O. Koenigsberg, D. Purohit. 2004. Strategic decentralization and channel coordination. *Quantitative Marketing and Economics* **2** 5–22. → pages 4, 57, 59, 62, 64, 65, 66, 73

Desai, P., O. Koenigsberg, D. Purohit. 2007. Research note: The role of production lead time and demand uncertainty in marketing durable goods. *Management Science* **53**(1) 150–158. → pages 59

Dixit, A.K. 1986. Comparative statics in oligopoly. *International Economic Review* **27**(1) 107–122. → pages 11

Doganis, R. 1992. *The Airport Business*. Routledge, London. → pages 1, 6, 35

Dresner, M., R. Windle, Y. Yao. 2002. Airport barriers to entry in the us. *Journal of Transport Economics and Policy* **36**(3) 389–405. → pages 7

Elmalghraby, W., A.Gulcu, P. Keskinocak. 2008. Designing optimal preannounced markdowns in the presence of rational customers with multiunit demands. *Manufacturing & Service Operations Management* **10** 126–148. → pages 58

FAA (US Federal Aviation Administration). 1999. Airport business practices and their impact on airline competition. Report, FAA/OST Taskforce Study. → pages 7

Forsyth, P. 1997. Price regulation of airports: Principles with australian applications. *Transportation Research Part E* **33**(4) 279–309. → pages 77

Forsyth, P. 2008. Access to airport facilities: Its impact on market competition. C. Winston, G. de Rus, eds., *Aviation Infrastructure Performance. A Study in Comparative Political Economy*. Washington DC: Brookings Institution Press. → pages 35

Forsyth, P., H.-M. Niemeier. 2008. Setting the slot limits at congested airports. A. Czerny, P. Forsyth, D. Gillen, H.-M. Niemeier, eds., *Airport Slots: International Experiences and Options for Reform*. Ashgate, Aldershot, UK. → pages 36

Fournier, G.M., M.E. Hartmann, T. Zuehlke. 2007. Airport substitution by travelers: Why do we have to drive to fly? D. Lee, ed., *Advances in Airline Economics*. Elsevier, Amsterdam. → pages 25

Francis, G., I. Humphreys, S. Ison. 2004. Airports' perspectives on the growth of low-cost airlines and the remodeling of the airport-airline relationship. *Tourism Management* **25** 507–514. → pages 7, 35

Friedman, J.W. 1997. *Oligopoly and the Theory of Games*. North Holland, Amsterdam. → pages 13

Fu, X., M. Lijensen, T. H. Oum. 2006. An analysis of airport pricing and regulation in the presence of competition between full service airlines and low cost carriers. *Journal of Transport Economics and Policy* **40** 425–447. → pages 34

Fu, X., A. Zhang. 2010. Effects of airport concession revenue sharing on competition and social welfare. *Journal of Transport Economics and Policy* **44**(2) 119–138. → pages 1, 7, 8, 11

GAO (US General Accounting Office). 1997. Domestic aviation: Barriers continue to limit competition. Report, GAO/T-RCED-98-32. → pages 7

Gillen, D. 2011. The evolution of airport ownership and governance. *Journal of Air Transport Management* **17**. → pages 36

Gillen, D.W., W.G Morrison. 2003. Bundling, integration and the delivered price of air travel: Are low cost carriers full service competitors? *Journal of Air transport Management* **9**(1) 15–23. → pages 9

Guo, L., M. Villas-Boas. 2007. Consumer stockpiling and price competition in differentiated markets. *Journal of economics & management strategy* **16**(4) 827–858. → pages 57

Hartmann, M.E. 2006. Access to airport facilities: Its impact on market competition. D. Lee, ed., *Advances in Airline Economics*. Elsevier, Amsterdam. → pages 7

Ho, T.-H., C.S. Tang, D.R. Bell. 1998. Rational shopping behavior and the option value of variable pricing. *Management Science* **44**(12) 145–160. → pages 57

Ishii, J., S. Jun, K. Van Dender. 2009. Air travel choices in multi-airport markets. *Journal of Urban Economics* **65**(2) 216–227. → pages 25

Jerath, K., S. Netessine, S.K. Veeraragharan. 2010. Rational shopping behavior and the option value of variable pricing. *Management Science* **56**(3) 430–448. → pages 58

Jones, I., I. Viehoff, P. Marks. 1993. The economics of airport slots. *Fiscal Studies* **14** 37–57. → pages 7, 35, 36

Kidokoro, Y. 2002. The effects of regulatory reform on quality. *Journal of the Japanese and International Economics* **16** 135–146. → pages 79

Krishna, A., I. Currim, R. Shoemaker. 1991. Consumer perceptions of promotion activity. *J. Mktg.* **55** 4–16. → pages 57

Kuchinke, A.B., J. Sickmann. 2005. The joint venture terminal 2 at munich airport and the consequences: A competition economic analysis. *4th Conference on Applied Infrastructure Research*. Berlin, 8 October 2005. → pages 7

Lai, G., L.G. Debo, K. Sycara. 2010. Buy now and match later: The impact of posterior price matching on profit with strategic consumers. *Manufacturing & Service Operations Management* **12**(1) 33–55. → pages 58

Lam, H., T. Kim, R. Tsang, R. Keung. 2010. High-speed rail less of a threat than you may think. Report, Goldman Sachs. → pages 81

Levin, Y., J. McGill, M. Nediak. 2009. Dynamic pricing in the presence of strategic consumers and oligopolistic competition. *Management Science* **55**(1) 32–46. → pages 58

Levin, Y., J. McGill, M. Nediak. 2010. Optimal dynamic pricing of perishable items by a monopolist facing strategic consumers. *Production and Operations Management* **19**(1) 40–60. → pages 58

Liston, C. 1993. Pc versus ror regulation. *Journal of Regulatory Economics* **5** 25–48. → pages 78

Liu, Q., G. van Ryzin. 2008. Strategic capacity rationing to induce early purchases. *Management Science* **54**(6) 1115–1131. → pages 58, 59, 68

Lu, C. C., R. Pagliari. 2004. Evaluating the potential impact of alternative airport pricing approaches on social welfare. *Transportation Research Part E* **40** 1–17. → pages 3, 37

McWilliams, G. 2004. Minding the store: Analyzing customers, best buy decides not all are welcome; retailer aims to outsmart dogged bargain-hunters, and coddle big spenders; looking for 'barrys' and 'jills'. *The Wall Street Journal* . → pages 4, 55

Melnikov, O. 2001. Demand for differentiated durable products: The case of the u.s. computer printer industry. Working paper, Yale Univesity. → pages 4, 55

Mueller, F., C. Konig, J. Mueller. 2010. Regulation of airport charges in germany. *14th ATRS (Air Transport Research Society) World Conference*. Porto, Portugal. → pages 35

Nair, H. 2007. Intertemporal price discrimination with forward-looking consumers: Application to the us market for console video-games. *Quantitative Marketing and Economics* **5**(3) 239–292. → pages 4, 56

Niemeier, H. M. 2002. Regulation of airports: the case of hamburg airport-a view from the perspective of regional policy. *Journal of Air Transport Management* **8**(1) 37–48. → pages 35

Oum, T.H., A. Zhang, Y. Zhang. 2004. Alternative forms of economic regulation and their efficiency implications for airports. *Journal of Transport Economics and Policy* **38**(2) 217–246. → pages 2, 11, 34, 37, 38, 44

Pels, E., P. Nijkamp, P. Rietveld. 2000. Airport and airline competition for passengers departing from a large metropolitan area. *Journal of Urban Economics* **48**(1) 29–45. → pages 25

Pels, E., P. Nijkamp, P. Rietveld. 2001. Airport and airline choice in a multiple airport region: An empirical analysis for the san francisco bay area. *Regional Studies* **35**(1) 1–9. → pages 25

Pels, E., P. Nijkamp, P. Rietveld. 2003. Access to a competition between airports: A case study for the san francisco bay area. *Transportation Research Part A* **37**(1) 71–83. → pages 25

Pels, E., E.T Verhoef. 2004. The economics of airport congestion pricing. *Journal of Urban Economics* **55**(2) 257–277. → pages 12, 39, 42

Pint, E. 1992. Price-cap versus rate-of-return regulation in a stochastic cost model. *Rand Journal of Economics* **23**(4) 564–578. → pages 78

Rovizzi, L., D. Thompson. 1992. The regulation of product quality in the public utilities and the citizens' charter. *Fiscal Studies* **13**(3) 74–95. → pages 77

Salant, S., S. Switzer, R. Reynolds. 1983. Losses from horizontal mergers: The effects of an exogenous change in industry structure on cournot-nash equilibrium. *Quarterly Journal of Economics* **98**(1) 185–199. → pages 27

Sappington, D. 2005. Regulating service quality: A survey. *Journal of Regulatory Economics* **27**(2) 123–154. → pages 77

Sappington, D., D. Weisman. 2010. Price cap regulation: what have we learned from 25 years of experience in the telecommunications industry? *Journal of Regulatory Economics* **38** 227–257. → pages 78

Shen, Z.J., X. Su. 2007. Customer behavior modeling in revenue management and auctions: A review and new research opportunities. *Production & Operations Management* **16**(6) 713–728. → pages 58

Song, I., P. Chintagunta. 2003. A micromodel of new product adoption with heterogeneous and forwardlooking consumers: Application to the digital camera category. *Quantitative Marketing and Economics* **1**(4) 371–407. → pages 4, 55

Spence, M. 1975. Monopoly, quality and regulation. *The Bell Journal of Economics* **6**(2) 417–429. → pages 77

Starkie, D. 2001. Reforming uk airport regulation. *Journal of Transport Economics and Policy* **35**(1) 119–135. → pages 7, 34, 35, 36, 39

Starkie, D. 2008. The airport industry in a competitive environment: A united kingdom perspective. Working paper, OECD-ITF Discussion Paper No. 2008-15, July 2008. → pages 9

Su, X. 2007. Inter-temporal pricing with strategic customer behavior. *Management Science* **53**(5) 726–741. → pages 58

Su, X., F. Zhang. 2008. Strategic customer behavior, commitment, and supply chain performance. *Management Science* **54**(10) 1759–1773. → pages 4, 57, 65, 66, 68, 73

Su, X., F. Zhang. 2009. On the value of inventory information and availability guarantees when selling to strategic consumers. *Management Science* **55**(5) 713–726. → pages 58

Tardiff, T., W. Taylor. 2003. Aligning price regulation with telecommunications competition. *Review of Network Economics* **2**(4) 338–354. → pages 77

Ter-Martirosyan, A., J. Kwoka. 2010. Incentive regulation, service quality, and standards in u.s. electricity distribution. *Journal of Regulatory Economics* **38** 258–273. → pages 77

Tirole, J. 1988. *The Theory of Industrial Organization*. MIT Press, Cambridge, Massachusetts. → pages 11, 15

Uri, N. D. 2004. The impact of incentive regulation on service quality in telecommunications in the united states. *Quality & Quantity* **38** 291–318. → pages 77

Van Dender, K. 2007. Determinants of fares and operating revenues at us airports. *Journal of Urban Economics* **62** 317–336. → pages 35

von der Fehr, N.H.M., K.U. Kühn. 1995. Coase versus pacman: Who eats whom in the durable-goods monopoly? *Journal of Political Economy* **103** 785–812. → pages 57

Winston, C., G. de Rus. 2008. *Aviation Infrastructure Performance: A Study in Comparative Political Economy*. Washington DC: Brookings Institution Press. → pages 2, 34

Yin, R., Y. Aviv, A. Pazgal, C. Tang. 2008. Optimal markdown pricing: Implications of inventory display formats in the presence of strategic customers. *Management Science* **55**(8) 1391–1408. → pages 58

Zhang, A., X. Fu, H. Yang. 2010. Revenue sharig with multiple airlines and airports. *Transportation Research Part B* **44** 944–959. → pages 79

Zhang, A., S. Hanaoka, H. Inamura, T. Ishikura. 2009. Low cost carriers in asia: Deregulation, regional liberalization and secondary airports. *Research in Transport Economics* **24**(1) 36–50. → pages 19

Zhang, A., Y. Zhang. 1997. Concession revenue and optimal airport pricing. *Transportation Research Part E* **33**(4) 287–296. → pages 11, 35

Zhang, A., Y. Zhang. 2003. Airport charges and capacity expansion: Effects of concessions and privatization. *Journal of Urban Economics* **53**(1) 54–75. → pages 11

Zhang, A., Y. Zhang. 2006. Airport capacity and congestion when carriers have market power. *Journal of Urban Economics* **60**(2) 229–247. → pages 12, 36, 37

Zhang, A., Y. Zhang. 2010. Airport capacity and congestion pricing with both aeronautical and commercial operations. *Transportation Research Part B* **44** 404–413. → pages 38, 41, 44

Appendix A

Proofs for Chapter 2

Proof of Proposition 2.2

1. We only need to show the price effect for the complements case (the other parts have been shown in the text). Use Δ to denote any difference of variables between the revenue-sharing regime and no-sharing regime. Applying the mean value theorem (MVT) to the function $p^i(q_1^*, q_2^*)$ yields:

$$\Delta p^i = p_i^i \cdot \Delta q_i^* + p_j^i \cdot \Delta q_j^*,$$

where p_i^i and p_j^i are evaluated at some point between (q_1^O, q_2^O) and (q_1^C, q_2^C), with superscript O denoting variables associated with the no-sharing regime. Under symmetry, $\Delta q_i^* = \Delta q_j^* > 0$ from part (i). Consequently, $\Delta p^i = (p_i^i + p_j^i)\Delta q_i^* < 0$ with the inequality following from the condition $p_1^1 p_2^2 - p_2^1 p_1^2 > 0$ and symmetry: noting that symmetry implies $(p_i^i + p_j^i)(p_i^i - p_j^i) > 0$. Since $p_i^i - p_j^i < 0$ for complements and independent services, it follows that $p_i^i + p_j^i < 0$.

2. (i) Applying MVT to $q_i^*(r_1, r_2)$ yields $\Delta q_i^* = (\partial q_i^*/\partial r_i)\Delta r_i + (\partial q_i^*/\partial r_j)\Delta r_j$, with $\partial q_i^*/\partial r_i$ and $\partial q_i^*/\partial r_j$ evaluated at some point between (r_1^O, r_2^O) and (r_1^S, r_2^S). Under symmetry, $\Delta r_i = \Delta r_j$ and $\partial q_i^*/\partial r_i = \partial q_i^*/\partial r_j$; consequently,

$$\Delta q_i^* = \frac{\partial (q_i^* + q_j^*)}{\partial r_i}\Delta r_i = \frac{h \cdot (\pi_{ji}^j - \pi_{jj}^j) \cdot \Delta r_i}{J}.$$

Since $\pi_{ji}^j - \pi_{jj}^j > 0$ and $J > 0$ under the second-order and substitutes con-

ditions and the stability condition respectively, Δq_i^* must have the same sign as $\Delta r_i = r_i^S - r_i^O = r_i^S$ (recall $r_i^O = 0$). For the welfare comparison, applying MVT to $\psi(q_1^*, q_2^*)$ in (3.18) yields $\Delta\psi = \psi_i \Delta q_i^* + \psi_j \Delta q_j^*$, where ψ_i and ψ_j are evaluated at some point between (q_1^O, q_2^O) and (q_1^S, q_2^S). Under symmetry, $\Delta q_i^* = \Delta q_j^*$. Consequently, $\Delta\psi = (\psi_i + \psi_j)\Delta q_i^*$ has the same sign as Δq_i^*, because $\psi_i = p^i - C_i' + h > 0$. The welfare result then follows from the above quantity comparison.

(ii) Applying MVT to $p^i(q_1^*, q_2^*)$ yields $\Delta p^i = p_i^i \Delta q_i^* + p_j^i \Delta q_j^*$, where p_i^i and p_j^i are evaluated at some point between (q_1^O, q_2^O) and (q_1^S, q_2^S). With $\Delta q_i^* = \Delta q_j^*$ under symmetry, $\Delta p^i = (p_i^i + p_j^i)\Delta q_i^*$ has the opposite sign as Δq_i^*, because $p_i^i < 0$ and, by (2.3), $p_j^i < 0$. The result then follows from the above quantity comparison.

■

Proof of Proposition 2.4

Use Δ to denote any difference of variables between the rivalry equilibrium and the non-rivalry solution. Here, we just show parts (i) and (iii); the proofs for parts (ii) and (iv) are similar to those of Proposition 2.2.

(i) Applying MVT to $q_i^*(r_1, r_2)$ yields $\Delta q_i^* = (\partial q_i^*/\partial r_i)\Delta r_i + (\partial q_i^*/\partial r_j)\Delta r_j$, with $\partial q_i^*/\partial r_i$ and $\partial q_i^*/\partial r_j$ evaluated at some point between (r_1^N, r_2^N) and (r_1^R, r_2^R). Under symmetry, $\Delta r_i = \Delta r_j$ and $\partial q_i^*/\partial r_i = \partial q_i^*/\partial r_j$; consequently,

$$\Delta q_i^* = \frac{\partial(q_i^* + q_j^*)}{\partial r_i}\Delta r_i = \frac{h \cdot (\pi_{ji}^j - \pi_{jj}^j) \cdot \Delta r_i}{J}.$$

Since $\pi_{ji}^j - \pi_{jj}^j > 0$ and $J > 0$ under the second-order and substitutes conditions and the stability condition respectively, Δq_i^* must have the same sign as $\Delta r_i = r_i^R - r_i^N$. By Proposition 2.3, $r_i^R > r_i^N$ and hence $q_i^R > q_i^N$.

(iii) Applying MVT to $\Pi^i(r_1, r_2)$, given by (3.23), yields $\Delta\Pi^i = \overline{\Pi}_i^i \Delta r_i + \overline{\Pi}_j^i \Delta r_j$, where $\overline{\Pi}_i^i$ and $\overline{\Pi}_j^i$ are evaluated at $(\overline{r}_1, \overline{r}_2)$ with $r_i^N < \overline{r}_i < r_i^R$ (using Proposition 2.3). Since $\Delta r_i = \Delta r_j$ under symmetry and $\Delta r_i \equiv r_i^R - r_i^N > 0$, it follows that $\Delta\Pi^i = (\overline{\Pi}_i^i + \overline{\Pi}_j^i)(r_i^R - r_i^N)$ and hence $\Delta\Pi^i < 0$ if (and only if) $\overline{\Pi}_i^i + \overline{\Pi}_j^i < 0$.

By (3.23) and symmetry, it follows that

$$\overline{\Pi}_i^i + \overline{\Pi}_j^i = (\overline{v}_i^i + \overline{v}_j^i)\frac{\partial(q_i^* + q_j^*)}{\partial r_i},$$

where $\overline{v}_i^i$ and $\overline{v}_j^i$ are evaluated at $\overline{q}_i = q_i^*(\overline{r}_1, \overline{r}_2)$. By (3.25), $\overline{v}_i^i = w + (1-\overline{r}_i)h$ which is negative given that $\overline{r}_i > r_i^N = 1 + w/h$. Furthermore, since $\overline{v}_j^i = \overline{R}_j^i$ (substitutable airports) and $\partial(q_i^* + q_j^*)/\partial r_i = h \cdot (\pi_{ji}^j - \pi_{jj}^j)/J > 0$, it follows that $\overline{\Pi}_i^i + \overline{\Pi}_j^i < 0$. Therefore, $\Delta\Pi^i < 0$.

■

Proof of Proposition 2.6

Each carrier's profit is given by

$$\pi^i(q_1, q_2) = R^i(q_1, q_2) - C_i(q_i) - wq_i + r_i h q_i, \qquad i = 1, 2. \tag{A.1}$$

The stage-2 equilibrium quantities are characterized by (2.5), and are expressed as with and given by (2.6). Then, the airport's profit in stage 1 is

$$\Pi(r_1, r_2) = w \cdot (q_1^* + q_2^*) + (1 - r_1)hq_1^* + (1 - r_2)hq_2^*. \tag{A.2}$$

The pure revenue-sharing equilibrium is determined, implicitly, by first-order conditions,

$$\frac{\partial \Pi}{\partial r_1} = [w + (1 - r_1)h]\frac{\partial q_1^*}{\partial r_1} + [w + (1 - r_2)h]\frac{\partial q_2^*}{\partial r_1} - hq_1^* = 0, \tag{A.3}$$

$$\frac{\partial \Pi}{\partial r_2} = [w + (1 - r_2)h]\frac{\partial q_2^*}{\partial r_2} + [w + (1 - r_1)h]\frac{\partial q_1^*}{\partial r_2} - hq_2^* = 0. \tag{A.4}$$

Multiplying (A.3) by $\partial q_1^*/\partial r_2$ and then subtracting (A.4) $\times \partial q_1^*/\partial r_1$ yields:

$$[w + (1 - r_2)h]\left(\frac{\partial q_1^*}{\partial r_2}\frac{\partial q_2^*}{\partial r_1} - \frac{\partial q_1^*}{\partial r_1}\frac{\partial q_2^*}{\partial r_2}\right) = h\left(q_1^*\frac{\partial q_1^*}{\partial r_2} - q_2^*\frac{\partial q_1^*}{\partial r_1}\right).$$

Further, by (2.6) we have

$$[w + (1 - r_2)h]\left(\frac{h^2(\pi_{12}^1\pi_{21}^2 - \pi_{11}^1\pi_{22}^2)}{J}\right) = h\left(q_1^*\frac{\partial q_1^*}{\partial r_2} - q_2^*\frac{\partial q_1^*}{\partial r_1}\right).$$

Since $\pi_{12}^1\pi_{21}^2 - \pi_{11}^1\pi_{22}^2 = -J$, it follows that $[w+(1-r_2)h]h = -[q_1^*\partial q_1^*/\partial r_2 - q_2^*\partial q_1^*/\partial r_1]$. By Lemma 2.1, $\partial q_1^*/\partial r_1 > 0$ and $\partial q_1^*/\partial r_2 = 0$ and < 0 for independent and substitutable services respectively, we must have $w+(1-r_2)h > 0$. Similarly, it can be shown that $w+(1-r_1)h > 0$ for independent and substitutable services. Therefore,

$$\hat{r}_i^I < 1 + \frac{w}{h} \text{ and } \hat{r}_i^S < 1 + \frac{w}{h}, \qquad i = 1,2. \tag{A.5}$$

For complements however, we need to assume the symmetry condition. Under symmetry, we have $w+(1-r_1)h = w+(1-r_2)h$ in (A.3), which reduces to:

$$[w+(1-r_1)h]\left(\frac{\partial q_1^*}{\partial r_1} + \frac{\partial q_2^*}{\partial r_1}\right) = hq_1^*.$$

Because $\partial q_1^*/\partial r_1 > 0$, and $\partial q_2^*/\partial r_1 > 0$ for complementary services, we must have $[w+(1-r_1)h > 0$, and so

$$\hat{r}_i^C < 1 + \frac{w}{h}, \qquad i = 1,2. \tag{A.6}$$

The rest of the proof is relatively straightforward and is available upon request from the authors.

■

Appendix B

Proofs for Chapter 3

Proof of Proposition 3.1

We first show that $H(p_c)+I(p_c)$ is maximized at $p_c = c_c$. Taking the first derivative with respect to p_c yields

$$\frac{d[H(p_c)+I(p_c)]}{dp_c} = -g(p_c)(p_c - c_c). \tag{B.1}$$

Note that (B.1) is negative when $p_c > c_c$, and is positive when $p_c < c_c$. In other words, $H(p_c)+I(p_c)$ is increasing in p_c when $p_c < c_c$, and is decreasing in p_c when $p_c > c_c$. Hence, the maximum is achieved at $p_c = c_c$. Plugging into the welfare function (3.13), we obtain

$$SW = (a - c - c_a - I(c_c))\,Q^* - \frac{2nv+b+n-1}{2n}Q^{*2} - F, \tag{B.2}$$

where Q^* is given by (3.10). Taking the first derivative with respect to p_a yields

$$\frac{dSW}{dp_a} = \frac{n\,(a-c-c_a-I(c_c))}{(n+1)v+2b+n-1} + \frac{n(2nv+b+n-1)(a-c-p_a)}{((n+1)v+2b+n-1)^2}, \tag{B.3}$$

and clearly, $d^2SW/dp_a^2 < 0$, i.e. the second-order condition holds. Therefore, the optimal aeronautical charge can be derived by setting (B.3) to zero, which yields (3.14).

■

Proof of Proposition 3.2

We first show that $H(p_c)$ has a unique root between c_c and u. The first-order condition gives

$$H'(p_c) = \bar{G}(p_c) - g(p_c)(p_c - c_c) = 0 \tag{B.4}$$

It follows that

$$\frac{g(p_c)}{G(p_c)} = \frac{1}{p_c - c_c}. \tag{B.5}$$

The profit-maximizing airport will not choose a concession price p_c that is less than unit concession cost c_c (otherwise, the concession revenue will be negative). So, the right-hand side of (B.5) is positive and decreasing in p_c. By the assumption of non-decreasing failure rate, the left-hand side of (B.5) is non-decreasing in p_c. It follows that the left-hand side and the right-hand side of (B.5) must cross each other exactly once. Hence, equation (B.4) has a unique root.

Next, we show that the unique root is indeed the global maximizer. Recall that the passengers' valuation has a positive support on the interval $[0, u]$. It is easy to check that $H'(0) = 1 + c_c g(0) > 0$, and $H'(u) = -g(u)(u - c_c) < 0$. Therefore, $H(p_c)$ is unimodal in p_c, and so has a unique maximizer between c_c and u. Plugging p_c^π into (3.11), we obtain

$$\Pi = (p_a - c_a)Q^* + Q^* H(p_c^\pi) - F, \tag{B.6}$$

where Q^* is given by (3.10). Taking the first derivative with respect to p_a yields

$$\frac{d\Pi}{dp_a} = \frac{n\,(a - c + c_a - 2p_a - H(p_c^\pi)}{(n+1)v + 2b + n - 1}, \tag{B.7}$$

and clearly, $d^2\Pi/dp_a^2 < 0$, i.e. the second-order condition holds. The privately optimal aeronautical charge can then be derived by setting (B.7) to zero, yielding (3.18).

■

Appendix C

Proofs for Chapter 4

Proof of Proposition 4.1

The optimization problem faced by the centralized seller with commitment is:

$$\begin{aligned}\max_{Q_1,Q_2} \Pi &= (p_1-c)Q_1+\delta_f(p_2-c)Q_2 \\ &= (1-c-(Q_1+\delta_c Q_2)/N)Q_1+\delta_f(1-c-(Q_1+Q_2)/N)Q_2.\end{aligned}$$

It is straightforward to calculate the Hessian matrix:

$$H=\begin{pmatrix} -2/N & -(\delta_c+\delta_f)/N \\ -(\delta_c+\delta_f)/N & -2\delta_f/N \end{pmatrix}.$$

The determinant of the Hessian matrix is

$$|H|=(4\delta_f-(\delta_c+\delta_f)^2)/N^2.$$

If $|H|\geq 0$, then the profit function Π is jointly concave in Q_1 and Q_2.

(a) If $\delta_f>\delta_c$, then $|H|>0$, i.e. the profit function Π is jointly concave in Q_1 and Q_2. Solving the first order conditions yields:

$$\begin{aligned}Q_1^{CC} &= N(1-c)(2-\delta_c-\delta_f)\delta_f/(4\delta_f-2\delta_c\delta_f-\delta_c^2-\delta_f^2), \\ Q_2^{CC} &= N(1-c)(\delta_f-\delta_c)/(4\delta_f-2\delta_c\delta_f-\delta_c^2-\delta_f^2), \\ \Pi^{CC} &= N(1-c)^2(1-\delta_c)\delta_f/(4\delta_f-2\delta_c\delta_f-\delta_c^2-\delta_f^2).\end{aligned}$$

(b) If $\delta_f \leq \delta_c$, the determinant of the Hessian matrix can be negative, zero, or positive. First note that if there was only one period, then the optimal production quantity would be $(1-c)/(2N)$. Now the seller can commit, so the optimal second period production quantity should not be greater than $(1-c)/(2N)$. Given Q_2, the profit function Π is strictly concave in Q_1 since $\frac{\partial^2 \Pi}{\partial Q_1^2} = -2/N < 0$. The first order condition $\frac{\partial \Pi}{\partial Q_1} = 0$ yields

$$Q_1 = (N(1-c) - (\delta_c + \delta_f)Q_2)/2. \tag{C.1}$$

It is easy to see (C.1) is nonnegative since $Q_2 \leq (1-c)/(2N)$. Plugging (C.1) into $\Pi(Q_1, Q_2)$, we obtain

$$\Pi(Q_2) = -N|H|Q_2^2 - 2(\delta_c - \delta_f)(1-c)Q_2 + N(1-c)^2. \tag{C.2}$$

Let's consider the three cases: $|H| = 0, |H| > 0$, and $|H| < 0$.

- Case 1: $|H| = 0$. Then $\Pi(Q_2) = -2(\delta_c - \delta_f)(1-c)Q_2$. Since $\delta_f \leq \delta_c$, then the optimal production in period 2 is $Q_2^{CC} = 0$.
- Case 2: $|H| > 0$. The first order condition of (C.2) yields $Q_2 = -(\delta_c - \delta_f)(1-c)/N|H| \leq 0$. Clearly, $\Pi(Q_1, Q_2)$ is strictly concave since $|H| > 0$. It follows that $Q_2^{CC} = 0$.
- Case 3: $|H| < 0$. The first and second order conditions of (C.2) are

$$\begin{aligned} \frac{\partial \Pi(Q_2)}{\partial Q_2} &= -(N|H|Q_2 + (\delta_c - \delta_f)(1-c))/2 \\ \frac{\partial^2 \Pi(Q_2)}{\partial Q_2^2} &= -N|H| > 0. \end{aligned}$$

  Note that $Q_2 \leq (1-c)/(2N)$. It follows that $\frac{\partial \Pi(Q_2)}{\partial Q_2} = -(N|H|Q_2 + (\delta_c - \delta_f)(1-c))/2 \leq 0$. Hence, $\Pi(Q_2)$ is strictly convex in Q_2, and decreasing in Q_2. So the optimal quantity Q_2^{CC} is zero. To summarize, when $\delta_f \leq \delta_c$, the optimal production quantity in period 2 is $Q_2^{CC} = 0$. The resulting

optimal first-period quantity and profit are

$$\begin{aligned} Q_1^{CC} &= N(1-c)/2, \\ \Pi^{CC} &= N(1-c)^2/4. \end{aligned}$$

■

Proof of Proposition 4.2

(a) If $\delta_f \leq \delta_c$, then $Q_2^{CC} = 0 < Q_2^C$. If $\delta_f > \delta_c$, then

$$\begin{aligned} Q_2^C - Q_2^{CC} &= \frac{N(1-c)(2-\delta_c)}{2(4-2\delta_c-\delta_f)} - \frac{N(1-c)(\delta_f-\delta_c)}{4\delta_f - 2\delta_c\delta_f - \delta_c^2 - \delta_f^2} \\ &= \frac{N(1-c)\delta_c(2-\delta_c-\delta_f)(4-\delta_c-\delta_f)}{2(4-2\delta_c-\delta_f)(4\delta_f-2\delta_c\delta_f-\delta_c^2-\delta_f^2)} \end{aligned}$$

Since $\delta_c > 0$ and $\delta_f > \delta_c$, then $Q_2^C - Q_2^{CC} > 0$.

(b) By Lemma 4.1, $\Pi^C = N(1-c)^2(2-\delta_c)^2/(4(4-2\delta_c-\delta_f))$. By Proposition 4.1, we have $\Pi^{CC} = N(1-c)^2/4$ if $\delta_f \leq \delta_c$. It follows that

$$\begin{aligned} \Pi_2^{CC} - \Pi_2^C &= \frac{N(1-c)^2(2\delta_c-\delta_f-\delta_c^2)}{4(4-2\delta_c-\delta_f)} \\ &\geq 0, \end{aligned}$$

where the equality holds if and only if $\delta_c = \delta_f = 1$. If $\delta_f > \delta_c$, then $\Pi^{CC} = N(1-c)^2(1-\delta_c)\delta_f/(4\delta_f - 2\delta_c\delta_f - \delta_c^2 - \delta_f^2)$. We have

$$\begin{aligned} \Pi_2^{CC} - \Pi_2^C &= \frac{N(1-c)^2\delta_c^2(2-\delta_c-\delta_f)^2}{4(4-2\delta_c-\delta_f)(4\delta_f-2\delta_c\delta_f-\delta_c^2-\delta_f^2)} \\ &> 0. \end{aligned}$$

■

Proof of Proposition 4.3

The subgame-perfect equilibrium values are

$$
\begin{aligned}
w_1^D &= c + \frac{1-c}{2\Delta(n+1)^2}\Big((2-\delta_c)^2 n^5 + (2-\delta_c)(10+\delta_f-3\delta_c)n^4 + \\
&\quad \Big(3\,{\delta_c}^2 + 40 + 2\,\delta_f - 24\,\delta_c\Big)\,n^3 + \Big({\delta_c}^2 + \big(-16+2\,\delta_f\big)\,\delta_c - 4\,\delta_f + 40\Big)\,n^2 \\
&\quad + \Big(\big(-4+\delta_f\big)\,\delta_c + 20 + {\delta_f}^2 - 6\,\delta_f\Big)\,n + 4 - 2\,\delta_f\Big) > c \\
w_2^D &= c + \frac{1-c}{2\Delta}\Big((2-\delta_c)\,n^3 + (8-3\,\delta_c)\,n^2 + \big(10-2\,\delta_c-\delta_f\big)\,n + 4\Big) > c \\
Q_1^D &= \frac{N(1-c)n}{\Delta}\Big(\big(2-\delta_c-\delta_f\big)\,n^2 + \big(4-\delta_c-\delta_f\big)\,n + 2 - \delta_f\Big) > 0 \\
Q_2^D &= \frac{N(1-c)n}{2\Delta(n+1)}\Big((2-\delta_c)\,n^3 + (8-3\delta_c)\,n^2 + (10-2\delta_c-\delta_f)n + 4\Big) > 0 \\
\Pi^D &= \frac{N(1-c)^2 n\Gamma}{4(n+1)^2\Delta^2}\Big((2-\delta_c)\,\big(4-2\delta_c-\delta_f\big)\,n^4 + \Big(32 + 4\,{\delta_c}^2 - \big(\delta_f+24\big)\,\delta_c\Big)\,n^3 \\
&\quad + \Big(2\,{\delta_c}^2 - \big(24+4\,\delta_f\big)\,\delta_c - {\delta_f}^2 + 10\,\delta_f + 48\Big)\,n^2 + \\
&\quad \Big(32 - 2\,{\delta_f}^2 + 12\,\delta_f - \big(8+2\,\delta_f\big)\,\delta_c\Big)\,n + 4\,\delta_f + 8\Big) > 0,
\end{aligned}
$$

where

$$
\begin{aligned}
\Delta &= \big(4-2\delta_c-\delta_f\big)\,n^3 + \big(12-4\delta_c-\delta_f\big)\,n^2 + 2\,\big(6-\delta_c-\delta_f\big)\,n + 4 > 0, \text{ and} \\
\Gamma &= (2-\delta_c)\,n^3 + (8-3\delta_c)\,n^2 + (10-2\delta_c-\delta_f)n + 4 > 0.
\end{aligned}
$$

We have solved the centralized case, and the centralized channel profit is

$$\Pi^C = N(1-c)^2(2-\delta_c)^2/(4(4-2\delta_c-\delta_f)).$$

Subtracting Π^D by Π^C yields

$$\Pi^D - \Pi^C = \frac{F_n(\delta_c,\delta_f)N(1-c)^2}{(n+1)^2(4-2\delta_c-\delta_f)\Delta^2}, \tag{C.3}$$

where $F_n(\delta_c, \delta_f) = -\sum_{i=0}^{7} a_i n^i$, where

$$
\begin{aligned}
a_7 &= (-2+\delta_c)\,\delta_c\left(\delta_f - 2 + \delta_c\right)\left(\delta_c - 2 + 1/2\,\delta_f\right) \\
a_6 &= 6{\delta_c}^4 + \left(9\delta_f - 42\right){\delta_c}^3 + (100 - 45\delta_f + \frac{13}{4}{\delta_f}^2){\delta_c}^2 \\
&\quad + \left(64\delta_f - 88 - 11{\delta_f}^2\right)\delta_c + 16 + 8\,{\delta_f}^2 - 20\delta_f \\
a_5 &= 13\,{\delta_c}^4 + (\frac{41}{2}\,\delta_f - 110){\delta_c}^3 + \left(10\,{\delta_f}^2 - 126\,\delta_f + 312\right){\delta_c}^2 + \\
&\quad \left(-336 + 3/2\,{\delta_f}^3 + 224\,\delta_f - 43\,{\delta_f}^2\right)\delta_c + 96 - 3\,{\delta_f}^3 - 104\,\delta_f + 44\,{\delta_f}^2 \\
a_4 &= 13\,{\delta_c}^4 + \left(22\,\delta_f - 142\right){\delta_c}^3 + (-171\,\delta_f + 492 + \frac{53}{4}\,{\delta_f}^2){\delta_c}^2 + \\
&\quad \left(-640 + 7/2\,{\delta_f}^3 - 71\,{\delta_f}^2 + 372\,\delta_f\right)\delta_c - 216\,\delta_f + 240 + 1/4\,{\delta_f}^4 + 92\,{\delta_f}^2 - 10\,{\delta_f}^3 \\
a_3 &= 6\,{\delta_c}^4 + \left(-96 + 11\,\delta_f\right){\delta_c}^3 + (428 + 7\,{\delta_f}^2 - 118\,\delta_f){\delta_c}^2 + \\
&\quad \left(-680 + 5/2\,{\delta_f}^3 + 322\,\delta_f - 52\,{\delta_f}^2\right)\delta_c + 1/2\,{\delta_f}^4 + 88\,{\delta_f}^2 + 320 - 11\,{\delta_f}^3 - 224\,\delta_f \\
a_2 &= {\delta_c}^4 + \left(2\delta_f - 32\right){\delta_c}^3 + \left({\delta_f}^2 - 38\delta_f + 204\right){\delta_c}^2 + \left(140\delta_f - 408 - 14{\delta_f}^2\right)\delta_c \\
&\quad + 240 + 36{\delta_f}^2 - 116\delta_f - 3{\delta_f}^3 \\
a_1 &= -4\,{\delta_c}^3 + \left(48 - 4\,\delta_f\right){\delta_c}^2 + \left(-128 + 24\,\delta_f\right)\delta_c - 24\,\delta_f + 96 + 4\,{\delta_f}^2 \\
a_0 &= 4\,(2-\delta_c)^2\,.
\end{aligned}
$$

Therefore,

$$\Pi^D - \Pi^C > 0 \Leftrightarrow F_n(\delta_c, \delta_f) > 0. \tag{C.4}$$

It is easy to check that if $\delta_c = 0$, then $F_n(\delta_c, \delta_f) < 0$, and so $\Pi^D < \Pi^C$, which is expected since with myopic customers the centralized system always performs better. However, when $\delta_c > 0$, the sign of $F_n(\delta_c, \delta_f)$ is indeterminate. For example, when $n = 2, \delta_c = 0.8, \delta_f = 0.9$, we have $F_n(\delta_c, \delta_f) = 385.43 > 0 \Rightarrow \Pi^D > \Pi^C$; when $n = 2, \delta_c = 0.2, \delta_f = 0.9$, we have $F_n(\delta_c, \delta_f) = -2483.85 < 0 \Rightarrow \Pi^D < \Pi^C$. When both customers and firms do not discount their future payoffs, i.e. $\delta_c = \delta_f = 1$, we have $F_n(\delta_c, \delta_f) = -(n^3 - 2n^2 - 6n - 4)^2 < 0$. In other words, without discounting, the centralized channel profit is highest.

■

Proof of Lemma 4.2

(a) Subtracting Q_2^C by Q_2^D yields

$$\begin{aligned}
& Q_2^C - Q_2^D \\
= \; & \frac{N(1-c)(2-\delta_c)}{2(4-2\delta_c-\delta_f)} \\
& -\frac{N(1-c)n}{2\Delta(n+1)}\Big((2-\delta_c)\,n^3+(8-3\delta_c)\,n^2+(10-2\delta_c-\delta_f)n+4\Big) \\
= \; & \frac{N(1-c)}{2(n+1)(4-2\delta_c-\delta_f)\Delta}\Big(8-4\delta_c+(16+2\delta_c^2+(2\delta_f-12)\delta_c)n \\
& +\big(8+8\delta_f+2\delta_c^2-(8+\delta_f)\delta_c-\delta_f^2\big)n^2+(4-\delta_c)\delta_f n^3\Big) \\
> \; & 0.
\end{aligned}$$

(b) Taking first derivative with respect to n, we obtain

$$\begin{aligned}
\frac{dQ_2^D}{dn} = \; & \frac{N(1-c)}{2(n+1)^2\Delta^2}\Big(\delta_f\,(4-\delta_c)\,n^6 \\
& +\Big(4\,{\delta_c}^2-\big(16+2\,\delta_f\big)\,\delta_c-2\,{\delta_f}^2+16\,\delta_f+16\Big)\,n^5 \\
& +\Big(12\,{\delta_c}^2+\big(5\,\delta_f-64\big)\,\delta_c+12\,\delta_f-2\,{\delta_f}^2+80\Big)\,n^4 \\
& +\Big(12\,{\delta_c}^2+\big(-96+12\,\delta_f\big)\,\delta_c-16\,\delta_f+160\Big)\,n^3 \\
& +\Big(4\,{\delta_c}^2+\big(-64+6\,\delta_f\big)\,\delta_c+2\,{\delta_f}^2-24\,\delta_f+160\Big)\,n^2 \\
& +\big(-16\,\delta_c+80-8\,\delta_f\big)\,n+16\Big) \\
> \; & 0.
\end{aligned}$$

So Q_2^D is increasing in the number of retailers, n. Moreover,

$$\lim_{n\to\infty} Q_2^D = \frac{N(1-c)(2-\delta_c)}{2(4-2\delta_c-\delta_f)} = Q_2^C.$$

■

Proof of Proposition 4.4

(a) Plugging $\delta_c = n = 1$ into $\Pi^D - \Pi^C$ yields

$$\Pi^D - \Pi^C = \frac{288 - 24\delta_f - 460\delta_f^2 + 78\delta_f^3 - 3\delta_f^4}{256(2-\delta_f)(6-\delta_f)^2} \cdot N(1-c)^2.$$

It follows that

$$sign\{\Pi^D - \Pi^C\} = sign\{288 - 24\delta_f - 460\delta_f^2 + 78\delta_f^3 - 3\delta_f^4\}.$$

By taking the first derivative with respect to δ_f, we get

$$\begin{aligned} & \frac{d(288 - 24\delta_f - 460\delta_f^2 + 78\delta_f^3 - 3\delta_f^4)}{d\delta_f} \\ = \; & -24 - 920\delta_f + 234\delta_f^2 - 12\delta_f^3 \\ = \; & -24 - 686\delta_f - 234\delta_f(1-\delta_f) - 12\delta_f^3 \\ < \; & 0. \end{aligned}$$

That is to say, the function $288 - 24\delta_f - 460\delta_f^2 + 78\delta_f^3 - 3\delta_f^4$ is strictly decreasing in δ_f. Solving the roots of the function numerically, we obtain a unique root $\delta_f = 0.821$ since $0 \leq \delta_f \leq 1$. Hence, we conclude that

$$\Pi^D > \Pi^C \Leftrightarrow 0 \leq \delta_f < 0.821.$$

(b) Plugging $\delta_f = n = 1$ into $\Pi^D - \Pi^C$ yields

$$\Pi^D - \Pi^C = \frac{-2263 + 5346\delta_c - 4508\delta_c^2 + 1464\delta_c^3 - 160\delta_c^4}{256(3-2\delta_c)(7-2\delta_c)^2} \cdot N(1-c)^2.$$

It follows that

$$sign\{\Pi^D - \Pi^C\} = sign\{-2263 + 5346\delta_c - 4508\delta_c^2 + 1464\delta_c^3 - 160\delta_c^4\}.$$

Taking the first derivative with respect to δ_f yields

$$\begin{aligned}
& \frac{d(-2263+5346\delta_c-4508\delta_c^2+1464\delta_c^3-160\delta_c^4)}{d\delta_f} \\
= \; & 5346-9016\delta_c+4392\delta_c^2-640\delta_c^3 \\
= \; & 4474+232(1-\delta_c)+4392(1-\delta_c)^2+640(1-\delta_c^3) \\
> \; & 0.
\end{aligned}$$

That is to say, the function $-2263+5346\delta_c-4508\delta_c^2+1464\delta_c^3-160\delta_c^4$ is strictly increasing in δ_c. Since $0 \leq \delta_c \leq 1$, plugging $\delta_c = 1$ into the function yields the maximum -121. Hence, we conclude that $\Pi^D < \Pi^C$.

(c) Plugging $n = 1$ into $\Pi^D - \Pi^C$ yields

$$\Pi^D - \Pi^C = \frac{F_1(\delta_c, \delta_f)}{64(4-2\delta_c-\delta_f)(8-2\delta_c-\delta_f)^2} \cdot N(1-c)^2, \text{ where}$$

$$\begin{aligned}
F_1(\delta_c, \delta_f) \;=\; & \frac{1}{4}\Big(-160\,{\delta_c}^4 - \big(264\,\delta_f - 1728\big)\,{\delta_c}^3 \\
& - \Big(140\,{\delta_f}^2 - 2032\,\delta_f + 6400\Big)\,{\delta_c}^2 \\
& - \Big(30\,{\delta_f}^3 - 768\,{\delta_f}^2 + 4608\,\delta_f - 9216\Big)\,\delta_c \\
& -3\,{\delta_f}^4 + 108\,{\delta_f}^3 - 1088\,{\delta_f}^2 + 2816\,\delta_f - 4096\Big).
\end{aligned}$$

It follows that

$$sign\{\Pi^D - \Pi^C\} = sign\{F_1(\delta_c, \delta_f)\}.$$

Hence, we conclude that

$$\Pi^D > \Pi^C \Leftrightarrow F_1(\delta_c, \delta_f) > 0.$$

■

Proof of Proposition 4.5

(a) Plugging $\delta_c = 1$ and $n = 2$ into $\Pi^D - \Pi^C$ yields

$$\Pi^D - \Pi^C = \frac{270 - 144\delta_f - 162\delta_f^2 + 29\delta_f^3 - \delta_f^4}{72(2-\delta_f)(9-2\delta_f)^2} \cdot N(1-c)^2.$$

It follows that

$$sign\{\Pi^D - \Pi^C\} = sign\{270 - 144\delta_f - 162\delta_f^2 + 29\delta_f^3 - \delta_f^4\}.$$

By taking the first derivative with respect to δ_f, we get

$$\begin{aligned} & \frac{d(270 - 144\delta_f - 162\delta_f^2 + 29\delta_f^3 - \delta_f^4)}{d\delta_f} \\ = \; & -144 - 324\delta_f + 87\delta_f^2 - 4\delta_f^3 \\ = \; & -144 - 237\delta_f - 87\delta_f(1-\delta_f) - 4\delta_f^3 \\ < \; & 0. \end{aligned}$$

That is to say, the function $270 - 144\delta_f - 162\delta_f^2 + 29\delta_f^3 - \delta_f^4$ is strictly decreasing in δ_f. Solving the roots of the function numerically, we obtain a unique root $\delta_f = 0.979$ since $0 \leq \delta_f \leq 1$. Hence, we conclude that with two competing retailers,

$$\Pi^D > \Pi^C \Leftrightarrow 0 \leq \delta_f < 0.979.$$

(b) Plugging $\delta_f = 1$ and $n = 2$ into $\Pi^D - \Pi^C$ yields

$$\Pi^D - \Pi^C = \frac{-1299 + 4379\delta_c - 4869\delta_c^2 + 2070\delta_c^3 - 297\delta_c^4}{36(3-2\delta_c)(23-9\delta_c)^2} \cdot N(1-c)^2.$$

It follows that

$$sign\{\Pi^D - \Pi^C\} = sign\{-1299 + 4379\delta_c - 4869\delta_c^2 + 2070\delta_c^3 - 297\delta_c^4\}.$$

By taking the second derivative with respect to δ_c, we get

$$\begin{aligned}
& \frac{d^2(-1299+4379\delta_c-4869\delta_c^2+2070\delta_c^3-297\delta_c^4)}{d\delta_c^2} \\
= \; & -9738+12420\delta_c-3564\delta_c^2 \\
= \; & -3564(1-\delta_c)^2-5292(1-\delta_c)-882 \\
< \; & 0.
\end{aligned}$$

That is to say, the function $-1299+4379\delta_c-4869\delta_c^2+2070\delta_c^3-297\delta_c^4$ is strictly concave in δ_c. Solving the roots of the function numerically, we obtain two roots $\delta_c = 0.635$ and $\delta_c = 0.949$. Hence, we conclude that with two competing retailers,

$$\Pi^D > \Pi^C \Leftrightarrow 0.635 < \delta_c < 0.949.$$

(c) Plugging $n = 2$ into $\Pi^D - \Pi^C$ yields

$$\Pi^D - \Pi^C = \frac{F_2(\delta_c, \delta_f)}{144(4-2\delta_c-\delta_f)(27-9\delta_c-4\delta_f)^2} \cdot N(1-c)^2, \text{ where}$$

$$\begin{aligned}
F_2(\delta_c, \delta_f) \; = \; & 4\Big(-297\,{\delta_c}^4-\big(468\,\delta_f-2538\big)\,{\delta_c}^3 \\
& -\Big(216\,{\delta_f}^2-2880\,\delta_f+7533\Big)\,{\delta_c}^2 \\
& -\Big(31\,{\delta_f}^3-954\,{\delta_f}^2+5292\,\delta_f-8748\Big)\,\delta_c \\
& -2\,{\delta_f}^4+89\,{\delta_f}^3-1062\,{\delta_f}^2+2592\,\delta_f-2916\Big).
\end{aligned}$$

It follows that

$$sign\{\Pi^D - \Pi^C\} = sign\{F_2(\delta_c, \delta_f)\}.$$

Hence, we conclude that with two retailers,

$$\Pi^D > \Pi^C \Leftrightarrow F_2(\delta_c, \delta_f) > 0.$$

■

Analysis of Uncertain Demamd

Recall that the demand uncertainty is resolved in the first period. So, the first period decisions depend only on the distribution of the demand, and the second period decisions depend on the realized demand state in the first period.

Let $\tilde{q}_{i1}$ be the order quantities of retailer i in the first period, where $i = 1, 2, \cdots, n$. Let $\tilde{q}_{i2h}$ ($\tilde{q}_{i2l}$) be the order quantities of retailer i in the second period with high (low) demand realization. Again, we use $\tilde{Q}_1, \tilde{Q}_{2h}$ and $\tilde{Q}_{2l}$ to denote the total order quantities in the first period, the second period with high demand state, the second period with low demand state, respectively. Let $\tilde{p}_{th}$ and $\tilde{p}_{tl}$ be the resulting retailer prices in period t with high and low demand, respectively.

Depending on when and whether to purchase the product, in equilibrium, there are three strategies that a customer can choose:

(i) do not buy in the first period, and buy in the second period (denoted by 'NB');

(ii) buy in the first period, and do not buy in the second period (denoted by 'BN');

(iii) do not buy in both periods (denoted by 'NN').

Although customers' equilibrium purchasing strategies are the same as the deterministic case, the equilibrium prices will depend on the demand distribution. We will only consider the high demand case. The lower demand case can be analyzed analogously. First, let us look at the lowest valuation customer who adopts the 'NB' strategy in equilibrium. Let $\tilde{v}_{2h}$ be the valuation of this customer. Since customers' valuations are uniformly distributed over the interval $[0, 1]$ then we have $N_h(1 - \tilde{v}_{2h})/(1 - 0) = \tilde{Q}_1 + \tilde{Q}_{2h}$. It follows that $\tilde{v}_{2h} = 1 - (\tilde{Q}_1 + \tilde{Q}_2)/N_h$. This customer must be indifferent between the 'NB' strategy and the 'NN' strategy. The net utility from following the 'NB' strategy is $\tilde{v}_{2h} - \tilde{p}_{2h}$, and the net utility from adopting the 'NN' strategy is 0. Then $\tilde{v}_{2h} - \tilde{p}_{2h} = 0$, and so

$$\tilde{p}_{2h} = 1 - (\tilde{Q}_1 + \tilde{Q}_{2h})/N_h. \tag{C.5}$$

Now consider the lowest valuation customer who chooses the 'BN' strategy in equilibrium. Denote the valuation of this customer by $\tilde{v}_{1h}$. Then $N_h(1 - \tilde{v}_{1h}) = \tilde{Q}_1$, and so $\tilde{v}_{1h} = 1 - \tilde{Q}_1/N_h$. This customer has to be indifferent between the 'BN' strategy and the 'NB' strategy. The net utility from following the 'BN' strategy is

$\tilde{v}_{1h} - \tilde{p}_{1h}$, and the net utility from adopting the 'NB' strategy is $\delta_c(\tilde{v}_{1h} - \tilde{p}_{2h})$. Then we must have $\tilde{v}_{1h} - \tilde{p}_{1h} = \delta_c(\tilde{v}_{1h} - \tilde{p}_{2h})$. It follows that

$$\tilde{p}_{1h} = 1 - (\tilde{Q}_1 + \delta_c \tilde{Q}_{2h})/N_h. \tag{C.6}$$

Analogously, for the low demand case, we have

$$\tilde{p}_{2l} = 1 - (\tilde{Q}_1 + \tilde{Q}_{2l})/N_l, \tag{C.7}$$

$$\tilde{p}_{1l} = 1 - (\tilde{Q}_1 + \delta_c \tilde{Q}_{2l})/N_l. \tag{C.8}$$

Again, we solve the game backwards for the centralized channel and decentralized channel, respectively. To avoid uninteresting cases, we will only focus on parameter values with which firms make positive productions in each period. The resulting profits are

$$\tilde{\Pi}^C = \frac{(1-c)^2((4-2\delta_c-\delta_f)(N_h-N_l)^2\delta_f\theta(1-\theta)+N_hN_l(2-\delta_c)^2)}{4(4-2\delta_c-\delta_f)(N_h-\theta(N_h-N_l))},$$

and

$$\tilde{\Pi}^D = \frac{B(\delta_c,\delta_f,n,N_h,N_l,\theta)n(1-c)^2}{(n+1)^2(N_h-(N_h-N_l)\theta)\Delta^2},$$

where $\Delta = \left(4-2\delta_c-\delta_f\right)n^3 + \left(12-4\delta_c-\delta_f\right)n^2 + 2\left(6-\delta_c-\delta_f\right)n + 4$,

and $B(\delta_c, \delta_f, n, N_h, N_l, \theta) = \sum_{i=0}^{7} b_i n^i$ with

$$
\begin{aligned}
b_7 &= \left(4-2\delta_c-\delta_f\right)\left(\theta(1-\theta)(N_h-N_l)^2\delta_f(2-\delta_c-\delta_f)+N_hN_l(2-\delta_c)^2\right)\\
b_6 &= \theta(1-\theta)(N_h-N_l)^2\delta_f(\delta_f^2+\delta_f(5\delta_c-12)+2(2-\delta_c)(8-3\delta_c))\\
&\quad +(2-\delta_c)N_hN_l((\delta_c-4)\delta_f+(2-\delta_c)(16-5\delta_c))/2\\
b_5 &= \theta(1-\theta)(N_h-N_l)^2\delta_f(9/4\,{\delta_f}^2+11\,\delta_f\delta_c-32\,\delta_f+14\,{\delta_c}^2-80\,\delta_c+108)\\
&\quad -1/4\,N_hN_l\left(4\,\delta_f\delta_c-3\,\delta_f{\delta_c}^2+8\,\delta_f-168\,{\delta_c}^2+480\,\delta_c-432+18\,{\delta_c}^3\right)\\
b_4 &= \theta(1-\theta)(N_h-N_l)^2\delta_f(16\,{\delta_c}^2-120\,\delta_c+15\,\delta_f\delta_c+200+7/2\,{\delta_f}^2-52\,\delta_f)+\\
&\quad N_hN_l(-3\,{\delta_f}^2+3/2\,{\delta_f}^2\delta_c+16\,\delta_f-15\,\delta_f\delta_c+3\,\delta_f{\delta_c}^2+48\,{\delta_c}^2-7/2\,{\delta_c}^3-180\,\delta_c+200)\\
b_3 &= \theta(1-\theta)(N_h-N_l)^2\delta_f(12\,\delta_f\delta_c+220-100\,\delta_c+9\,{\delta_c}^2+3\,{\delta_f}^2-54\,\delta_f)+\\
&\quad N_hN_l(1/4\,{\delta_f}^3-9\,{\delta_f}^2+3\,{\delta_f}^2\delta_c+3\,\delta_f{\delta_c}^2+39\,\delta_f-24\,\delta_f\delta_c+27\,{\delta_c}^2-{\delta_c}^3-150\,\delta_c+220)\\
b_2 &= \theta(1-\theta)(N_h-N_l)^2\delta_f(4\,\delta_f\delta_c+2\,{\delta_f}^2+2\,{\delta_c}^2-32\,\delta_f+144-44\,\delta_c)+\\
&\quad N_hN_l(1/2\,{\delta_f}^3+3/2\,{\delta_f}^2\delta_c-9\,{\delta_f}^2+40\,\delta_f+\delta_f{\delta_c}^2-16\,\delta_f\delta_c-66\,\delta_c+144+6\,{\delta_c}^2)\\
b_1 &= \theta(1-\theta)(N_h-N_l)^2\delta_f(-8\,\delta_f-8\,\delta_c+52)+N_hN_l(-3\,{\delta_f}^2-4\,\delta_f\delta_c+20\,\delta_f+52-12\,\delta_c)\\
b_0 &= 8\theta(1-\theta)(N_h-N_l)^2\delta_f+N_hN_l(4\,\delta_f+8).
\end{aligned}
$$

Proof of Proposition 4.6

First, we consider the single-retailer case.

(a) Plugging $\delta_c = n = 1$ into $\tilde{\Pi}^D - \tilde{\Pi}^C$ yields

$$
\begin{aligned}
\tilde{\Pi}^D - \tilde{\Pi}^C &= \frac{(1-c)^2}{16(2-\delta_f)(6-\delta_f)^2(N_h-\theta(N_h-N_l))}\times\\
&\quad \Big(N_hN_l(288-24\delta_f-460\delta_f^2+78\delta_f^3-3\delta_f^4)/16\\
&\quad -\theta(1-\theta)(N_h-N_l)^2\delta_f(2-\delta_f)(6-\delta_f)^2\Big).
\end{aligned}
$$

It follows that

$$
\begin{aligned}
sign\{\tilde{\Pi}^D - \tilde{\Pi}^C\} &= sign\{N_hN_l(288-24\delta_f-460\delta_f^2+78\delta_f^3-3\delta_f^4)/16\\
&\quad -\theta(1-\theta)(N_h-N_l)^2\delta_f(2-\delta_f)(6-\delta_f)^2\}.
\end{aligned}
$$

Note that if $\theta = 0$, 1, or $\delta_f = 0$, the nonpositive term $-\theta(1-\theta)(N_h - N_l)^2\delta_f(2-\delta_f)(6-\delta_f)^2$ equals zero, then we return to Proposition 4.4(a). We have shown the function $288 - 24\delta_f - 460\delta_f^2 + 78\delta_f^3 - 3\delta_f^4$ is strictly decreasing in δ_f, and is positive if and only if $0 \leq \delta_f < 0.821$. Hence, we conclude that there exists $0 < \delta_{f1} < 0.821$ such that $\tilde{\Pi}^D > \tilde{\Pi}^C$ if $0 \leq \delta_f < \delta_{f1}$.

(b) Plugging $\delta_f = n = 1$ into $\tilde{\Pi}^D - \tilde{\Pi}^C$ yields

$$\begin{aligned}\tilde{\Pi}^D - \tilde{\Pi}^C &= \frac{(1-c)^2}{16(3/2-\delta_c)(7/2-\delta_c)^2(N_h - \theta(N_h - N_l))} \cdot \\ &\Big(\frac{N_h N_l}{128}(-2263 + 5346\delta_c - 4508\delta_c^2 + 1464\delta_c^3 - 160\delta_c^4) \\ &-\theta(1-\theta)(N_h - N_l)^2(3/2-\delta_c)(7/2-\delta_c)^2\Big).\end{aligned}$$

It follows that

$$\begin{aligned}sign\{\tilde{\Pi}^D - \tilde{\Pi}^C\} &= sign\{\frac{N_h N_l}{128}(-2263 + 5346\delta_c - 4508\delta_c^2 + 1464\delta_c^3 - 160\delta_c^4) \\ &\quad -\theta(1-\theta)(N_h - N_l)^2(3/2-\delta_c)(7/2-\delta_c)^2\}.\end{aligned}$$

We have shown in the proof of Proposition 4.4(b) that the function $-2263 + 5346\delta_c - 4508\delta_c^2 + 1464\delta_c^3 - 160\delta_c^4$ is negative. And the extra term $-\theta(1-\theta)(N_h - N_l)^2(3/2-\delta_c)(7/2-\delta_c)^2$ is negative. Hence, we conclude that $\tilde{\Pi}^D < \tilde{\Pi}^C$.

Now, we turn to the two-retailer case.

(a) Plugging $\delta_c = 1$ and $n = 2$ into $\tilde{\Pi}^D - \tilde{\Pi}^C$ yields

$$\begin{aligned}\tilde{\Pi}^D - \tilde{\Pi}^C &= \frac{(1-c)^2}{36(2-\delta_f)(9/2-\delta_f)^2(N_h - \theta(N_h - N_l))} \cdot \\ &\Big(\frac{N_h N_l}{8}(270 - 144\delta_f - 162\delta_f^2 + 29\delta_f^3 - \delta_f^4) \\ &-\theta(1-\theta)(N_h - N_l)^2\delta_f(\delta_f^3 - 11\delta_f^2 + 153\delta_f/4 - 81/2)\Big).\end{aligned}$$

It follows that

$$\begin{aligned} sign\{\tilde{\Pi}^D - \tilde{\Pi}^C\} &= sign\{\frac{N_h N_l}{8}(270 - 144\delta_f - 162\delta_f^2 + 29\delta_f^3 - \delta_f^4) \\ &\quad -\theta(1-\theta)(N_h - N_l)^2\delta_f(\delta_f^3 - 11\delta_f^2 + \frac{153\delta_f}{4} - \frac{81}{2})\}. \end{aligned}$$

Note that if $\theta = 0$, 1, or $\delta_f = 0$, the nonpositive term $-(\theta(1-\theta)(N_h - N_l)^2\delta_f(2-\delta_f)(6-\delta_f)^2$ equals zero, then we return to Proposition 4.5(a). We have shown the function $270 - 144\delta_f - 162\delta_f^2 + 29\delta_f^3 - \delta_f^4$ is strictly decreasing in δ_f, and is positive if and only if $0 \leq \delta_f < 0.979$. Hence, we conclude that there exists $0 < \delta_{f2} < 0.979$ such that $\tilde{\Pi}^D > \tilde{\Pi}^C$ if $0 \leq \delta_f < \delta_{f2}$.

(b) Plugging $\delta_f = 1$ and $n = 2$ into $\tilde{\Pi}^D - \tilde{\Pi}^C$ yields

$$\tilde{\Pi}^D - \tilde{\Pi}^C = \frac{(1-c)^2}{5832(3-2\delta_c)(23-9\delta_c)^2(N_h - \theta(N_h - N_l))} G(\delta_c, N_h, N_l, \theta),$$

where $G(\delta_c, N_h, N_l, \theta) = \frac{11N_hN_l}{1782}(-1299 + 4379\delta_c - 4869\delta_c^2 + 2070\delta_c^3 - 297\delta_c^4) - \frac{\theta(1-\theta)}{162}(N_h - N_l)^2(3-2\delta_c)(23-9\delta_c)^2$. It follows that

$$sign\{\tilde{\Pi}^D - \tilde{\Pi}^C\} = sign\{G(\delta_c, N_h, N_l, \theta)\}.$$

We have shown in the proof of Proposition 4.5(b) that the function $-1299 + 4379\delta_c - 4869\delta_c^2 + 2070\delta_c^3 - 297\delta_c^4$ is strictly concave in δ_c, and is positive if and only if $0.635 < \delta_c < 0.949$. Note that the extra term $-\frac{\theta(1-\theta)}{162}(N_h - N_l)^2(3-2\delta_c)(23-9\delta_c)^2$ is negative, and

$$\begin{aligned} &\frac{d^2G(\delta_c, N_h, N_l, \theta)}{d^2\delta_c} \\ = \; & -\frac{N_hN_l(541 - 690\delta_c + 33\delta_c^2) + \theta(1-\theta)(N_h - N_l)^2(119 - 54\delta_c)}{9} \\ < \; & 0. \end{aligned}$$

If $G(\delta_c, N_h, N_l, \theta) > 0$ for some $\delta_c, N_h, N_l, \theta$, then there exist $0.635 < \delta_{c1} < \delta_{c2} < 0.949$ such that $G(\delta_c, N_h, N_l, \theta) > 0$ if and only if $\delta_{c1} < \delta_c < \delta_{c2}$. Note

that $G(\delta_c, N_h, N_l, \theta) > 0$ for some $\delta_c, N_h, N_l, \theta$ is equivalent to

$$\begin{aligned} & \frac{\theta(1-\theta)(N_h - N_l)^2}{N_h N_l} \\ < & \max_{0 \le \delta_c \le 1} \left(\frac{\frac{11}{1782}(-1299 + 4379\delta_c - 4869\delta_c^2 + 2070\delta_c^3 - 297\delta_c^4)}{(3-2\delta_c)(23-9\delta_c)^2/162} \right) \\ = & \ 0.754, \end{aligned}$$

where the maximum is achieved at $\delta_c = 0.8104$. Therefore, if $(N_h - N_l)^2\theta(1-\theta) \le 0.754 N_h N_l$ (demand uncertainty is very small), then there exist $0.635 < \delta_{c1} < \delta_{c2} < 0.949$ such that the decentralized channel profit is higher if and only $\delta_{c1} < \delta_c < \delta_{c2}$. Otherwise, the centralized channel profit is higher.

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