ECONOMIC AND POLICY ANALYSIS ON AIR AND RAIL TRANSPORT

by

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Abstract

This dissertation focuses on two major topics in air and rail transportation. The first one is related to various aspects of interactions between airlines and high-speed rail (HSR). We first analyze the effects of cooperation between a hub-and-spoke airline and an HSR operator when the hub airport may be capacity-constrained (Chapter 2). We find that, as compared to the case of modal competition, such cooperation may increase or decrease social welfare, depending on modal substitutability and hub capacity. Then we study the impact of air-HSR competition on the environment and welfare (Chapter 3). We show that the introduction of HSR, even if it is more environmentally friendly than airlines on a per-seat basis, may have a net negative effect on the environment and social welfare. Lastly we investigate the long-term impacts of HSR competition on airlines (Chapter 4). We find that when HSR enters the trunk routes or increases its competitiveness, an airline will have a greater incentive to cover more regional (foreign) markets and move towards hub-and spoke network if the trunk market is larger.

The second topic is related to the strategic coalitions among airlines. First we analyze the partnership formation for two competing local airlines and two global alliances (Chapter 5). We find that the equilibrium outcome depends on whether they play in a simultaneous game or a sequential game. Then we examine the strategic vertical relationship between network and regional airlines (Chapter 6). We develop a model to illustrate how network airlines can use the contractual relationship with regional airlines as an efficient tool to simultaneously drive out inefficient network airlines and also accommodate other cost efficient network airlines in any specific market. The model is tested on U.S. data using simultaneous and sequential choice models.

Finally, major results of the thesis and future research directions are discussed (Chapter 7). In particular, we propose to study the general impacts of HSR projects on an economy, including urban development as well as the positive spillovers of HSR technology.
Preface

A version of Chapter 2 has been published as Jiang, C. and Zhang, A. (2014) “Effects of High-speed Rail and Airline Cooperation under Hub Airport Capacity Constraint,” Transportation Research Part B: Methodological, 60 (1), 33-49. Anming Zhang and I came up with the research question, and I conducted the initial modeling analysis and all the mathematical proofs, and wrote the first draft of the manuscript. Anming Zhang made some major revisions to the manuscript.

Chapter 3 is a joint work with Tiziana D’Alfonso. Tiziana D’Alfonso came up with the original research question while I proposed major extensions to the question (the cases of endogenous frequency and speed). The modeling and mathematical proof were executed by the two co-authors together.

Chapter 4 is original, unpublished, independent work by the author, Changmin Jiang.

A version of Chapter 5 has been accepted by and will be forthcoming in Journal of Transport Economics and Policy. It is a joint work with Yulai Wan and Tiziana D’Alfonso. I came up with the research question and assumed most of the writing. The rest of the work, such as modeling, mathematical proof, as well as simulation study, was conducted by the three co-authors together.

A version of Chapter 6 has been accepted by and will be forthcoming in Transportation Research Part B: Methodological. It is a joint work with Hamed Hasheminia and David Gillen. Hamed Hasheminia and I came up with the research question, conducted the modeling as well as the mathematical proof, and wrote the paper together. I collected and compiled the data, while Hamed Hasheminia conducted statistical analysis. David Gillen provided practical insights and helped with literature review as well as manuscript revision.
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Dedication

To my parents, Liehua Jiang and Ping Zhang.
1 Introduction

This dissertation includes two major research topics in transportation economics: (1) interactions between airlines and high-speed rail (HSR); and (2) strategic coalition among airlines. These two topics are under a unified theme: the interplay between different companies in a transportation system. In particular, I am interested in the different types of interactions between companies within a particular transport mode (air) and across various transport modes (air and rail).

1.1 Interactions between Airlines and High-speed Rail

Chapters 2-4 relate to the first topic, i.e. interaction between airlines and HSR. This line of research was motivated by the fact that as train speeds become faster over the years, HSR has become a de facto substitute and effective competitor of air transport, especially for short-haul routes with distance up to 1,000 km (e.g., Janic, 1993; Rothengatter, 2011). In countries with HSR development, the air transport sector has felt the shock and largely gone through significant changes. Examples abound where airlines have been forced by HSR to withdraw from, or cut back on, short-haul routes. Recent cases of air route cancellations include a number of Chinese domestic markets such as Nanjing-Shanghai, Zhengzhou-Xi’an, Changsha-Guangzhou and Wuhan-Nanjing. Deep cuts of airfares after the entry of HSR service are even more common. For example, the market between Wuhan and Xiamen, two Chinese cities recently linked by HSR, saw an 80% drop in air ticket price. As a result, the three major Chinese airlines all posted miserable financial reports in 2013 (net profits dropped 32 percent for Air China, 25 percent for China Eastern Airlines, and 24 percent for China Southern Airlines). In fact, China’s HSR now moves twice as many passengers as its airline industry. The Chinese carriers are not alone in this gloomy weather. For the first time ever, HSR has outpaced air travel in Spain. Figures released by the National Statistics Institute (INE) in 2014 show that 1.9 million people used the country’s extensive AVE network in January compared with 1.8 million people who bought plane tickets. This represents a 7.3-percent year-on-year drop for airplane travel and a 22-percent rise in high-speed rail journeys.
However, in spite of its growing importance, the interaction between the air sector and the rail sector has not yet drawn proper attention. In particular, the existing literature focuses mainly on the short-run competition aspect between the two modes mainly from a qualitative or empirical perspective (Gonzalez-Savignat, 2004; Park and Ha, 2006; Adler et al., 2010; Behrens and Pels, 2012). Many other important features in this modal interaction, including complementarity between the two modes and the potential intermodal cooperation (Givoni and Banister, 2006), the longer-term impacts of the modal competition on issues such as airline network structure as well as environmental implication, are largely left untouched.

I start with a theoretical model in Chapter 2 investigating the impacts of airline-HSR cooperation. Under cooperation contracts, HSR service that connects the hub airport is used in combination with a flight as one journey, with one booking for the entire trip. A few cases of such airline-HSR cooperation have existed in Europe for quite a while, such as the AIRail Service provided by Lufthansa and Deutsche Bahn in Germany that connected Frankfurt airport with Stuttgart and Cologne. And it is also getting popular in Asia especially in China. Despite its growing popularity, overall airline-HSR cooperation is still a relatively new phenomenon and so its market outcomes and welfare effects are largely unknown to date. However, a better understanding of its impact is necessary and timely given that China is developing HSR quite ambitiously and countries like Brazil, India, Russia, Turkey, the UK and the US are evaluating the options of investing in HSR (Fu et al., 2012). The investigation incorporates some of the most salient features of the two modes: in addition to an explicit examination of potential hub airport capacity constraints, we consider modal asymmetries in the demands and costs, heterogeneous passenger types, and economies of traffic density. Such an exercise is important because airline-HSR cooperation can involve substantial investment in access/connecting facilities and management time and effort. We show that airline-HSR cooperation will, as expected, reduce traffic in the markets where prior competition between the partners occurs, but may increase traffic in other markets of the network. The cooperation would improve social welfare, independent of whether or not the hub capacity is constrained, as long as the substitutability between air service and HSR service in the overlapping
markets is low. However, if the modal substitutability is high (and hence the negative effect from dampening competition becomes larger), then hub capacity plays an important role in assessing the welfare impact. If the hub airports are significantly capacity-constrained, then airline-HSR cooperation could help alleviate the constrained capacity and benefit passengers in the non-overlapping markets of the network, leading to a net welfare improvement. Otherwise, the cooperation should be carefully examined, owing to its likely welfare-reducing effect. Through simulations we further find that airline-HSR cooperation is welfare enhancing irrespective of the hub capacity level if any one of the following conditions holds: 1) the unit cost of the HSR operator is sufficiently lower than that of the airline; 2) the HSR service is sufficiently superior to that of the airline; 3) the price sensitivity of HSR demand is higher than that of airline demand; and 4) a sufficiently large proportion of the passengers are business passengers. Our analysis shows that the economies of traffic density alone cannot justify airline-HSR cooperation. Moreover, when the density effect in the air sector is strong, the cooperation is less likely to be welfare enhancing under hub capacity constraints; but when the density effect in the rail sector is strong, this cooperation is more likely to improve welfare. This piece of work has significant policy implications, because it provides a general guideline for the policy makers to determine when such intermodal cooperation should be generally encouraged and when it is worthwhile to be cautious.

Chapter 3 studies the impact of air transport and HSR competition on the environment and social welfare. One of the main arguments to support the development of HSR is that HSR is more environmentally friendly than air transport on a per-seat basis. By substituting air traffic with rail traffic, our transport system will be more sustainable (EC, 2011; TRB, 2013; US DOT, 2002). Given the growing concerns in environmental protection and sustainability all over the world, this issue has become more and more important in HSR development evaluations. However, such statement takes a static viewpoint and fails to take into account the market dynamics of both the air sector and the rail sector in different perspectives.

Taking market dynamics into consideration, we show that despite of the relatively mild environmental impact of HSR on a per-seat basis (compared with other transport modes),
the introduction of HSR may have a net negative effect on the environment, since it may result in additional demand, i.e., there is a trade-off between the substitution effect and the traffic generation effect. Furthermore, if environmental externalities are taken into account when assessing social welfare, the surplus measure may be higher in the monopoly case - when only the airline serves the market - than in the competition case. When the airline and HSR decide on frequencies, the airline tends to reduce the aircraft size in order to offer high frequency. In these circumstances, the introduction of HSR is detrimental to the environment on a per-passenger basis if the market size is large enough. When HSR decides on speed, it has incentive to keep it at the maximum level in order to reduce travel time. When the increase in the emissions of HSR due to the increase in the speed of the train is sufficiently high, the overall level of emissions after the introduction of the HSR will be higher than in the monopoly case. Therefore, there can be a trade-off between the attractiveness of the service due to reduced travel time and the effects on the environment. These results are important from a policy perspective. On the one hand, we help to foster a better understanding of the impacts of HSR. On the other hand, we point out that introducing HSR competition is not always beneficial to the environment, which should be useful for the policy makers in considering future transport policy.

Chapter 4 studies the long-run impact of the HSR competition on the airlines. Specifically, other than looking only at the short-run strategic decisions such as price and traffic volume, we also examine the longer-term decisions of the airlines, including market selection and network choice, when HSR competition is present. Virtually all of the existing literature on the air transport–HSR interaction has focused on such short-run impacts such as price and traffic. However, once established, competition from HSR will likely stay; therefore, it might be even more important for the airlines to come up strategies to compete against HSR in the long run.

With a theoretical model, we show that facing the HSR competition on a trunk route, an airline will under some conditions be better off to shift from a point-to-point network to a hub-and-spoke network, as well as to expand into the smaller markets that it ignores before. In particular, if the network structure of the airline is exogenously given, an increase of HSR competitiveness will more likely push the airline to cover more regional
(or foreign) markets when the trunk market is larger, or when the network of the airline is closer to hub-and-spoke. And this effect is more prominent when the diminishing rate of the airline’s traffic density benefits (including higher frequency effect on the demand side and economies of traffic density on the cost side) is higher. Meanwhile, if the market coverage of the airline is exogenously given, an increase of the HSR competitiveness will more likely move the airline towards hub-and spoke network when the trunk market is larger, or when the airline covers more regional (or foreign) markets. This effect is also more prominent when the diminishing rate of the airline’s traffic density benefits is higher. These findings offer important insights to airline managers, especially those in China. As we know, China has built the world’s largest HSR network, which has exerted significant pressure on the Chinese airlines that still use point-to-point networks nowadays. Our paper offers useful business strategies to these airlines. On the other hand, it also provides a bigger picture for the competition aspect in the airline-HSR interaction, which might help the policy makers in relevant issues.

Overall, these three chapters show that the interaction between air transport and HSR is very dynamic and complicated. Some important implications will be missed if we treat these two transport modes as mere competitors and focus only on the price and the traffic level. These three chapters provide some other angles to explore this intermodal interaction. The chapters reveal that the air-rail relationship is much less straightforward than many people may believe. For example, we show that allowing the two transport modes to cooperate with each other might under some conditions improve social welfare, while the introduction of HSR – a cleaner transport mode than the air transport – might in fact have a negative impact on the environment in particular circumstances. These results, from the first sight, are somehow counterintuitive, which make them even more important to the regulators. In particular, given the fact that its interaction with the air transport is one of the major considerations in HSR development, which involves tremendous sunk investment, a clearer understanding of these aspects is crucial.

1.2 Strategic Coalition among Airlines

Chapter 5 and Chapter 6 deal with the intra-modal cooperation between airlines.
Compared with the air-rail interaction, airline cooperation is a much more developed topic. In particular, studies abound in the impacts of airline alliance on social welfare and factors related such as the equilibrium fares (e.g., Park, 1997; Park and Zhang, 1998, 2000; Park et al., 2001; Brueckner, 2001; Bilotkach, 2005). However, there are still a few aspects that are left under-explored. For example, in the literature alliance partnership is often assumed to be only possible between particular airlines. Little effort has been paid to investigate the decision making of airlines in choosing which alliance to join when multiple options are available (as in reality, there are three global airline alliances: Star, SkyTeam and oneworld). And the decision making process of global alliances in whether to take one or more airlines from a country as its member(s) has never been touched. Besides, most of the literature focuses on the partnership or alliance between major (network) airlines. The relationship between major and regional airlines draws much less attention. Only a few papers investigate this vertical relationship as independent cases and ignore the interactions between airline groups and the possible strategic function of setting up contracts with independent regional airlines. (Forbes and Lederman, 2007; 2009; 2010; Levine, 2011). In an industry as competitive as the airline sector, it is not very likely that an important decision of a network airline like outsourcing traffic to regional airlines will be made without considering the strategic dynamics of its competitors. Therefore, it would be of interest to look at the problem bearing strategic interaction in mind.

Chapter 5 takes care of the first topic. It proposes a game theoretic structure to analyze the equilibrium outcomes for two local airlines and two global alliances to form partnership with the presence of competition. This paper differs from previous studies mainly in that it specifically takes into account the possibility that local airlines may join the same global alliance, even with the existence of another global alliance. We find that it is very likely to get multiple equilibrium outcomes in a simultaneous game. On the other hand, if a sequential game is played, local airlines will join the same global alliance when either the market size or the substitutability between airlines is relatively small. This paper provides an explanation for the little mentioned phenomenon of local competitors joining the same global alliance, which may help to deepen the
understandings of airline strategic alliance, a defining characteristic of the modern aviation industry.

Chapter 6 studies the second topic. It investigates the strategic vertical relationship between network and regional airlines. We develop a model to illustrate how network airlines can use their contractual relationship with regional airlines as an efficient tool to drive out inefficient network airlines and to accommodate cost efficient network airlines in any specific market. The model is tested using Airline Origin and Destination Survey (DB1B) data. The empirical results confirm our theoretical predictions, suggesting that market size, and the relative cost differences between network airlines, as well as cost differences between network and regional airlines, are the chief determinants of the network airlines' decisions on whether or not to serve a market with their own fleet, as well as how many regional airlines to contract with.

These two chapters provide new insights to the different cooperative schemes between airlines. On the one hand, they can help to give a better understanding of the airline industry. On the other hand, they also have substantial policy implications. In particular, in an industry where merger and acquisition are less common due to various reasons, airlines achieve synergy and market collusion mainly through different cooperative mechanisms. Therefore, it is important for the anti-trust regulators to fully understand those mechanisms before efficient legal judgments can be made.
2 Effects of High-speed Rail and Airline Cooperation under Hub Airport Capacity Constraint

2.1 Introduction

Since the first modern high-speed rail (HSR) began operation between Tokyo and Osaka, Japan in 1964, a number of countries including the United Kingdom, France, Spain, Germany, Italy, Belgium, the Netherlands and South Korea have also successfully launched HSR lines. By 2012, China had the world’s largest HSR network, amounting to 9300 km of HSR coverage, with speeds between 200 km and 350 km per hour. In the United States, President Barack Obama’s (fiscal year) 2012 budget allocated $8 billion for HSR development, representing the first installment of a six-year, $53 billion plan.

As train speeds have increased over the years, HSR has been viewed as a de facto substitute and effective competitor of air transport, especially for routes with distances up to 1,000 km (e.g., Janic, 1993; Rothengatter, 2011). However, as pointed out by Givoni and Banister (2006), the relationship between HSR and air transport is far more complicated than pure competition alone. In particular, HSR can complement air service by offering connections between airports and nearby cities, and the potential for airline-HSR cooperation exists due to the hub-and-spoke network adopted by most major airlines. Under hub-and-spoke operation, two flights (“legs”) are offered to passengers as one journey from their origin airport to the destination airport through a hub airport. With HSR, however, both these two legs need not be air flights: on legs where HSR service is comparable with flights in terms of (total) journey time and cost, HSR service may also be used in combination with a flight as one journey, with one booking for the entire two-leg trip. Such airline-HSR cooperation may be viewed simply as a special type of “code sharing” – i.e. two airlines cooperate to offer a hub-and-spoke operation with each offering one leg of a flight (and a non-operating carrier is allowed to put its code on the

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operating airline’s flight number) – which has been a common practice in the airline industry (e.g. Oum et al., 1996; Brueckner, 2001; Ito and Lee, 2007; Gayle, 2008).

There are several cases of such airline-HSR cooperation in Europe. The AIRail Service provided by Lufthansa and Deutsche Bahn has connected Frankfurt airport with Stuttgart since March 2001, and with Cologne since May 2003. Passengers purchase a single ticket for the entire trip, and the luggage coordination between the airline and the HSR enables the passengers to pick up their luggage at the final destination without worrying about the transfer problem. Onboard the train, Deutsche Bahn staff provides services comparable to the ones offered onboard European short-haul flights. In France, Air France and SNCF launched TGV AIR in 1994, under which the intermodal passenger transportation between Charles de Gaulle (CDG) and Lille is exclusively operated by TGV (all Air France flights are cancelled). The TGV journey has an associated flight number appearing in the airline’s computer reservation system (CRS), but luggage check-in is not included in the intermodal service. Similarly, Thalys International has cooperated with several airlines (Air France, KLM, American Airlines, Lufthansa and SN Brussels) to provide intermodal services to passengers on three Thalys links, namely, Brussels-CDG, Anvers-Schiphol, and Paris (Nord)-Brussels National Airport. These agreements differ from TGV AIR in that travelers check in at the rail stations for the entire journey. In Switzerland, the Swiss railway operator, SBB, cooperates with Swiss Airlines and Finnair to offer an intermodal product, called FlugZug, which covers four destinations (Basel, Bern, Lausanne and Lucerne) beyond Zurich. This product is displayed on the airlines’ CRSs such that it looks like a Swiss or Finnair “flight.” The traveler is “through checked” and obtains a boarding pass for the train leg of the journey. The service originally offered luggage through-check but the luggage transfer was stopped eventually due to under-utilization (Cokasova, 2006).

While airline-HSR cooperation has become more popular, overall it is still a relatively new phenomenon and so its market outcomes and welfare effects are largely unknown to date. Such cooperation can obviously hurt competition between the two modes in the markets where prior competition between the two occurs. A less obvious question is how such cooperation affects other “secondary” markets, owing to the network nature of a
transportation system. The European Union appears to encourage such cooperation, stating in its White Paper that “network planning should therefore seek to take advantage of the ability of HSR to replace air transport and encourage rail companies, airlines and airport managers not just to compete, but also to cooperate” (EC, 2001); no rigorous analysis was given however. In the existing literature the two main arguments in favor of airline-HSR cooperation are 1) the relief of congestion at some major airports subject to capacity constraints and 2) the reduction of environmental pollutions (Givoni and Banister, 2006; Socorro and Viecens, 2013), as HSR service can divert airport traffic and is further considered a cleaner mode of transportation than air service, on a per-passenger basis. The arguments are made largely qualitatively with the use of empirical observations.

The present paper investigates analytically air transport-HSR interactions so as to address the impact of airline-HSR cooperation on market outcome and social welfare. Our investigation incorporates some of the most salient features of the two modes: in addition to an explicit examination of potential hub airport capacity constraints, we consider modal asymmetries in the demands and costs, heterogeneous passenger types, and economies of traffic density. Such an exercise is important because airline-HSR cooperation can involve substantial investment in access/connecting facilities and management time and effort. A better understanding of its impact is necessary and timely given that China is developing HSR quite ambitiously and countries like Brazil, India, Russia, Turkey, the UK and the US are evaluating the options of investing in HSR (Fu et al., 2012).

We show that airline-HSR cooperation will, as expected, reduce traffic in the markets where prior competition between the partners occurs, but may increase traffic in other markets of the network. The cooperation would improve social welfare, independent of whether or not the hub capacity is constrained, as long as the substitutability between air service and HSR service in the overlapping markets is low. However, if the modal substitutability is high (and hence the negative effect from dampening competition becomes larger), then hub capacity plays an important role in assessing the welfare impact. If the hub airports are significantly capacity-constrained, then airline-HSR
cooperation could help alleviate the constrained capacity and benefit passengers in the non-overlapping markets of the network, leading to a net welfare improvement. Otherwise, the cooperation should be carefully examined, owing to its likely welfare-reducing effect. Through simulations we further find that airline-HSR cooperation is welfare enhancing irrespective of the hub capacity level if any one of the following conditions holds: 1) the unit cost of the HSR operator is sufficiently lower than that of the airline; 2) the HSR service is sufficiently superior to that of the airline; 3) the price sensitivity of HSR demand is higher than that of airline demand; and 4) a sufficiently large proportion of the passengers are business passengers. Our analysis shows that the economies of traffic density alone cannot justify airline-HSR cooperation. Moreover, when the density effect in the air sector is strong, the cooperation is less likely to be welfare enhancing under hub capacity constraints; but when the density effect in the rail sector is strong, this cooperation is more likely to improve welfare.

The existing literature focuses mainly on the competition aspect of the airline-HSR interaction. For example, Gonzalez-Savignat (2004) indicates that HSR service significantly reduces the market share of air transport when the two modes compete head-on. Park and Ha (2006) find that the opening of the first HSR line in South Korea has a significant (negative) impact on the domestic air transport industry. Adler et al. (2010) use a game theory setting to analyze aviation-HSR competition in the medium- to long-distance transport markets. They conclude that the European Union should encourage the development of the HSR network across Europe. With a Hotelling (differentiated Bertrand) model in which the HSR’s objective is to maximize a weighted sum of welfare and profit, Yang and Zhang (2012) show that both airfare and HSR fare fall as the weight on welfare rises, and that airfare decreases, and HSR fare increases, in the airport access time. Behrens and Pels (2012) use pooled cross-sectional data from the London-Paris passenger market to identify the degree to and conditions under which HSR is a viable substitute for airline travel. They show empirically that there is fierce competition between aviation and HSR, and that the frequency of trips offered, total travel time and distance to the UK port are the main determinants of travelers’ behavior in terms of their modal choice.
Research on airline-HSR cooperation is relatively rare in the literature, and is composed mostly of case studies and simulations.\textsuperscript{2} Using the case of London’s Heathrow airport, Givoni and Banister (2006) examine the possibility of airline-HSR intermodal integration and its potential benefits for airlines and the society. Cokasova (2006) undertakes a microscopic (operational) passenger and baggage movement simulation at an airline-HSR intermodal airport terminal to analyze the impact of intermodal passenger flow on such factors as passenger throughput and passenger delays. The simulation results show that intermodal passenger movement is socially beneficial only at airports with a large volume of short-haul frequent traffic, but the intermodal movement nonetheless increases the level of passenger delays. Socorro and Vievens’s (2013) paper is the only attempt besides ours to investigate the impact of airline-HSR intermodal cooperation from an analytical point of view. They show that at capacity-constrained airports airline-HSR integration will reduce airport traffic and thereby relieve hub airport capacity (and reduce aircraft emissions), but the overall effect of the integration on welfare is ambiguous. While Socorro and Vievens’s work is the most relevant to ours, they model hub airport capacity in a specific manner and make strong assumptions about the airlines’ priorities for different markets. In particular, they assume that the airlines have a given order of importance for different markets, and fulfill all demands in one market before they consider the demands in another market. We adopt a different framework in which we are able to endogenize the airlines’ decisions of allocating hub airport capacity to different markets, and hence avoid assuming that some markets are exogenously more important than others. In addition, we study the impact of some important features including economies of traffic density, vertical differentiation between modes, difference in price sensitivity of demand and heterogeneous passenger types, which were not addressed in Socorro and Vievens (2013). To the best of our knowledge, this paper is the first analytical work that uses an endogenous decision-making framework to study the effects

\textsuperscript{2} This is in contrast to a large literature gauging the impacts of airline code sharing: International code-sharing alliances have been analyzed by, e.g., Oum et al. (1996), Brueckner and Whalen (2000), Brueckner (2001) and Whalen (2007). For analysis of US domestic airline alliances see, e.g., Bamberger et al. (2004), Clougherty (2000), Ito and Lee (2007), Gayle (2008) and Armantier and Richard (2008).
of airline-HSR cooperation with a specific consideration of hub airport capacity and other salient features of the two transport modes.

The paper is organized as follows. Section 2.2 sets up the basic model and characterizes our analytical benchmark (the competition case). Section 2.3 examines the effects of airline-HSR cooperation on traffic and welfare, focusing on the role of hub airport capacity. Section 2.4 extends, using simulation analysis, the welfare analysis to situations with modal asymmetries in the demands and costs, heterogeneous passenger types, and economies of traffic density. Section 2.5 contains concluding remarks.

2.2 Model

2.2.1 Basic setting

Consider a network structure in which there are three cities with inter-city transport services being offered on only two links. The situation is depicted in Figure 2.1, with three cities \( N_1, N_2 \) and \( N_3 \). One link, \( N_1N_2 \), is operated only by an air carrier; while the other, \( N_2N_3 \), is served by both the airline and an HSR operator. The different market structures on the two links may be due to geographical reasons. For instance, the first link is a long-haul journey and can be competitively served only by airlines, whilst the second link is short-haul with no distinct journey time difference between flights and HSR service.\(^3\) It is also possible that cities \( N_1 \) and \( N_2 \) are separated by water or mountains, thus making HSR access technologically challenging. An example would be Morocco and Spain, which are not far away from each other in terms of distance but are separated by the Strait of Gibraltar, resulting in no train service between the two countries.\(^4\) While

\(^3\) Janic (1993) and Rothengatter (2011), among others, find that fierce competition between HSR and air transport can occur on links with distances up to 1,000 km, most likely between 400 km and 800 km. HSR in general has little competitive impact on airlines for routes longer than 1,200 km.

\(^4\) In some cases, geographical obstacles may be overcome by technologies like the Channel Tunnel, but these cases are rare since the infrastructures are extremely expensive to build. Note that the different market structures on the two links might be due to political or technological factors also. For example, the air-only link connects two cities located in different countries, as international train service will likely impose a
relevant practically, this transportation network is also likely the simplest structure in which HSR-airline cooperation under hub airport capacity constraint can be addressed. It contains not only the market in which HSR and air transport directly compete prior to their cooperation but also other markets which, as we shall show, will be affected by such cooperation owing to strategic interactions in a transportation network.\(^5\)

**Figure 2.1 Network structure**

With three cities there are in total three origin-destination (OD) markets, which are $N_1N_2$, $N_2N_3$ and $N_1N_3$. As indicated above, the $N_1N_2$ market is served only by the airline (hereafter, the *HSR-inaccessible market*), whereas the $N_2N_3$ market is served by both the airline and the HSR (hereafter, the *HSR-accessible market*). In addition, the air carrier serves the $N_1N_3$ market using a hub-and-spoke strategy with $N_2$ as its hub. That is, it carries passengers from $N_1$ to $N_3$ (and back) through hub $N_2$ and so there is no direct flight service in the $N_1N_3$ market (hereafter, the *connecting market*). This structure is treated as exogenous for two reasons. First, major (legacy) carriers have adopted the hub-and-spoke strategy since the advent of deregulation (e.g., Zhang et al., 2011), which is long before HSR became a legitimate competitor to airlines. Competition from HSR, important and noteworthy as it is, does not appear to have forced airlines to change their networks from hub-and-spoke to “point-to-point”.\(^6\) Second, the factors considered in this

---

\(^5\) This network structure is similar to the airline networks examined in, e.g., Brueckner and Spiller (1991) and Oum et al. (1995).

\(^6\) To our knowledge, there is no reported case of airline de-hubbing as a result of HSR competition. Fu et al.
paper, including hub airport capacity constraint and economies of traffic density, will only be significant under a hub-and-spoke network. This is because the economies of traffic density are a major reason why airlines adopt hub-and-spoke in the first place (e.g., Hendricks et al., 1995; Oum et al., 1995) and hub airports usually encounter capacity constraints owing to their “connecting” function (e.g., Ball et al., 2010).

Following Singh and Vives (1984) we use a quadratic consumer utility function:

\[
U = \sum_i \sum_j \alpha_i^j q_i^j - \frac{1}{2} \sum_i \left( \sum_j \beta_i^j q_i^j \right)^2 + 2\gamma \prod_j q_j^i
\]  

(2.1)

where \(i=1, 2, 3\) indicates the three OD markets (1 for \(N_1N_2\), 2 for \(N_2N_3\), and 3 for \(N_1N_3\)), whereas \(j\) indicates the transportation products. Specifically, only air service is available in the \(N_1N_2\) market, so \(j=A\) when \(i=1\) (\(A\) for air service). With both air flights and HSR service being provided in the \(N_2N_3\) market, \(j=A\) or \(R\) when \(i=2\) (\(R\) for HSR service). The connecting market (\(N_1N_3\)) requires special attention, since its market structure will be different under the two scenarios (competition and cooperation) investigated in this paper. We assume that when the airline and the HSR operator are pure competitors, a connecting flight is the only product available in this market; but if the airline cooperates with the HSR operator, passengers can choose connecting flight or flight-HSR connecting service to complete their journeys. In other words, \(j=AA\) when \(i=3\) under airline-HSR competition (\(AA\) for connecting flight), but \(j=AA\) or \(AR\) when \(i=3\) under airline-HSR cooperation (\(AR\) for flight-HSR connecting service). The assumption corresponds to the observation that cooperation between the two modes can significantly increase attractiveness of the flight-HSR connecting service by integrating tickets, coordinating schedules, providing connections between airports and train stations and possibly streamlining baggage transfer. As a consequence, passengers could treat it as a valid alternative to the connecting-flight service (Cokasova, 2006; Grimme, 2007).

(2012) state that an effective hub-and-spoke network is a way to confront HSR competition, suggesting that even if an airline network were influenced by HSR competition, it would be from a point-to-point network to a hub-and-spoke network, not the other way around.
Specification (2.1) implies that air service and HSR service are horizontally differentiated in the same market. This is justifiable by noting that for passengers the most important quality differentiator between the two modes is total journey time (e.g., Cokasova, 2006; Behrens and Pels, 2012). As analyzed in Yang and Zhang (2012), although air service results in a lower travel time for most routes, passengers in general need to spend more access/egress time for a flight, owing to its complicated check-in and security-check procedures as well as to the fact that airports are usually located far away from city centers. As a result, the total journey times of the two modes may vary across different passengers due to the access/egress times. Specifically, we consider that the two services are (imperfect) substitutes in the HSR-accessible market and the degree of substitutability is captured by parameter \( \gamma \), with \( \gamma \in [0,1] \) and larger values of \( \gamma \) indicating more substitutable services.

For simplicity we first assume, in Sections 2.2 and 2.3, \( \alpha_i^j = \alpha \) and \( \beta_i^j = 1 \) across all \( i \)'s and \( j \)'s. Note that \( \alpha_i^j \) measures service quality in a vertical sense, so the case of the two modes being vertically differentiated is abstracted away from the analysis. (We will relax these assumptions and consider, in Section 2.4, the case in which \( \alpha_i^j \) and \( \beta_i^j \) are heterogeneous across the modes.) In the analysis, the common parameter \( \alpha \) is used to represent the market size.\(^7\) Following Yang and Zhang (2012), we further consider that the airline and the HSR operator choose quantities to maximize their profits. That is, the two modes engage in Cournot competition, taking airport and other capacities as given. This is, in a sense, a direct consequence of our intention for the model to be short run (in which case assuming Cournot competition would probably be more appropriate, because of capacity constraints) rather than long run (in which case Bertrand competition would

---

\(^7\) Another (and more accurate) interpretation of \( \alpha \) is the “highest willingness-to-pay” of passengers in a particular market, given that it is the intercept of the inverse demand functions. The intercept of the demand functions is the real “market size”. These two are identical for a monopoly market, but are slightly different for an oligopoly market. For a duopoly market, the real “market size” is \( \alpha/(1 + \gamma) \), which is related not only to \( \alpha \) but also to substitutability factor \( \gamma \). Overall these two concepts are closely related and can be used interchangeably.
Another issue we need to address is the feasible range of parameter combinations. Here feasibility requires three groups of conditions: 1) the non-negativity conditions for (equilibrium) traffic volumes, prices, profits, marginal costs and marginal revenues; 2) the second-order conditions held for each maximization problem; and 3) the stability conditions of Cournot equilibrium. For the cases considered in Sections 2.2 and 2.3, feasibility does not impose any extra bounds for the parameters under consideration. However, it does play a role when other features (e.g., economies of traffic densities) are taken into account in Section 2.4.

2.2.2 Benchmark case: modal competition

With passengers’ maximizing utility subject to budget constraint, it is straightforward to obtain the inverse demand functions for the three markets. Under the competition scenario, these functions are given by

\[ p_1^A = \alpha - q_1^A \]  
\[ p_2^A = \alpha - q_2^A - \gamma q_2^R \]  
\[ p_2^R = \alpha - q_2^R - \gamma q_2^A \]

8 There are some good reasons to believe that quantity competition might be more realistic than price competition in the present case. First, Quinet and Vickerman (2004, p. 263) note: “The general idea which emerges from the theoretical analysis is that when transport capacities are high, or can be enlarged through the transfer of capacity from other locations, and the services provided are not differentiated, then competition is likely to be of a Bertrand type, based on price. ... If, on the other hand, capacity is difficult to increase, then competition is likely to be of a Cournot type, based on quantities. This is the case found, for example, in rail, maritime or inland waterway transport.” The main reason why high-speed rail capacity is difficult to change (relative to the ease and rapidity with which prices can be adjusted) is that its investment is lumpy, time-consuming and irreversible. Second, papers like Brander and Zhang (1990, 1993) and Oum et al. (1993) find some empirical evidence that rivalry between duopoly airlines is consistent with Cournot behavior. We discuss the issue further in the concluding remarks.
Further, the airline’s maximization problem is given as,

\[
p^A = \alpha - q^A \tag{2.5}\]

\[
\max_{q_1^A, q_2^A, q_3^AA} \pi^A = p_1^A q_1^A + p_2^A q_2^A + p_3^AA q_3^AA - C_1^A(q_1^A + q_3^AA) - C_2^A(q_2^A + q_3^AA) \]

\[
s.t. q_1^A + q_2^A + 2q_3^AA \leq K \tag{2.6}\]

where \(K\) denotes the hub airport capacity, which may be fully utilized; the superscripts of the cost functions (\(C_1^A\) and \(C_2^A\)) denote the operator (the same apply to the following expression for HSR) and the subscripts denote the links (1 for \(N_1N_2\) and 2 for \(N_2N_3\)). Similarly, the problem of the HSR operator is given as,

\[
\max q^R = p^R_2 q^R_2 - C^R_2(q^R_2) \tag{2.7}\]

Social welfare is given by the sum of consumer surplus and producer surplus. In this benchmark case it is equal to (“hat” denoting the values of variables in the competition case):

\[
\hat{W} = \hat{C}S + \hat{R}^A + \hat{R}^R \tag{2.8}\]

The consumer surplus is given by

\[
\hat{C}S = \alpha(\hat{q}^A_1 + \hat{q}^A_2 + \hat{q}^A_3) - \frac{1}{2}(\hat{q}^A_1 + \hat{q}^A_2 + \hat{q}^A_2 + \hat{q}^A_2 + \hat{q}^AA^2 + 2\gamma \hat{q}^A_2 \hat{q}^A_2) - (\hat{p}^A \hat{q}^A_1 + \hat{p}^A \hat{q}^A_2 + \hat{p}^R \hat{q}^R_2 + \hat{p}^AA^A \hat{q}^AA) \tag{2.9}\]

For simplicity we first assume away cost asymmetry and the economies of traffic density: \(C_i^A(Q) = c_A Q\ (i = 1, 2), C_2^R(Q) = c_R Q\) and \(c_A = c_R = c_H\), which is, without loss of generality, further normalized to be \(c_H = 0\). A more complete analysis incorporating the modal cost asymmetry and economies of traffic density in both modes will be presented in Section 2.4.

The consideration of capacity in a multi-market network problem may cause diversity in
market structure, owing to potential market abandoning. More specifically, when the hub capacity is very limited, it is possible for the airline to abandon one or more markets such that the resources are used to serve the most profitable markets. In our model, the connecting market would be the first market to be relinquished by the airline when the hub capacity constraint reaches a certain level, given that serving this market imposes the highest opportunity cost. Here it is reasonable to assume that such withdrawal does not affect the demand functions of the other two markets. The assumption is needed to guarantee consistent and tractable analytical results that cover the entire feasible range of hub airport capacity.\(^9\)

It is also worth noting that whether the hub airport faces capacity constraint is determined not only by the capacity level but also by the market size. In effect, the Cournot equilibrium, characterized by the first-order conditions of problems (2.6) and (2.7), depends on the ratio of capacity over market size. We denote this ratio as \( k (k = K/\alpha) \) and present, in Table 2.1, the equilibrium traffic and welfare levels for different ranges of \( k \) under the competition scenario.\(^{10}\)

\(^9\) The cost structure is also assumed to be unaffected by the airline’s withdrawal from any of the markets, which is reasonable since the fixed cost an airline needs to pay for a specific link is relatively small and so its decision of entering or exiting a market is fairly flexible even in the short run.

\(^{10}\) A technical appendix with detailed derivation that gives rise to Table 2.1 (and the subsequent tables in this chapter) is available upon request from the author.
Table 2.1 Equilibrium traffic and welfare for ranges of $k$ (ratio of hub capacity to market size): The competition scenario

<table>
<thead>
<tr>
<th>$k (= \frac{K}{\alpha})$</th>
<th>Traffic volume</th>
<th>Welfare</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k \leq \frac{\gamma}{4}$</td>
<td>$\tilde{q}_1^A = \alpha k$</td>
<td>$\tilde{W} = \frac{\alpha^2}{8} (3 + 8k - 4k^2)$</td>
</tr>
<tr>
<td>$\frac{\gamma}{4} &lt; k \leq \frac{8 - 4\gamma - \gamma^2}{4(4 - \gamma^2)}$</td>
<td>$\tilde{q}_1^A = \frac{\alpha(\gamma + k(4 - \gamma^2))}{8 - \gamma^2}$</td>
<td>$\tilde{W} = \frac{\alpha^2}{2(8 - \gamma^2)^2} [2(24 - \gamma^2) + 2k(64 - 24\gamma - 16\gamma^2) + \gamma^3 + \gamma^4) - k^2(32 - 20\gamma^2 + \gamma^4)]$</td>
</tr>
<tr>
<td>$\frac{8 - 4\gamma - \gamma^2}{4(4 - \gamma^2)} &lt; k \leq \frac{8 + 3\gamma}{2(2 + \gamma)}$</td>
<td>$\tilde{q}_1^A = \frac{\alpha[(4 + \gamma - \gamma^2) + k(4 - \gamma^2)]}{24 - 5\gamma^2}$</td>
<td>$\tilde{W} = \frac{\alpha^2}{8(24 - 5\gamma^2)^2} [(2304 - 768\gamma - 280\gamma^2 + 80\gamma^3 + 15\gamma^4) + 8k(384 - 72\gamma - 144\gamma^2 + 5\gamma^3 + 15\gamma^4) - 4k^2(96 - 52\gamma^2 + 5\gamma^4)]$</td>
</tr>
<tr>
<td>$k &gt; \frac{8 + 3\gamma}{2(2 + \gamma)}$</td>
<td>$\tilde{q}_1^A = \frac{\alpha}{2}$</td>
<td>$\tilde{W} = \frac{\alpha^2(24 + 16\gamma + 3\gamma^2)}{4(2 + \gamma)^2}$</td>
</tr>
</tbody>
</table>

\[
\tilde{q}_2^A = \frac{\alpha}{2 + \gamma}
\]
\[
\tilde{q}_2^B = \frac{\alpha}{2 + \gamma}
\]
\[
\tilde{q}_3^{AA} = \frac{\alpha}{2}
\]
Comparative statics analysis of the equilibrium traffic volumes in Table 2.1 gives rise to:

**Proposition 2.1** At the Cournot equilibrium (the competition scenario), 1) the number of passengers carried by the airline (non-strictly) increases with the hub capacity in all three markets, while the number of passengers carried by the HSR (non-strictly) decreases with the hub capacity. 2) If substitutability between air service and HSR service rises, then the number of passengers carried by the airline (non-strictly) increases in both the HSR-inaccessible market and the connecting market but (non-strictly) decreases in the HSR-accessible market, while the number of passengers carried by the HSR increases if the hub capacity is at a relatively low level, decreases if the hub capacity is at a relatively high level, and first falls and then rises for the middle capacity level.

Part 1 of the proposition is intuitive. Under the (binding) hub capacity constraint an increase in capacity $K$ raises the airline’s (equilibrium) outputs in all three markets, noting that at equilibrium the marginal profit from each additional unit of hub capacity is equalized across all the markets. The airline’s commitment to greater output in the HSR-accessible market would induce an output contraction by the rival HSR, since the firms’ outputs are strategic substitutes under the quantity competition with linear demands and costs. The second part of Proposition 2.1 is concerned with the comparative statics with respect to air-HSR substitutability. When the substitutability is higher, the rivalry in the HSR-accessible market is more intense, and the airline’s profit margin in the market becomes lower as a result. The airline thus allocates more resources to the other two markets, increasing its outputs in these two markets and decreasing its output in the HSR-accessible market. The impact of a higher substitutability on the HSR operator is two-fold: on the one hand, the more fierce the rivalry, the less output it would provide. On the other hand, due to the hub capacity constraint the airline is less aggressive in its rivalry with the HSR than it would have been without the constraint, which induces the HSR operator to act more aggressively. If the hub capacity is not too limited, the second effect is dominated by the first, leading to the HSR serving fewer passengers when the substitutability is higher. However, when the hub airport is seriously short of capacity, the second effect can become so strong that it dominates the first effect. In that case, the
HSR’s output is greater as the substitutability is higher.

2.3 Effects of Airline-HSR Cooperation

The competition case serves as a useful base for comparison with the case of airline-HSR cooperation. Here we consider full-scale cooperation between the airline and the HSR, under which the two firms make decisions jointly to maximize their total profit. Under this cooperation scenario, the demand functions become:

\[
\begin{align*}
 p_1^A &= \alpha - q_1^A \\
 p_2^A &= \alpha - q_2^A - \gamma q_2^R \\
 p_2^R &= \alpha - q_2^R - \gamma q_2^A \\
 p_3^{AA} &= \alpha - q_3^{AA} - \gamma q_3^{AR} \\
 p_3^{AR} &= \alpha - q_3^{AR} - \gamma q_3^{AA}
\end{align*}
\]  

Note that equations (2.10), (2.11) and (2.12) are the same as equations (2.2), (2.3) and (2.4) as the cooperation will not alter the demand structures in the HSR-inaccessible market and the HSR-accessible market. The partners’ problem is thus given by:

\[
\max_{\{q_1^A, q_2^A, q_3^{AA}, q_3^{AR}, q_3^R\}} \pi^{AR} = p_1^A q_1^A + p_2^A q_2^A + p_2^R q_2^R + p_3^{AA} q_3^{AA} + p_3^{AR} q_3^{AR} - C_1^A (q_1^A + q_3^{AA} + q_3^{AR}) - C_2^A (q_2^A + q_3^{AA}) - C_2^R (q_2^R + q_3^{AR})
\]

s.t. \( q_1^A + q_2^A + q_3^{AR} + 2q_3^{AA} \leq K \)  

\[\text{\textsuperscript{11}}\text{ Lower levels of cooperation also exist. As discussed in the introduction, airline-HSR cooperation exhibits various degrees of collaboration ranging from simple code sharing to joint schedule planning, single check-in and through baggage transfer. In these situations one firm could maximize its own profit and a fraction of its partner’s profit (as in, e.g., Zhang and Zhang, 2006), and levels of cooperation could arise endogenously. The main insights obtained here can be extended to the partial cooperation cases as well.} \]
It is assumed, again (in this section), that $C_i^A(Q) = c_A Q$ ($i = 1, 2$), $C_i^R(Q) = c_R Q$, $c_A = c_R = c_H$ and $c_H = 0$.\footnote{It can be easily seen that the total profit under cooperation will not be lower than that under competition, and so the airline and the HSR have incentives to cooperate.} Consumer surplus and social welfare are, respectively, expressed as (“bar” denoting the values of variables in the cooperation case):

$$
\bar{CS} = \alpha(q_1^A + \bar{q}_2^A + \bar{q}_2^R + \bar{q}_3^{AA} + \bar{q}_3^{AR}) - \frac{1}{2}(\bar{q}_1^{A^2} + \bar{q}_2^{A^2} + \bar{q}_2^{R^2} + \bar{q}_3^{AA^2} + \bar{q}_3^{AR^2} + 2\gamma \bar{q}_2^A q_2^R + 2\gamma \bar{q}_3^{AA} \bar{q}_3^{AR}) - (\bar{p}_1^A q_1^A + \bar{p}_2^A q_2^A + \bar{p}_2^R q_2^R + \bar{p}_3^{AA} \bar{q}_3^{AA} + \bar{p}_3^{AR} \bar{q}_3^{AR}) \quad (2.16)
$$

$$
\bar{W} = \bar{CS} + \bar{\pi}^{AR} \quad (2.17)
$$

The (equilibrium) traffic and welfare levels in the cooperation case are summarized in Table 2.2. It can be easily seen from the table that Proposition 2.1 holds largely for the cooperation case as well. The only difference is in the connecting market, due to the introduction of the flight-HSR connecting service. When $\gamma$ is small, the number of passengers taking the joint flight-HSR service increases with the hub capacity level; but when $\gamma$ is sufficiently large, this number first rises and then falls. The flight-HSR connecting service is special because its provision requires the services of both the airline and the HSR operator. On one hand, the larger the hub capacity, the larger the number of passengers the airline can serve, raising the flight-HSR connecting traffic. On the other hand, an increase in the hub capacity will increase the number of connecting flight passengers, which in turn will reduce the amount of flight-HSR connecting traffic through a substitutability effect. When $\gamma$ is large, the substitutability effect dominates the pure capacity effect, so the flight-HSR connecting traffic falls. For this reason, the fall will only happen when the hub capacity is large enough to support both the connecting flights and the flight-HSR connecting service.
Table 2.2 Equilibrium traffic and welfare for ranges of k (ratio of hub capacity to market size): The cooperation scenario

<table>
<thead>
<tr>
<th>$k (= \frac{K}{\alpha})$</th>
<th>Traffic volume</th>
<th>Welfare</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k \leq \gamma$</td>
<td>$\bar{q}_1^A = \frac{a k}{2}$</td>
<td>$\bar{q}_2^A = \frac{\alpha}{2}$</td>
</tr>
<tr>
<td>$\gamma &lt; k \leq \frac{3 + \gamma}{2(2 + \gamma - \gamma^2)}$</td>
<td>$\bar{q}_1^A = \frac{\alpha[y + 2k(1 - \gamma^2)]}{6 - 4\gamma^2}$</td>
<td>$\bar{q}_2^A = \frac{\alpha(k - \gamma)}{3 - 2\gamma^2}$</td>
</tr>
<tr>
<td>$\frac{3 + \gamma}{2(2 + \gamma - \gamma^2)} &lt; k \leq \frac{5 + \gamma}{2(1 + \gamma)}$</td>
<td>$\bar{q}_1^A = \frac{\alpha[1 + k(1 - \gamma^2)]}{7 - 4\gamma - \gamma^2}$</td>
<td>$\bar{q}_2^A = \frac{\alpha[(2 - 5\gamma - \gamma^2) + 2k(1 + \gamma)]}{2(1 + \gamma)(7 - 4\gamma - \gamma^2)}$</td>
</tr>
<tr>
<td>$k &gt; \frac{5 + \gamma}{2(1 + \gamma)}$</td>
<td>$\bar{q}_1^A = \frac{\alpha}{2}$</td>
<td>$\bar{q}_2^A = \frac{\alpha}{2 + 2\gamma}$</td>
</tr>
</tbody>
</table>
It should be noted that although Tables 2.1 and 2.2 cover all possible values of the airport capacity/market size ratio, it does not necessarily mean that these ranges are equally important. For instance, the situations when the hub airport is extremely capacity-constrained, which correspond to the first few rows in both tables, may not be very common in reality. Even if new terminals or new airports cannot be built due to certain reasons, alternative infrastructure solutions would be proposed and passenger behavior is also likely to adapt accordingly even in the short run. Therefore, it may be worthwhile to pay more attention to the bottom parts of the two tables. Bearing this in mind can be helpful for the interpretation of the tables.

With Tables 2.1 and 2.2, we are able to compare the two scenarios and draw conclusions about the impact of the airline-HSR cooperation on traffic volumes and welfare. The details are presented in Tables A1 and A2 (see Appendix A.1). The comparison first reveals underlying reasons for the diversified market forms observed in real-world airline-HSR cooperation projects. In particular, the market form/product choice following airline-HSR cooperation could depend on the hub capacity level also (rather than just on the degree of cooperation). We summarize the effects of the airline-HSR cooperation in two propositions, one for traffic volumes (Proposition 2.2) and the other for welfare levels (Proposition 2.3):

**Proposition 2.2** The airline-HSR cooperation will (non-strictly) reduce traffic in the HSR-accessible market and strictly increase traffic in the connecting market. Furthermore, it can increase or decrease traffic in the HSR-inaccessible market.

It is noted that the effect of the airline-HSR cooperation on traffic in the HSR-inaccessible market depends on the value of substitutability parameter $\gamma$. For example, if

---

13 For example, ever since Air France and SNCF cooperated, all Air France flights between Lille to Charles de Gaulle have been cancelled, with only TGV train service being available on the route. However, passengers travelling between Frankfort and Stuttgart can choose a Lufthansa flight or a Deutsche Bahn train to complete their trips, despite the fact that these two companies have formed a close cooperative relationship in this market. In fact, both services can be purchased from the Lufthansa website.
\( \gamma \) is sufficiently large, \( q_1^A \) in the third row of Table A1 always rises following the cooperation, and \( q_1^A \) in the fourth row of Table A1 rises for large \( k \) but falls for small \( k \). But for small \( \gamma \), \( q_1^A \) in the third row increases when \( k \) is large and decreases when \( k \) is small, whilst \( q_1^A \) in the fourth row always decreases. This reflects the impact of cooperation on resource reallocation. When air and HSR services are close substitutes, the cooperation will significantly reduce the airline’s output in the HSR-accessible market, freeing up a large amount of hub capacity, which can be used in the HSR-inaccessible market. Thus traffic in the HSR-inaccessible market tends to rise for a large range of hub capacity levels when substitutability between the two modes is high. For the other two markets however, the results are clear-cut. In the HSR-accessible market, traffic will fall because of the dampening of competition following the airline-HSR cooperation. In the connecting market, traffic always rises due to two reasons: first, the demand rises with the availability of the flight-HSR connecting service. Second, the hub capacity is reallocated from the HSR-accessible market to the connecting market, thus relieving its input constraint and increasing connecting traffic.

**Proposition 2.3** The airline-HSR cooperation improves welfare if either substitutability between air service and HSR service is sufficiently low, or the hub airport faces a severe capacity constraint. It reduces welfare, otherwise.

Figure 2.2 provides a graphical representation of Proposition 2.3. Instead of investigating the impact of the absolute level of hub capacity, \( K \), on welfare, we introduce a measure of the relative hub capacity level as \( \sigma_K = K/K_m \), where \( K_m \) denotes the minimum capacity level required for the hub airport to be not capacity-constrained.\(^{14}\) Figure 2.2 shows a threshold of substitutability parameter \( \gamma \) (i.e., the vertical demarcation line at \( \gamma = 0.7 \)) that divides the welfare comparison into two parts. On its left side, the airline-HSR cooperation improves welfare if either substitutability between air service and HSR service is sufficiently low, or the hub airport faces a severe capacity constraint. It reduces welfare, otherwise.

\(^{14}\) Note that \( K_m \) depends on substitutability parameter \( \gamma \) and market-size parameter \( \alpha \), so a certain value of \( K \) might be either sufficient or insufficient under different combinations of \( \gamma \) and \( \alpha \). Since it is the airport capacity discrepancy (rather than the airport capacity itself) that drives the implications of the airline-HSR cooperation, \( \sigma_K \) is a more appropriate index for discussing if the hub is capacity-constrained or not.
cooperation improves welfare regardless of hub capacity level $\sigma_K$. On the right side of the demarcation line, however, there exists a cutoff value of $\sigma_K$, above (below) which welfare falls (rises) following the airline-HSR cooperation. This cutoff value, $\bar{\sigma}_K$, is between 0.87 and 1 and is a function of $\gamma$, i.e., $\bar{\sigma}_K = F_\gamma(\gamma)$ with $\gamma \in [0.7,1]$.\footnote{$F_\gamma(\gamma)$ can be shown to be monotonically decreasing in $\gamma$, for $\gamma \in [0.7,1]$.} Thus, when the substitutability between air and HSR services is high ($\gamma > 0.7$) and there is no or little capacity constraint at the hub airport, the airline-HSR cooperation will reduce welfare.

**Figure 2.2 Welfare effects of airline-HSR cooperation: The $\gamma$--$\sigma_K$ interaction**

Note: In this figure (and in Figures 2.3, 2.5, 2.6 and 2.7), the regions with the + (-) sign are the regions where the airline-HSR cooperation increases (decreases) welfare.

Proposition 2.3 has clear policy implications. First, it shows that the modal substitutability in the market where the airline and the HSR would compete (absent an airline-HSR cooperation) plays a key role in assessing the welfare impact of such cooperation. As long as the modal substitutability is low, the cooperation would improve welfare, independent of whether or not the hub capacity is constrained. The social benefit
comes from the fact that the flight-HSR connecting service – made possible by the cooperation – raises total demand in the connecting market, while the negative effect of dampening competition in the HSR-accessible market is relatively small (owing to the low substitutability).\textsuperscript{16} Second, when the modal substitutability is high and hence the negative effect from dampening competition becomes larger, it would benefit policy makers to pay attention to hub capacity. If the hub is significantly capacity-constrained, then the airline-HSR cooperation could help alleviate the constrained capacity and benefit passengers in other transport markets of the network, leading to a net welfare improvement.\textsuperscript{17} Otherwise, the cooperation should be carefully examined, owing to its likely welfare-reducing effect.

Furthermore, it would be interesting to see the impact of an airline-HSR cooperation on firms and passengers separately. This is because welfare is, as defined here, an equally weighted sum of producer surplus and consumer surplus. Under some circumstances however, policy makers may put different weights on these two types of surplus.\textsuperscript{18} It has been argued that competition authorities in reality care much more or even exclusively about consumer surplus. For example, as pointed out by Banal-Estanol et al. (2008), “In the US, the ‘substantial lessening of competition’ test (SLC) has been interpreted such

\textsuperscript{16}This mechanism is similar to the study of airline alliance (e.g., Brueckner, 2001), in which total welfare implication depends on the tradeoff between a negative anti-competitive effect in the “parallel market” and a positive double marginalization removal effect in the “complementary market”. Double marginalization is not an issue in our setting, but the positive market expansion effect also comes from the interline market. In other words, it is more likely for both the airline alliance and the air-HSR cooperation to be welfare improving when the number or the size of the interline markets is larger.

\textsuperscript{17}In particular, the cooperation enables the partners to redistribute traffic from the capacity-constrained air sector to the (unconstrained) rail sector, accommodating more passengers and thus improving economic efficiency. This “traffic reallocation” effect is increasing in the hub airport capacity shortage, so is decreasing in $\sigma_K$ (and totally disappears when $\sigma_K \geq 1$). The larger the $\gamma$ is, the larger the difference between the anticompetitive effect and the “demand stimulation” effect would be, and a greater hub capacity shortage is needed to make the net welfare effect positive. That is why in Figure 2.2 $\delta_K$ is decreasing in $\gamma$.

\textsuperscript{18}Some papers such as Yang and Zhang (2012) have examined the importance of these “weights” in their analysis of airline-HSR interactions.
that a merger is unlawful if it is likely that it will lead to an increase in price (i.e., to a
decrease in consumer surplus). In the EU, the Horizontal Merger Guidelines state that the
Commission should take into account, above all, the interests of consumers when
considering efficiency claims of merger firms (art. 79-81)”. Subsequent paper, such as
Duso et al. (2013) and Flores-Fillol et al. (2014), have also used this criterion. The policy
implication of airline-HSR cooperation may be very different in this case. Since the
airline-HSR cooperation considered here will not reduce the joint profit but may under
some conditions reduce welfare, the positive consumer-surplus effect of the cooperation
is much less likely than the positive welfare effect. In particular, we find that the positive
c consumer-surplus effect arises only when the modal substitutability is very low and the
hub airport is not capacity-constrained.19 The passengers’ gain comes mainly from the
increased traffic in the connecting market due to the flight-HSR connecting service.
When the hub capacity is ample and the modal substitutability is low, this gain is
significant and it dominates the negative market-power effect naturally associated with
the cooperation (which is small when the substitutability is low). This finding is crucial in
policy making where consumer surplus is considered more important than producer
surplus; it suggests that a stricter attitude may be adopted in the evaluation of such
cooperation.

2.4 Extended Analysis on Welfare Effects

2.4.1 Baseline for simulation study

In this section we relax our assumptions on cost and demand, in order to see the
sensitivity of the welfare implications of the airline-HSR cooperation. For this purpose,
we first construct a baseline case with values of $\alpha$ and $\gamma$ estimated from relevant
empirical studies, and then examine the impact of various factors one at a time.

The baseline case is derived from Behrens and Pels (2012), who conduct an interesting

19 See the 5th columns of Tables A1 and A2 for detailed comparison results.
analysis of the airlines-HSR competition in the London-Paris passenger market. They report both the direct and cross elasticities of demand for the two transport modes, from which we could obtain a reasonable estimate of substitutability parameter $\gamma$. This is then followed by an estimation of market-size parameter $\alpha$, leading to our baseline of $\alpha = 600$ and $\gamma = 0.71$.\(^{20}\) Note that this $\gamma$ value is fairly large, which, while fitting the London-Paris market well, may not be true for other markets.\(^{21}\) For example, Fu et al. (2014) find that there exists substantial product differentiation between air travel and HSR service in Japan, suggesting a smaller value for $\gamma$. An examination of the relevant literature (e.g., Ivaldi and Vibes, 2008; Meunier and Quinet, 2012) suggests that while $\gamma$ may cover a wide range of values due to the diversity of market characteristics, it is more likely to be relatively large.\(^{22}\)

As shown in Figure 2.2 of Section 2.3, there exists a threshold of substitutability parameter $\gamma$ (0.7) that breaks the welfare comparison into two parts.\(^{23}\) On one side of the threshold, the airline-HSR cooperation improves welfare irrespective of relative hub capacity level $\sigma_K$. On the other side, there exists a cutoff value of $\sigma_K$, denoted $\tilde{\sigma}_K$, such that welfare rises only when $\sigma_K < \tilde{\sigma}_K$. As shown below, similar patterns emerge for the variables investigated in this section, and these patterns will be illustrated using figures that are similar to Figure 2.2.

---

\(^{20}\) For the detailed procedure of parameter estimation, see Appendix A.2.

\(^{21}\) Behrens and Pels (2012) suggest that there was fierce competition between the airlines and the HSR in the London-Paris passenger market. The distance between the two cities is 457 km, which also falls into the “fierce competition” distance range defined by Janic (1993) and Rothengatter (2011).

\(^{22}\) Ivaldi and Vibes (2008) study the Cologne-Berlin market (600 km long) and report both the own and cross price elasticities of demand for the rail and the air sectors. Their study would imply a relatively high modal substitutability in that market. Meunier and Quinet (2012) demonstrate the own and cross price elasticities of demand for the two modes based on simulations of a few European markets, which would also imply a relatively high modal substitutability.

\(^{23}\) Note that the baseline value of $\gamma$ is higher than the threshold, meaning that the welfare implication of the airline-HSR cooperation is not universal (depending on $\sigma_K$ as well).
2.4.2 Cost asymmetry (factor $c$)

Consider first that $c_R = 0$ and $c_A = c$ where the constant $c$ can be non-zero. While the “common” view would be $c > 0$, it appears that the literature has yet to reach a consensus. Studies such as Froidh (2008) and Meunier and Quinet (2012) estimate that airlines have a higher unit operating cost than HSR operators. On the other hand, Levinson et al. (1997) report that HSR incurs a higher unit operating cost than airlines. Union Internationales des Chemins de Fer (UIC, 2008) suggests that low rail access charges need to be assumed for HSR to obtain a lower unit operating cost than airlines. For completeness, we do not impose restrictions on the sign of $c$. Nonetheless, if $c$ is too large or too small, cases do exist in which one mode squeezes the other out of the market due to cost advantage. These cases are less relevant to our study and so are deliberately assumed away. As a consequence, the non-negativity condition in the feasibility analysis is more stringent than the other two groups of feasibility conditions.\(^{24}\) In particular, feasibility requires $c \in (-246, 135)$.

Similar to Section 2.3, the welfare implication of the airline-HSR cooperation for the values of $c$ and $\sigma_K$ is illustrated in Figure 2.3. There is a vertical demarcation line ($c = 6.55$ in this case) that divides the welfare implication into two parts. When $c > 6.55$, welfare always rises after the cooperation, irrespective of the relative hub capacity level. When $c < 6.55$ however, there exists a cutoff value of $\sigma_K$, over which welfare is reduced by the cooperation. This value is an increasing function of $c$, denoted $\tilde{\sigma}_K = F_c(c)$. That is, the larger (smaller) the HSR cost advantage (disadvantage), the more likely the cooperation is welfare improving. This finding is intuitive, because the demand-stimulation effect (a main positive impact of the airline-HSR cooperation) will be strengthened if HSR is more cost efficient than the airline. In particular, the smaller the HSR cost, the more the flight-HSR connecting traffic will be generated post-cooperation, and the greater the benefit of such cooperation. Therefore, the hub capacity shortage

\(^{24}\) We adopt the same treatment in the subsequent cases of this section. If similar patterns are found, we shall just present the feasible ranges without much discussion.
required to justify the cooperation decreases in $c$, and when $c$ reaches a certain value, the airline-HSR cooperation becomes welfare enhancing unambiguously.

**Figure 2.3** Welfare effects of airline-HSR cooperation: The $c \cdot \sigma_K$ interaction

![Diagram showing welfare effects of airline-HSR cooperation]

2.4.3 Economies of traffic density (factors $\theta_A$ and $\theta_R$)

A prominent feature in the air and the rail sectors is the economies of traffic density: the unit cost on a link declines with total traffic on the link. The existence of the density effect in the airline industry has been demonstrated by a number of empirical studies (e.g., Caves et al., 1984; Brueckner et al., 1992; Brueckner and Spiller, 1994); strong economies of traffic density have also been identified in the rail industry (Braeutigam et al., 1984; McGeehan, 1993; Graham et al., 2003). To capture this feature we follow such papers as Brueckner and Spiller (1991), Zhang (1996), Brueckner (2001) and Bilotkach (2007) by using the following cost function for each link:

$$C^s(Q) = Q - \theta_s Q^2$$  \hspace{1cm} (2.18)

where $Q$ is the total traffic of a specific mode on the link and $\theta_s$ is a positive density
effect parameter, with \( s = A, R \) representing the air and the rail modes, respectively.\(^{25}\)

Given the baseline combination of \( \alpha \) and \( \gamma \), the feasible ranges for \( \theta_A \) and \( \theta_R \) are \([0, 0.0015]\) and \([0, 0.0028]\), respectively. We find that the thresholds over which the airline-HSR cooperation unambiguously improves welfare are not within the feasible combinations of \( \theta_A \) and \( \theta_R \). This suggests that economies of traffic density alone cannot justify the intermodal cooperation. However, if the hub airport faces a certain level of capacity constraint, the cooperation can still be welfare enhancing. In other words, we can still find \( \bar{\sigma}_K \). Figure 2.4 is an illustration of how \( \bar{\sigma}_K \) shifts with different combinations of \( \theta_A \) and \( \theta_R \).

![Figure 2.4 Values of \( \bar{\sigma}_K \) for given \( \theta_A \) and \( \theta_R \)](image)

In Figure 2.4, the contour lines represent different values of \( \bar{\sigma}_K \). We observe that given a specific \( \theta_A \), the larger the \( \theta_R \) is, the larger the \( \bar{\sigma}_K \) will be. By contrast, given a specific \( \theta_R \), the larger the \( \theta_A \) is, the smaller the \( \bar{\sigma}_K \) will be. This means that the economies of traffic density in the two transport modes play different roles in the evaluation of the airline-

\(^{25}\) Since link-specific total cost can be separated into variable costs and fixed costs, the economies can come from two sources: falling marginal costs and spreading fixed costs over more traffic. Specification (18) captures the case of falling marginal costs. Note that \( \theta_s = 0 \) represents the absence of density economies.
HSR cooperation. In particular, when the density effect in the air sector is strong, the intermodal cooperation is less likely to be socially beneficial under hub capacity constraints; but when the density effect in the rail sector is strong, this cooperation is more likely to improve welfare. The mechanism is similar to what we discussed in Section 2.4.2. Thus, the higher the cost advantage of the rail sector relative to the air sector (in terms of either the unit cost or the density effect), the more likely the cooperation is welfare enhancing.

2.4.4 Vertical differentiation (factor $\delta$)

We have so far assumed that the two transportation modes are purely horizontally differentiated. As shown by Behrens and Pels (2012), vertical differentiation appears important between rail and air (in addition to the horizontal-differentiation aspect). This subsection considers a situation where the air-HSR differentiation is not only horizontal but also vertical. Recall that assuming vertical differentiation is equivalent to assigning various values to $\alpha_i^j$ in equation (2.1). Here we consider that vertical differentiation exists only across the two modes but not across markets: $\alpha_1^A = \alpha_2^A = \alpha_3^{AA} = \alpha = 600$ whilst $\alpha_3^{AR} = \alpha_2^R = \delta \alpha = 600\delta$, with $\delta > 0$ capturing vertical differentiation between the two modes. Which transport mode possesses a higher quality, i.e., whether $\delta > 1$ or not, is generally case-dependent. As suggested by the empirical literature (e.g., González-Savignat, 2004; Ivaldi and Vibes, 2008; Behrens and Pels, 2012; Fu et al., 2014), such factors as travel time and frequency play an important role in affecting passengers’ perception about quality and hence their modal choice. And these factors may vary across different markets for both modes. Therefore, to make our analysis robust we allow $\delta$ to be greater or smaller than 1. In effect, the feasible range of $\delta$ is $(0.71, 1.41)$.

We find that when $\delta$ is sufficiently large (> 1.01) the airline-HSR cooperation always improves welfare. And when $\delta$ is relatively small, a cutoff value of $\sigma_K$ can be found, above which the cooperation reduces welfare. This value $\bar{\sigma}_K$ depends on $\delta$, denoted $\bar{\sigma}_K = F_\delta(\delta)$, and the corresponding welfare implication is illustrated in Figure 2.5. As can be seen from the figure, $\bar{\sigma}_K$ first decreases, and then increases, as $\delta$ rises. The analysis
shows that the cooperation is more likely to be welfare improving when HSR is superior or much inferior to the airline with respect to quality. This is because two effects of the cooperation are related to the vertical differentiation between modes. First, the demand-stimulation effect increases monotonically with the relative attractiveness of the HSR, since the higher the quality of the HSR service is relative to the airline service, the more passengers will be attracted to the flight-HSR connecting service. Second, a new type of reallocation effect (other than the one concerning hub capacity discussed in Section 2.3) arises following the cooperation, since the cooperation allows more passengers to be redistributed from a low-quality product to a high-quality product. This effect increases with the quality differentiation between the two modes. When $\delta > 1$, these two effects both increase in $\delta$, and they dominate the negative anticompetitive effect of the cooperation when $\delta > 1.01$. When $\delta < 1$, the demand-stimulation effect still increases but the reallocation effect decreases in $\delta$. The net (positive) effect first decreases and then increases in $\delta$, but is in general dominated by the negative anticompetitive effect.

Figure 2.5 Welfare effects of airline-HSR cooperation: The $\delta - \sigma_k$ interaction

2.4.5 Differential price sensitivities of demand (factor $\beta$)

Next we examine the impact of differential values of $\beta_i\gamma$ which, for given $\alpha_i\gamma$ and $\gamma$,
measure the price sensitivities of demand. It is possible that $\beta_i^j$ is different across the transport modes due to the heterogeneity of service characteristics. Empirical findings also support this possibility. For example, Ivaldi and Vibes (2008), Meunier and Quinet (2012) and Behrens and Pels (2012) find very different own price elasticities for airlines and HSR. Consider that $\beta_1^A = \beta_2^A = \beta_3^{AA} = 1$, while $\beta_3^{AR} = \beta_2^R = \beta$, with $\beta > 0$. The feasibility analysis suggests that $\beta > 0.71$, which is reasonable given that $\gamma = 0.71$. We find that within the feasible $\beta$ range, the airline-HSR cooperation unambiguously increases welfare when $\beta$ is smaller than a particular value (0.97). For $\beta > 0.97$, the welfare implication of the cooperation can be ambiguous however, depending on both $\beta$ and $\sigma_K$. Similar to Sections 2.4.2 and 2.4.4, the welfare implication for the case of differential price sensitivities of demand is summarized in Figure 2.6.

---

26 Assume that there are two products, $m$ and $n$, in market $i$, the inverse demand function for product $m$ is then given by $p_i^m = a_i^m - \beta_i^m q_i^m - \gamma q_i^n$. The corresponding demand function is $q_i^m = [\beta_i^n (a_i^n - p_i^n) - \gamma(a_i^n - p_i^n)]/(\beta_i^m \beta_i^n - \gamma^2)$. The own price sensitivity of demand is thus $\beta_i^m/(\beta_i^m \beta_i^n - \gamma^2)$. Given a specific $\beta_i^m$ and a specific $\gamma$, the larger the $\beta_i^m$, the smaller this sensitivity.

27 Ivaldi and Vibes (2008), Meunier and Quinet (2012) and Behrens and Pels (2012) all find that the own elasticity of demand is lower for HSR than for airlines, suggesting $\beta > 1$. To keep the analysis complete however, we also consider the case of $\beta < 1$. 

---
Figure 2.6 Welfare effects of airline-HSR cooperation: The $\beta-\sigma_K$ interaction

Note: $\beta$ is not bounded on the right. $F_\beta(\beta)$ first decreases in $\beta$ and then increases slowly but never reverts to 1 again.

From Figure 2.6 we can see that $\bar{\sigma}_K$ first decreases and then increases in $\beta$. Note that the larger the $\beta$, the smaller the price sensitivity of demand for HSR relative to the airline. This implies that it is more likely for the cooperation to be welfare enhancing when HSR demand is either very price sensitive or very price insensitive. The price sensitivity of demand would have an impact on both the demand-stimulation effect and the anticompetitive effect. On one hand, the higher the price sensitivity of HSR demand, the lower the flight-HSR connecting service will be priced, and the more passengers will be served. In other words, the positive demand-stimulation effect monotonically decreases in $\beta$. On the other hand, when the price sensitivity of HSR demand is very high or very low, the anticompetitive effect of the cooperation is weak since the two modes do not compete fiercely in the first place. That is, the negative anticompetitive effect first increases and then decreases in $\beta$. When $\beta$ is small, the (strong) demand-stimulation effect dominates the (weak) anticompetitive effect, thereby improving welfare unambiguously. As $\beta$ increases, the anticompetitive effect first increases and dominates the ever decreasing demand-stimulation effect; and then the anticompetitive effect decreases, closing the gap between these two effects but never reversing the relationship again.
2.4.6 Heterogeneous passengers (factor $\varphi$)

Studies such as González-Savignat (2004), Ivaldi and Vibes (2008), Czerny and Zhang (2011) and Behrens and Pels (2012) have stressed the distinction between different passenger groups, particularly between business and leisure passengers. It is suggested that these two groups exhibit large differences in both the willingness-to-pay and the degree of substitutability between transport modes (Ivaldi and Vibes, 2008). Therefore, where the aggregate demand is concerned, the percentage of these passenger groups may have an impact on both market size indicator $\alpha$ and modal substitutability parameter $\gamma$. In particular, the higher the percentage of business passengers in a market is, the larger the $\alpha$ and the smaller the $\gamma$. Here we use parameter $\varphi$ to denote the percentage of business passengers. Assuming that the interaction between this percentage and $\alpha$ as well as $\gamma$ are both linear, we estimate, based on the information derived from Behrens and Pels (2012), that $\alpha = 494 + 298\varphi$ and $\gamma = 0.825 - 0.235\varphi$. Further, it can be shown that the feasible range for $\varphi$ is between 0 and 1.

It is straightforward to see that, when $\varphi$ is larger than a specific value (0.535 in this case) the intermodal cooperation will improve welfare, irrespective of the hub capacity level. For $\varphi < 0.535$ however, only when the hub airport is capacity-constrained can the cooperation be welfare improving. The situation is depicted in Figure 2.7. The figure shows that $\tilde{\sigma}_R$ increases with $\varphi$ (when $\varphi < 0.535$). Furthermore, the analysis reveals that the higher the percentage of business passengers in a market, the more likely the cooperation is welfare enhancing. This is because the higher the percentage of business passengers, the larger the market size and the smaller the modal substitutability. In other words, the (positive) demand-stimulation effect is larger while the (negative) anticompetitive effect is smaller, both pointing in the welfare-enhancing direction.

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28 Ivaldi and Vibes (2008) explicitly state that the degree of substitutability between rail and air transport is higher in the leisure market than in the business market.

29 Please refer to Appendix A.2 for the detailed estimation procedure. Note that we adopt a very restricted functional form to describe the relationship between $\varphi$ and $\alpha$ as well as $\gamma$, so as to give a rough idea about the role $\varphi$ plays in the welfare implication of the airline-HSR cooperation.
2.4.7 A reference case

In this subsection, we attempt to offer a complete picture of the welfare implications of airline-HSR cooperation. This is done with a reasonable case in which we incorporate all the factors that have been considered in the paper. More specifically, the utility function used to obtain the demand functions is given by:

\[
U = \alpha(q_1^A + q_2^A + q_3^{AA}) + \alpha \delta(q_2^R + q_3^{AR})
\]

\[
-\frac{1}{2} \left[ (q_1^{A^2} + q_2^{A^2} + q_3^{AA^2}) + \beta \left( q_2^{R^2} + q_3^{AR^2} \right) + 2\gamma (q_2^A q_2^R + q_3^{AA} q_3^{AR}) \right]
\]

(2.19)

whereas the cost functions for the two modes are:

\[
C^A(Q) = c_A(1 - \theta_A Q)Q
\]

\[
C^R(Q) = c_R(1 - \theta_R Q)Q
\]

(2.20)

Next, we need to derive a set of parameter estimates from relevant empirical studies. We
first estimate $\alpha$ and $\gamma$ as well as $\delta$ and $\beta$ from Behrens and Pels (2012), and then obtain $c_A$ and $\theta_A$ from Brueckner and Spiller (1994).\textsuperscript{30} The estimation of $c_R$ and $\theta_R$, on the other hand, is based on information from Campos and de Rus (2009).\textsuperscript{31} The estimates are listed in Table 2.3:

**Table 2. 3 Parameter estimates for the reference case**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>600</td>
</tr>
<tr>
<td>$\delta$</td>
<td>0.92</td>
</tr>
<tr>
<td>$\beta$</td>
<td>1.36</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>0.71</td>
</tr>
<tr>
<td>$c_A$</td>
<td>126.4</td>
</tr>
<tr>
<td>$c_R$</td>
<td>63.8</td>
</tr>
<tr>
<td>$\theta_A$</td>
<td>$9.7 \times 10^{-5}$</td>
</tr>
<tr>
<td>$\theta_R$</td>
<td>$1.6 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

With this combination of parameters we find that when the hub airport does not face capacity constraint, welfare falls following the airline-HSR cooperation (226,687 vs. 236,672). Only when the hub capacity level is under a certain value (700), would the cooperation improve welfare. This reference case shows again the importance of hub capacity in assessing the welfare impact of airline-HSR cooperation.

### 2.5 Concluding Remarks

This paper has developed a simple, tractable model to study the impact of cooperation between a hub-and-spoke airline and a high-speed rail (HSR) operator when the hub airport is under a possible capacity constraint. We found that the airline-HSR cooperation reduces traffic in the HSR-accessible market where prior competition between the partners occurs. But outside of this direct market, the cooperation increases traffic in the

\textsuperscript{30} Note that the data used in Brueckner and Spiller (1994) are from the fourth quarter of 1985, which is much earlier than the data sources of other empirical papers used for the estimation. It is reasonable to conjecture that $c_A$ would be lower while $\theta_A$ would be higher if more recent data were available, due to the fact that technology developments tend to improve cost efficiency.

\textsuperscript{31} The information in Levinson et al. (1997) also gives very similar estimates.
hub-and-spoke connecting market, and has an ambiguous effect on traffic in the HSR-inaccessible market. The airline-HSR cooperation improves welfare whenever the substitutability between air flights and HSR service is low – in this situation the anticompetitive effect of the intermodal cooperation is not strong and is likely to be dominated by its demand-stimulation effect in the connecting market. When the substitutability is high, then hub capacity plays an important role in assessing the welfare impact of airline-HSR cooperation. Such cooperation improves (reduces) welfare if the hub airport is (is not) seriously capacity-constrained.

We have further examined the impact of other factors on welfare through simulation. We found that the airline-HSR cooperation is welfare enhancing irrespective of the hub capacity level if any one of the following conditions holds: 1) the unit cost of the HSR operator is sufficiently lower than that of the airline; 2) the HSR service is sufficiently superior to the airline service; 3) the price sensitivity of HSR demand is higher than that of airline demand; and 4) a sufficiently large proportion of the passengers are business passengers. Our analysis shows that economies of traffic density alone cannot justify the airline-HSR cooperation. Furthermore, when the density effect in the air sector is strong, the cooperation is less likely to be welfare enhancing under hub capacity constraints. On the other hand, when the density effect in the rail sector is strong, this cooperation is more likely to be welfare enhancing. As airline-HSR cooperative activities have become more popular (but have yet to draw serious attention from researchers and regulators), these findings are suggestive to policy makers. A careful examination of airport capacity, network interactions and other salient features in both modes is warranted. In particular, some less-mentioned benefits of the cooperation, such as the market-expansion effect due to the creation of new intermodal service and the allocation-efficiency effect due to modal asymmetry in quality, should draw policy makers’ attention.

The paper has also raised a number of issues and avenues for further research. First, we modeled airline-HSR rivalry as quantity competition, with the intention of examining a short-run model. In general, which model of competition is applicable to a particular market depends in large part on the production technology (in addition to the time horizon). In quantity competition firms commit to quantities, and prices then adjust to
clear the market, implying the industry is flexible in price adjustments, even in the short run. On the other hand, in price (Bertrand) competition, capacity is unlimited or easily adjusted in the short run. Although there are some good reasons to believe that quantity competition may be more relevant for the present paper, it would be interesting to see how the results might change with price competition, and to further study the empirical relevance of alternative oligopoly models to the transport markets under consideration.

Second, we considered the case of a single airline and a single HSR operator. In reality the markets are likely to have more firms, especially in the airline sector. When multiple firms in each sector converge in a network of transportation markets, the possibilities of strategic interactions will be enlarged and complicated. Extending the analysis to a framework with more competitors would be a useful future study.

Third, several empirical studies suggest that factors such as travel time and frequency can be important in airline-HSR interactions (González-Savignat, 2004; Ivaldi and Vibes, 2008; Behrens and Pels, 2012; Fu et al., 2014). While the present paper has implicitly modeled (and, to a certain extent, studied) their impacts as the modal differentiation, horizontally and/or vertically, it would be a natural extension to explicitly incorporate these factors into a more complete analytical framework. Finally, we have abstracted away the environmental effects from our analysis. Whether HSR service is superior to air flights with respect to emissions remains controversial empirically (e.g., Chester and Horvath, 2010). Even if environmental benefits do exist for HSR, some studies suggest that they are insignificant when deciding on the social desirability of HSR (de Rus, 2011). Furthermore, different countries may value environmental benefits differently, depending

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32 Although it is generally accepted that HSR incurs less per passenger-km emission than airlines, it also leads to additional environmental costs in terms of land occupied, barrier effects, visual intrusion and noise (de Rus, 2011). The environmental effect of the HSR technology is particularly acute in the construction phase. Kageson (2009) concludes “investment in high speed rail is under most circumstances likely to reduce greenhouse gases from traffic compared to a situation when the line was not built. The reduction, though, is small and it may take decades for it to compensate for the emissions caused by construction.” This aspect is less relevant to our analysis since we study an existing HSR line, but it is still a notable point to consider in a more comprehensive investigation.
on their economic development stages and the focus of the government at the time.\textsuperscript{33} However, the environmental impact needs to be taken into account for a more complete policy assessment on airline-HSR cooperation. A general conjecture may be that if HSR exhibits substantial advantage over air transport with respect to the environment, the intermodal cooperation tends to be more socially favorable.

\footnotesize{33} In the present study we thus follow the advice of Sichelschmidt (1999) by focusing only on the “economic” issue. Nevertheless, as noted by an anonymous referee, there is little doubt that diverting air traffic to existing HSR lines is beneficial to the environment, and the environmental concern is a strong motive in individual circumstances for airline-HSR cooperation. See also Adler et al. (2010).
3 Would Competition between Air Transport and High-speed Rail Benefit Environment and Social Welfare?

3.1 Introduction

Air transport and high-speed rail (HSR) substitution has been supported by many for environmental reasons (EC, 2011; TRB, 2013; US DOT, 2002). One of the main statements to justify policies for modal shift from air to rail relates to the claimed environmental friendliness of HSR on a per-seat base. The European Commission, for instance, while deciding on benchmarks for achieving the 60% greenhouse gases (GHG) emissions reduction, states that the majority of medium-distance passenger transport should go by rail by 2050, with the length of the existing high-speed rail network to be tripled by 2030 (EC, 2011). Similarly, in the US the National Environmental Policy Act (NEPA) underlines the importance of comparing the environmental impact of alternative modes. As highlighted in the Passenger Rail Investment and Improvement Act (PRIIA), US rail plans are to address a broad spectrum of issues, including an analysis of rail’s environmental impacts in the State.

In fact, some empirical evidences show that the (per seat) impact on Local Air Pollution (LAP) and climate change of airlines is higher than that of HSR (Givoni and Banister, 2006; Janic, 2003, 2011). For instance, Givoni and Banister (2006), based on the Heathrow-Paris route, report that the toxicity factor of LAP emission is 9,760 units for air transport and 5,882 units for HSR (per seat supplied on the route). On the same route, LAP pollutants include hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_{x}), sulfur dioxide (SO_{2}), and particulates (PM). Impact on climate change, instead, is mainly due to GHG emissions like carbon dioxide (CO_{2}). In general, HSR operations are not considered to contribute significantly to climate change due to lower emission rates of CO_{2}. Moreover, CO_{2} emissions at high altitude affect climate change much more than emissions at ground level, by a factor of more than 100 (Archer, 1993; Dings et al., 2002). HSR contribution to LAP depends mainly on the level of SO_{2}, which is related to the share of coal used to generate the electricity employed to operate the HST. Finally, rail operations result in high levels of noise at high speeds (Brons et al., 2003). However, the impact (the actual noise heard and number of people exposed to it) is lower than can be expected since, in densely populated areas, speed is reduced when approaching the stations due to the distance required for the train to stop.

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34 LAP pollutants include hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_{x}), sulfur dioxide (SO_{2}), and particulates (PM). Impact on climate change, instead, is mainly due to GHG emissions like carbon dioxide (CO_{2}). In general, HSR operations are not considered to contribute significantly to climate change due to lower emission rates of CO_{2}. Moreover, CO_{2} emissions at high altitude affect climate change much more than emissions at ground level, by a factor of more than 100 (Archer, 1993; Dings et al., 2002). HSR contribution to LAP depends mainly on the level of SO_{2}, which is related to the share of coal used to generate the electricity employed to operate the HST. Finally, rail operations result in high levels of noise at high speeds (Brons et al., 2003). However, the impact (the actual noise heard and number of people exposed to it) is lower than can be expected since, in densely populated areas, speed is reduced when approaching the stations due to the distance required for the train to stop.
NO\textsubscript{x} (\text{CO\textsubscript{2}}) emissions are 192.55 (43,265) grams for air transport and 17.57 (7,194) grams for HSR (per seat supplied on the route). Overall speaking, the impact of aircraft operations on LAP and climate change depends on flying time, aircraft seat capacity, height of the mixing zone, modal share on the journey to/from the airport, and distance of the airport from the city center. HSR operations impact depends mainly on the mix of sources used to generate the electricity, the route distance, the energy consumption and the train capacity (Givoni, 2007; Janic, 2003).

Nevertheless, the introduction of HSR services does not necessarily lead to environmental advantages. The net environmental effect can be negative since the introduction of the new transport mode often results in additional demand. In other words, there is a the trade-off between the substitution effect - how many passengers using the HSR are shifted from air transport - and the traffic generation effect - how much new demand is generated by the HSR.

In this paper, we build a simple but representative duopoly model to show how the competition between air transport and HSR affects the environment and social welfare when new travel demand is induced.\textsuperscript{35}

Such an exercise is necessary from a policy perspective. The argument that introducing HSR as a substitute for air transport will doubtlessly benefit the environment may have led to potential bias amongst policy makers when considering future transport policy. After all, HSR development can involve substantial investment, so a better understanding of its impact is necessary and timely. So far, partial substitution of short-haul flights with

\textsuperscript{35} In our analysis, we abstract away from road transport and conventional rail. Most attention in the literature is given to substitution from air to HSR. Many empirical studies show that HSR mainly diverts passenger from air transport, and mode substitution to HSR from other services appears modest. This is the case of the Paris-Lyon route on which most of the demand shifted to the HSR is from air travel, rather than from conventional train, cars or coaches (Givoni, 2007). As opposite, there are also cases in which the modal shift from road and conventional rail is relevant, such as the Wuhan-Guangzhou route, on which half of the passengers using HSR have been diverted from conventional rail (Bullock et al., 2012). Extending the analysis to a framework including road transport or conventional rail would be an insightful future study.
HSR services, either through modal competition or cooperation, has already taken place at Frankfurt Main, Paris CDG, Madrid Barajas or Amsterdam Schiphol airports, which are all connected to the Trans-European High-Speed Rail Network. China, Britain, Italy, Belgium and South Korea have also successfully launched HSR lines. Many others, like Brazil, India, Russia, Turkey, the UK and the US are evaluating the options of investing in HSR.

Our contribution is twofold. First, we show that, when HSR is introduced into the market but it is not sufficiently more environmentally friendly than the airline on a per-seat base, the gain from shifting former air passengers to a cleaner mode of transport is not able to compensate the amount of pollution due to newly generated traffic. Moreover, if the impact on the environment is taken into account when assessing social welfare, the surplus measure may be lower in the competition case than when only the airline serves the market for travel. When HSR is (partially) owned by the public sector and maximizes a (weighted) sum of its profit and social surplus excluding environmental impacts, the more HSR cares about social surplus, the more it is detrimental to social welfare including environmental impacts.

Second, we point out analytically that the decisions on the frequency of flights (HSR departures) and on the speed of the high-speed train (HST) may also affect the environment. On the one hand, when a new mode of transport is introduced in the market, we show that the airline may tend to reduce the size of the aircraft used while offering high frequency services. For instance, this has been observed in the routes of Paris-Nantes, Paris and Bordeaux, Paris-Rennes or Paris-Brest (Chi, 2004). Some analysis suggests that decreasing aircraft size and adjusting service frequency to offer similar seating capacity will increase the environmental impact (Givoni and Rietveld, 2010). If the market size is sufficiently small, we show that reduced aircraft size will make the introduction of HSR detrimental to environment even on a per-passenger base.

HSR may have incentive to raise the train speed, in order to reduce travel time and increase its attractiveness to travelers when competing with air transport. This may affect the environment, since the HSR impact on LAP and climate change depends on its
energy consumption, which, in turn, rises when the speed of the vehicle increases. When HSR decides on the train speed, the operator will choose the maximum level of speed given the technology of the power car, the legal requirements and the number of stops on the HSR line. When the increase in the emissions of HSR due to the increase in the speed of the train is sufficiently high, the overall level of emissions after the introduction of the HSR will be higher than in the monopoly case.

To the best of our knowledge, the existing literature has mainly focused on the market equilibrium of airline-HSR competition (i.e., traffic and price levels) abstracting away environmental considerations, with empirical approaches (Behrens and Pels, 2012; Dobruskes, 2011; González-Savignat, 2004; Park and Ha, 2006), game theory settings (Adler et al., 2010) or theoretical analysis (Yang and Zhang, 2012). Some contributions have examined the possibility of airline-HSR cooperation and its potential benefits for airlines and the society. Again, these are mainly empirical studies (Cokasova, 2006; Givoni and Banister, 2006), while only a few papers addressed this issue analytically (Jiang and Zhang, 2014; Socorro and Viecens, 2013).

The environmental impact of air-rail substitution has been mostly object of case studies on specific routes. Part of the debate has been concentrating on the assessment of the potential reduction in pollution (per seat or per passenger), which could be achieved by substituting some short-haul flights with equivalent HSR services. Janic (2011) compares quantities and related costs savings in airport side congestion and delays, noise, and emissions of GHG at London Heathrow. Givoni and Banister (2006) evaluate the environmental benefits from air and HSR substitution for the London Heathrow-Paris Charles de Gaulle route and show, on a per-seat base, a clear and significant reduction of climate change impact and, though less significant, in local air pollution. Similar results have been later confirmed on the London-Manchester route (Miyoshi and Givoni, 2013). Part of the debate has also focused on the effects on the environment when intermodal substitution leads to runway capacity being freed up at the airport. The main argument is that, if this capacity is used to accommodate more flights and to meet more demand, there would be no environmental gains from mode substitution (Dobruszkes and Givoni, 2013; Givoni and Dobruszkes, 2013; Givoni and Banister, 2006; Givoni et al., 2012). Socorro
and Viecens (2013) confirm, with a theoretical model, this prediction.

All these papers have adopted a static perspective in abstracting away from induced demand due to the introduction of a new mode of transport. Because of the importance of ridership in environmental assessments, induced demand is often cited as a critical consideration for understanding future HSR performance (Behrens and Pels, 2012; Chester and Ryerson, 2014). To circumvent the need for ridership forecasts, it has been considered parametrically (Jamin et al., 2004). Other studies explore the sensitivity of environmental performance to ridership, finding that ridership uncertainty can tip the balance to either mode (Chester and Horvath, 2012). While all the above papers utilize empirical or survey data, to the best of our knowledge this paper is the first attempt in literature at deriving an analytical framework to evaluate the impact of intermodal competition between air transport and HSR on the environment and social welfare while pointing out the effect of induced demand. Moreover, though flights (HSR departures) frequency and HSR speed have been cited as critical parameters and formally modeled in a competition game between the two modes (Yang and Zhang, 2012), their effects on the environment have never been addressed analytically. This paper bridges this gap.

An important feature of our analysis is that air and rail operators can have different objective functions. While the deregulation process in the airline industry makes it reasonable to assume that airlines maximize profits, the HSR decision maker may also take into account other objectives. In some cases HSR operators are owned by the government or, even in cases in which they are private companies, like in Europe, the networks are often co-invested by public administrations due to the huge capital requirements. Therefore, we assume that HSR maximizes a weighted sum of its profit and social welfare, taking into account the surplus of consumers and the surplus that the other (air) transport operator brings about. This approach seems reasonable, since the companies serve the same population and the State cares about the productivity of the country and the well-being and travel possibilities of all inhabitants. This makes our contribution different from literature, where Adler et al. (2010) and Socorro and Viecens (2013) considers a profit maximizing HSR and Yang and Zhang (2012) assume that the HSR operator maximizes his own profit plus a portion of the surplus of passengers taking
only HSR.

The structure of the paper is as follows. Section 3.2 presents the basic model and main results on the effects of competition between air and HSR on the environment and social welfare. Section 3.3 describes some extensions of the basic model with respect to the frequency and the speed. Section 3.4 contains some concluding remarks.

### 3.2 The Basic Model

Consider a competition model between air transport and HSR over a single origin (O) - destination (D) link.\(^{36}\) Total journey time of transport mode \(i\) – with \(i = A\) (air transport) or \(i = H\) (HSR) – is:

\[
\bar{T}_i := a_i + t_i
\]  

(3.1)

where \(a_i\) is the access time and \(t_i\) is the travel time.\(^{37}\) Usually, air service results in a lower in-vehicle time for most of the routes, i.e. \(t_A < t_H\), since the speed is different between the two modes. Moreover, trains do not follow the direct routes due to the orography of the territory.\(^{38}\) In general passengers need to spend a significant

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\(^{36}\) Direct competition between the two modes usually takes place on distances in the range 300-1000 km (Janic, 1993; Rothengatter, 2011; Yang and Zhang, 2012). On routes of less than 300 km, evidence shows that the introduction of HSR services almost leads to a withdrawal of aircraft services (e.g. between Tokyo and Nagoya and between Brussels and Paris), while on routes of around 1000 km and above, the HSR ceases to be a good substitute for the aircraft.

\(^{37}\) Total journey time also includes schedule delay, which represents the time between the passenger's desired departure time and the actual departure time. It was introduced by Douglas and Miller (1974) as the sum of two components: frequency delay and stochastic delay. The former is induced by the fact that flights do not leave at a passenger request but have a schedule. Stochastic delay has to do with the probability that a passenger cannot board her desired flight because it is overbooked. Overbooking arises in the presence of stochastic demands, which is not the case here. Instead, we will include frequency and frequency delay in Section 3.3.1.

\(^{38}\) For instance, distances as the crow flies (vs. HSR distance) are 481 km (621 km) between Madrid and Barcelona, 398 km (524 km) between Paris and Amsterdam and 435 km (621 km) between Munich and Cologne.
access/egress time for a flight, owing to the fact that airports are usually located far away from city centers (Adler et al., 2010; González-Savignat, 2004; Jiang and Zhang, 2014; Yang and Zhang, 2012). As a result, the total journey time may vary across the two modes. Let $\bar{T}$ denote the difference (positive or negative) between the total journey time between the two modes, i.e., $\bar{T} = \bar{T}_A - \bar{T}_H$, and $\nu > 0$ be the passenger value of time. With these specifications, the full prices perceived by travelers are, respectively:

$$\theta_A = p_A + T$$
$$\theta_H = p_H$$

where $p_i$ is the ticket price of transport mode $i$ and $T = \nu \bar{T}$ is a parameter measuring quality differentiation between the two modes in a vertical sense. Other things equal, as $T$ increases, e.g. when the total journey time of air transport increases relative to the total journey time of HSR, the relative attractiveness of HSR increases. This modeling allows assessing the importance of total journey time, in addition to the ticket price, in passengers’ choice. Indeed, empirical evidence shows that this is the most important quality differentiator between the two modes (Adler et al., 2010; Behrens and Pels, 2012), accounting for 80% - 90% of the reasons for choosing to travel by air or HSR for given fares (Cokasova, 2006).

---

39 Without loss of generality, we let $a_i$ denote the sum of access and the egress time. For instance, Adler et al. (2010), estimate that the access (and egress) time to (from) European hub airports and HSR stations are $a_A = 1h$ and $a_H = 0.5h$. Other than accessibility from main urban agglomerations, factors affecting ease of access/egress are parking availability, ease of transfer (baggage trolleys, ramps, escalators, design adaptation for disabled passengers), real time information on board, identification of staff and information service, baggage handling, check-in and security-check procedures (EC, 2006; IATA, 2003; Janic, 2011).

40 In this paper, we abstract away from the case of passengers’ different value of time - e.g., leisure and business passengers - and price discrimination, since our focus is on the environment and each passenger contributes the same amount of pollution. However, the relative importance of price and time factors varies with the demand segment that is considered. Some empirical evidences show that leisure passengers are more sensitive to ticket price than business travelers (who pay more attention to travel time) (Behrens and Pels, 2012; Cokasova, 2006). The reader may refer to Yang and Zhang (2012) for a competition model with passengers’ different (gross) travel benefit and time value.
Travelers maximize a (strictly concave) quadratic utility function as proposed by Singh and Vives (1984). This approach has been used in transport literature (Flores-Fillol and Moner-Colonques, 2007; Oum and Fu, 2007; Socorro and Viecens, 2013). Let \( q_A \) and \( q_H \) be the number of passengers travelling by air or HSR, respectively. The utility function is:

\[
U(q_A, q_H) = \alpha_A q_A + \alpha_H q_H - \frac{1}{2} (q_A^2 + q_H^2 + 2\beta q_A q_H)
\]  

(3.3)

The parameter \( \alpha_i > 0 \) denotes the gross benefit that the consumer derives from traveling from the origin \( O \) to the destination \( D \), using transport mode \( i \). The parameter \( \alpha_i \) measures service quality in a vertical sense, on dimensions such as reliability, punctuality, safety, on board comfort, customer service, (IATA, 2003; Cokasova, 2006; EC, 2006). For the sake of simplicity, we shall assume in what follows \( \alpha_A = \alpha_H = \alpha \).

The parameter \( \beta > 0 \) measures the degree of substitutability between the two modes. Some factors that affect substitutability might not be captured by the travel time or the ticket price: for instance, different emotional association may play a role (Bennett et al., 1957), as well as cultural/personal mode preference (IATA, 2003). Habit may also form a significant barrier to mode shift, as past mode choices are a strong predictor of current mode choice (Blainey et al., 2012; Thøgersen, 2006).\(^{41}\) Larger values of \( \beta \) indicate more substitutable services: it ranges from zero, when the two modes are independent, to one when they are perfect substitutes.\(^{42}\)

In this setting, the representative consumer solves the following problem:

\(^{41}\) The term “habit” can describe various sources of resistance to changes in behavior that would be made on purely rational grounds, including a reluctance to upset an ordered and well understood routine, perception thresholds below which changes in the relative attractiveness of different modes are not noticed and barriers to the relevant information on different modes reaching travelers (Goodwin, 1977).

\(^{42}\) For instance, in the London – Paris market, Behrens and Pels (2012) found \( \alpha = 600 \) and \( \beta = 0.71 \). This \( \beta \) value fits quite well the London–Paris market, where the degree of substitutability between the two modes is high. Literature suggests that while \( \beta \) may cover a wide range of values due to the diversity of market characteristics, it is more likely to be relatively large (Jiang and Zhang, 2014).
\[
\max_{q_A, q_H} U(q_A, q_H) - \theta_A q_A - \theta_H q_H
\]  \hspace{1cm} (3.4)

subject to the budget constraint \( \theta_A q_A + \theta_H q_H \leq m \), where \( m \) denotes the income.\(^{43}\) First order conditions determining the inverse demand function for \( q_i \) is:

\[
\theta_i(q_A, q_H) = \alpha - q_i - \beta \cdot q_{-i}
\]  \hspace{1cm} (3.5)

where \( -i \) indicates the mode other than \( i \), i.e., \( -i = A \) if \( i = H \) and \( -i = H \) if \( i = A \). From equations (3.2) and (3.5) it follows that:

\[
p_A(q_A, q_H) = \alpha - T - q_A - \beta q_H \]
\[
p_H(q_A, q_H) = \alpha - q_H - \beta q_A
\]  \hspace{1cm} (3.6)

where \( p_i(q_A, q_H) \) is the ticket price. Thus, this model enables an assessment of the importance of (horizontal and vertical) differentiation in the demand for travel when two modes compete.

We now turn to the supply side. Let \( Q_A \) and \( Q_H \) be the total number of flights offered by the airline and the train departures offered by the HSR operator, respectively. We have 

\[
q_i = Q_i \times \text{Size}_i \times \text{LF}_i
\]

where \( \text{Size}_i \) represents the number of aircraft seats (\( i = A \)) or HST seats (\( i = H \)) and \( \text{LF}_i \) represents the load factor of mode \( i \). Each mode operates under a fixed-proportions relation such that load factor is 100% and the product between the size and load factor is constant for both modes. With fixed load factors and sizes, prices per passenger and per flight/HSR departure are equivalent and the profit of mode \( i \) can be written as:

\[
\pi_i(q_A, q_H) = [p_i(q_A, q_H) - c_i] q_i
\]  \hspace{1cm} (3.7)

\(^{43}\) Note that we are considering an economy composed of a duopolistic transport sector and a competitive (numeraire) sector summarizing the rest of the economy. The utility function is separable and linear in the numeraire good. Therefore, there are no income effects on the transport sector, and we perform partial equilibrium analysis.
where \( c_i \) is the unit (per seat) variable cost of transport mode \( i \) and the fixed costs of operating a flight (HSR departure) are assumed to be zero.\(^{44}\) Finally, without loss of generality, in what follows, we normalize \( v_t^H = 0 \). Thus, HSR operating costs, \( c_H \), and ticket price, \( p_H \), are considered gross of \( v_t^H \).

While the deregulation process in the airline industry makes it reasonable to assume that airlines maximize profits, the HSR decision maker may also take into account other objectives. Indeed, in some cases HSR operators are owned by the government or, even in cases in which they are private companies, like in Europe, the networks are often co-invested by public administrations due to the huge capital requirements.\(^{45}\) Moreover, different groups of owners, i.e. the State and the private company, are likely to put different weights on social welfare and profit since they pursue different goals. In light of these considerations, we assume that the airline is a pure private firm, while HSR is a privatized firm that is jointly owned by both public and private sectors. Thus, while the airline maximizes its own profits, HSR maximizes a weighted sum of its profit and social welfare, taking into account the surplus of consumers and the surplus that the other transport operator brings about. This approach seems reasonable, since the companies serve the same population and the State cares about the productivity of the country and the well-being and travel possibilities of all inhabitants. The social welfare is:

\[
W(q_A, q_H) = U(q_A, q_H) - (c_A + T)q_A - c_Hq_H
\]  

(3.8)

With these specifications, HSR objective function is:

\(^{44}\) Several researchers have found that HSR travelling at higher speeds would require higher per-seat cost (Bousquet et al., 2013; Kemp, 2004; Garcia, 2010). We will include this engineering specification in Section 3.3.2, where we examine the case in which the HSR operator endogenously decides the speed of the HST.

\(^{45}\) For instance, in China, all high-speed rails belong to China Railway Corporation, a state-owned company supervised directly by the Chinese Central Government. Similarly, in Italy, Trenitalia is 100% shareholded by FSI (Ferrovie dello Stato Italiane), which, in turn, has been transformed into a public company controlled by the Ministry of Economics and Finance since 1992.
The parameter $\delta = \delta(x)$ may be referred to as the “weight” on welfare relative to profits, where $x \in [0,1]$ denotes the share of the HSR property owned by the public sector. The parameter $\delta(x)$ ranges from 0 to 1. If HSR is fully privatized (i.e., $x = 0$), $\delta$ becomes zero and HSR maximizes profits (Adler et al., 2010; Socorro and Viecens, 2013). If HSR is fully nationalized (i.e., $x = 1$), $\delta$ becomes one and HSR maximizes social welfare. If the shares owned by the government increase, then $\delta$ increases. Formally we make the following assumption, that is $\delta(x)$ is continuous and non-decreasing, with $\delta(0) = 0$, and $\delta(1) = 1$.

A similar approach has been proposed in the literature developed to discuss the welfare consequences of partial privatization of a public firm in mixed oligopolies (Ishibashi and Kaneko, 2008; Matsumura, 1998).

### 3.2.1 Effects on the environment

In this section, we examine a basic case in which competition between the two modes take place à la Cournot. Thus, the airline and the HSR operator compete on quantities and solve simultaneously the following decision problems:

$$
\begin{align*}
\max_{q_A} & \quad [p_A(q_A, q_H) - c_A]q_A \\
\max_{q_H} & \quad (1 - \delta)[p_H(q_A, q_H)q_H - c_H] + \delta W(q_A, q_H)
\end{align*}
$$

It is straightforward to derive equilibria for the basic model (the superscript * stands for equilibrium):

\[ (1 - \delta)\pi_H(q_A, q_H) + \delta W(q_A, q_H) \]  

---

\[ \text{This modeling differs from Yang and Zhang (2012). With use of a locational model to describe competition between air transport and HSR, they assume that the HSR operator maximizes his own profit plus a portion of the surplus of passengers taking HSR. The main difference between their paper and our work is in the fact that the surplus of all consumers (even those traveling by air) and the surplus that the other transport operator brings about are considered.} \]
\[ q_A^* = \frac{[\alpha - (c_A + T)](\delta - 2) + \beta(\alpha - c_H)}{2(\delta - 2) + \beta^2} \]

\[ q_H^* = \frac{[\alpha - (c_A + T)]\beta + 2(c_H - \alpha)}{2(\delta - 2) + \beta^2} \quad (3.11) \]

where the parameters are assumed in the ranges where both \( q_A^* \) and \( q_H^* \) are non-negative.

In order to analyze the impact on the environment of competition between HSR and airline we refer to the benchmark case of a monopoly airline serving the same OD link.\(^{47}\)

Similarly, we assume linear demand function. Thus, the inverse demand with respect to full price in the market served by the monopoly airline is \( \theta_M(q_M) = \alpha - q_M \) where \( \alpha \) is the size of the market and \( q_M \) is the number of passengers (the subscript \( M \) stands for the monopoly case). If \( p_M \) denotes the air ticket price charged by the monopoly carrier, full price can be written as \( \theta_M = p_M + T \), where \( T = vT_A \) measures the cost of total journey time for travelers when air is the only available transport mode. We easily obtain the inverse demand function with respect to air ticket price, that is \( p_M(q_M) = \alpha - T - q_M \).

While assuming that the fixed proportions and 100% load factor assumptions are maintained, the airline profit is \( \pi_M(q_M) = [p_M(q_M) - c_A] q_M \). Maximization of profit with respect to quantity leads to the equilibrium:

\[ q_M^* = \frac{\alpha - T - c_A}{2} \quad (3.12) \]

**Lemma 3.1** The introduction of high speed rail in the market for travel results in lower air market share, compared to the monopoly case, i.e. \( q_A^* < q_M^* \), and additional traffic generated, i.e., \( \Delta q = q_H^* + q_A^* - q_M^* > 0 \).

Proof: At the equilibrium, it results:

\(^{47}\) We realize that in reality, more airlines may compete in the market for air travel. A technical appendix containing the analysis of the case of an oligopolistic airlines market is available upon request from the authors. We find that the less fragmented the airline market is, the less likely that introducing HSR will be beneficial to the environment but results do not qualitatively change compared with the case of a single airline presented in the manuscript.
\[
q_M - q_A^* = \frac{\beta \{[\alpha - (c_A + T)]\beta - 2(\alpha - c_H)\}}{2(\beta^2 + 2\delta - 4)}
\]

\[
\Delta q = q_H^* + q_A^* - q_M^* = \frac{(2 - \beta) \{[\alpha - (c_A + T)]\beta - 2(\alpha - c_H)\}}{2(\beta^2 + 2\delta - 4)}
\]

where \([\alpha - (c_A + T)]\beta + 2(c_H - \alpha) < 0\), since \(q_H^* > 0\). The thesis follows immediately, given \(0 < \beta < 1\), \(0 < \delta < 1\).

\[Q.E.D.\]

Empirical evidence confirms theoretical predictions on the traffic generation effect. Although assessing induced traffic is difficult (Bonsall, 1996; Givoni and Dobruszkes, 2013; Mokhtarian et al., 2002), data collected after the launch of HSR in Asia and Europe suggest that induced traffic ranges from 6% to 37% of HSR ridership (Givoni and Dobruszkes, 2013). Some estimates related to different periods starting from 1980 indicate that additional traffic generated accounted for 29% of total HSR traffic on the Paris-Lyon route, 50% on the Madrid-Seville route, 20% on the Madrid-Barcelona route, 11% on the Paris-Brussels route and 20% on the London-Paris route (Preston, 2009). The share of newly generated demand for the London-Midlands-North UK HS2 project is expected to 267% higher than it is today for 2043 (Aizlewood and Wellings, 2011).

In order to analyze the environmental impact of HSR introduction, we will focus on LAP and climate change emissions during the phase of operation.\(^{48}\) For each seat the aircraft level of emissions (including LAP, or climate change or an equivalent aggregate of both of them\(^{49}\)) is denoted by \(e_A\), while the HSR level of emissions is denoted by \(e_H\). In

\(^{48}\) In fact, phases other than operation in the life-cycle analysis of both modes need attention (ERA, 2011). These phases (construction/production, maintenance and disposal) can be responsible for environmental impact. The effects relating to the construction of rail infrastructure, for instance, include emissions from building a new line as well as land take, affecting landscape, townscape, biodiversity and heritage. In this paper, we focus on the impact of the operations phase on the environment and abstract away from the effects of phases other than operation in the life-cycle analysis.

\(^{49}\) Summing total emission across pollutants is meaningless since different pollutants have different nature and degree of impact.
particular, we assume that $e_A > e_H$, i.e., HSR is more environmentally friendly - per seat - than air transport.

Let $E$ denote the difference between the total pollution before and after the introduction of HSR. We define $E$ as:

$$E(q_M^*, q_A^*, q_H^*) := e_A q_M^* - (e_A q_A^* + e_H q_H^*)$$  \hspace{1cm} (3.13)

If $E(q_M^*, q_A^*, q_H^*) > 0$, then competition between HSR and air is beneficial to the environment. Note that $E(q_M^*, q_A^*, q_H^*)$ can also be negative, that means that the introduction of HSR may actually result in an environmental damage.

**Proposition 3.1** If HSR is not sufficiently more environmentally friendly than air transport, i.e., if $e_H/e_A > \beta/2$, the introduction of HSR will increase the environmental pollution.

Proof: At the equilibrium, it results $E(q_M^*, q_A^*, q_H^*) := e_A q_M^* - (e_A q_A^* + e_H q_H^*)$ with

$$\frac{\partial E(q_M^*, q_A^*, q_H^*)}{\partial e_A} = \frac{\beta[\alpha - (c_A + T)]\beta + 2(c_H - \alpha)}{4(\delta - 2) + 2\beta^2} > 0$$

since $q_H^* = \beta[\alpha - (c_A + T)]\beta + 2(c_H - \alpha)/[2(\delta - 2) + \beta^2] > 0$, $0 < \beta < 1$, $0 < \delta < 1$. Thus, the overall environmental benefit of HSR introduction is increasing in the level of airline emissions, $e_A$. In particular, $E(q_M^*, q_A^*, q_H^*) = 0$ when $e_A = 2e_H/\beta$. It follows that $(e_A q_A^* + e_H q_H^*) > e_A q_M^*$, i.e., $E(q_M^*, q_A^*, q_H^*) < 0$, when $e_H/e_A > \beta/2$.

Q.E.D.

The intuition behind Proposition 3.1 is as follows. The introduction of a new mode of travel induces an increase in the total market size and HSR ridership is made up of former airline passengers who shift to the new mode and newly generated demand (e.g., people who did not travel before or people who shift from other transportation modes like
If the level of pollution emitted by HSR is not sufficiently lower than that of the airline, the gain from shifting former air passengers to a cleaner mode of transport is not able to compensate the amount of pollution due to newly generated traffic. At the equilibrium, $e_H q_H^* > e_A(q_M^* - q_A^*)$ and competition from the new mode is detrimental to the environment, i.e. $E(q_M^*, q_A^*, q_H^*) < 0$.

Proposition 3.1 shows that the introduction of HSR is not necessarily beneficial to the environment. Benefits depend on the environmental friendliness of HSR. For instance, the operation of electric trains – used on high speed and intercity routes – results in significantly less CO$_2$ emissions than diesel trains. However, the extent to which electric trains can be regarded as significantly more environment-friendly than other modes – like air – depends on the mix of energy sources used to generate the electricity. Generally speaking, the more renewable and nuclear energy is used to generate electricity, the more environment-friendly rail operations would be. In fact, the generation mix for train electricity is heavily constrained from the country in which HSR operates – electricity sources available, dispatch merit rules, topology of the electricity grid. Thus, energy efficiency technologies and strategies should be promoted in order to increase the environmental friendliness of HSR when compared to air transport. They may be mass reduction, aerodynamics and friction reduction, space utilization on the train, conversion losses reduction, regenerative braking and energy storage, reduction of energy consumption for comfort function, load factors and flexible trains (UIC, 2003).

From Proposition 3.1 we can also observe that the higher the substitutability between the two modes, the less likely that the introduction of HSR is detrimental to environment.

---

50 For instance, EC (1998) found that former airline passengers accounted for 42% of HSR ridership between Madrid and Seville, while Cascetta et al. (2011) found that traditional rail passengers accounted for 69% of HSR ridership between Rome and Naples.

51 The difference is a result of greater technical efficiency of electric trains, different operating conditions (fewer stops i.e. less energy used for acceleration) and, crucially, the CO$_2$ content of electricity. For instance, the reader may refer to ATOC (2007) for some exercises on comparisons of CO$_2$ emissions from diesel and electric trains operations in the UK (operation data for 2006/2007).
Indeed, the minimum ratio between the levels of pollution of the two modes required for HSR being beneficial to the environment, i.e. $\beta/2$, increases with the substitutability $\beta$. This means that, when $\beta$ is larger, it is harder for the constraint $e_H/e_A > \beta/2$ to be satisfied.

**Proposition 3.2** There exists a value $\hat{e} > 0$ such that, $\forall (e_A, e_H) \text{ with } e_H/e_A < \hat{e}$, it results $\partial E(q_M^*, q_A^*, q_H^*)/\partial \beta > 0$, that is when HSR is sufficiently more environmentally friendly than air transport the environmental benefit of HSR introduction is increasing in the substitutability between the two modes of transport. Moreover, $\forall (e_A, e_H) \text{ with } e_H/e_A < \beta/2 < \hat{e}$, $E(q_M^*, q_A^*, q_H^*)$:

(a) is increasing in the market size, $\alpha$;

(b) is increasing in the time-dimension differentiator, $T$;

(c) is increasing in the weight on welfare relative to profit for the HSR, $\delta$.

Proof: At the equilibrium, it results:

$$
\frac{\partial E(q_M^*, q_A^*, q_H^*)}{\partial \beta} = e_H \left[ \frac{(\alpha - (c_A + T))(4 + \beta^2 - 2\delta) - 4\beta (\alpha - c_H)}{(-4 + \beta^2 + 2\delta)^2} \right] \\
+ e_A \left[ \frac{(\alpha - (c_A + T))(2\beta (-2 + \delta)) - ((4 + \beta^2 - 2\delta))(\alpha - c_H)}{(-4 + \beta^2 + 2\delta)^2} \right]
$$

Denote

$$
\{ [\alpha - (c_A + T)](4 + \beta^2 - 2\delta) - 4\beta (\alpha - c_H) \} = \Gamma
$$

and

$$
\{ [\alpha - (c_A + T)][2\beta (-2 + \delta)] - [(4 + \beta^2 - 2\delta)](\alpha - c_H) \} = \Theta.
$$

It is easy to demonstrate that $\Theta > 0$ when $q_A^* > 0$ and $q_H^* > 0$, while $\Gamma$ can be either positive or negative. When $\Gamma \geq 0$, $\partial E(q_M^*, q_A^*, q_H^*)/\partial \beta > 0$ always holds. When $\Gamma < 0$...
and \(-|\Gamma|e_H + \theta e_A > 0\), i.e., \(e_H/e_A < \theta/|\Gamma| = \hat{\epsilon}\), \(\partial E(q^*_M, q^*_A, q^*_H)/\partial \beta > 0\) holds.

(a) At the equilibrium, it results:

\[
\frac{\partial E(q^*_M, q^*_A, q^*_H)}{\partial \alpha} = \frac{(-2 + \beta)(-2e_H + \beta e_A)}{2(-4 + \beta^2 + 2\delta)}
\]

where \((-2 + \beta) < 0\) and \((-4 + \beta^2 + 2\delta) < 0\), since \(0 < \beta < 1\) and \(0 < \delta < 1\). Thus, when \(-2e_H + \beta e_A > 0\), i.e., when \(e_H/e_A < \beta/2\), \(\partial E(q^*_M, q^*_A, q^*_H)/\partial \alpha > 0\). It easy to demonstrate that when \(q^*_A > 0\) and \(q^*_H > 0\), \(\beta/2 < \hat{\epsilon}\).

(b) At the equilibrium, it results:

\[
\frac{\partial E(q^*_M, q^*_A, q^*_H)}{\partial T} = \frac{\beta(-2e_H + \beta e_A)}{2(-4 + \beta^2 + 2\delta)}
\]

Thus, when \(2e_H - \beta e_A < 0\), \(\partial E(q^*_M, q^*_A, q^*_H)/\partial T > 0\).

(c) At the equilibrium, it results:

\[
\frac{\partial E(q^*_M, q^*_A, q^*_H)}{\partial \delta} = \frac{(2e_H - \beta e_A)(2c_H + \alpha(-2 + \beta) - (c_A + T)\beta)}{(-4 + \beta^2 + 2\delta)^2}
\]

where \(-(2c_H + \alpha(-2 + \beta) - (c_A + T)\beta) > 0\) when \(q^*_H > 0\). Thus, when \(e_A > 2e_H/\beta\), it results \(\partial E(q^*_M, q^*_A, q^*_H)/\partial \delta > 0\).

\textit{Q.E.D.}

The intuition behind Proposition 3.2 can be easily drawn. It is easy to show that: (i) \(d\Delta q/\partial \alpha > 0\) and (ii) \(dq^*_H/\partial \alpha > 0\), \(dq^*_A/\partial \alpha > 0\), \(d(q^*_M - q^*_A)/\partial \alpha > 0\). Thus, the larger the market size, the larger the traffic induced by competition. Besides, the larger the market size the more passengers are diverted towards HSR: though \(q^*_H\) and \(q^*_A\) both increase with \(\alpha\), the quantity of passengers taking air increases proportionally less than what would have happened absent competition from HSR. Thus, if the airline is much more polluting than HSR, the increase in HSR emissions due to the newly generated
demand is compensated by the fact that increasingly more passengers are diverted toward the cleaner mode of transport.

A similar argument applies to the effect of $T$. Other things equal, as $T$ increases, e.g., when the total journey time of air increases compared to the total journey time of HSR, HSR becomes more attractive compared with air transport. Indeed, we have $d\Delta q/dT > 0$, $dq_H^*/dT > 0$ and $dq_A^*/dT < 0$. At the same time, $d(q_M^* - q_A^*)/dT > 0$ and increasingly more passengers are diverted towards the more environmentally friendly transport mode.

It is easy to demonstrate that $d\Delta q/d\delta$, $dq_H^*/d\delta > 0$ and $dq_A^*/d\delta < 0$. Thus, when the weight on welfare relative to profit for the HSR is higher, increasingly more passengers take HSR relative to air. The increase in HSR emissions due to its increased traffic is compensated by the decrease in the (very polluting) airline traffic.

$\beta$ measures the substitutability between the two modes: as $\beta$ increases, it can be shown that the signs of $dq_H^*/d\beta$ and $dq_A^*/d\beta$ are not determined, while $d(q_M^* + q_A^*)/d\beta < 0$. Thus, at the equilibrium, the traffic generation effect decreases when the substitutability between the two modes is higher and higher. If the HSR is sufficiently more environmentally friendly than air transport, the increase in total traffic is compensated by the fact that the newly generated demand goes to the more environmentally friendly sector and at the equilibrium, the total pollution after HSR introduction, i.e., $e_A q_A^* + e_H q_H^*$, decreases.

While observing Propositions 3.1 and 3.2, we note that we can analyze the environmental impact of HSR introduction in three different scenarios. Let with $Z := \{\alpha, T, \delta, \beta\}$. When $e_H/e_A < \beta/2$ the introduction of HSR is beneficial to the environment, i.e., $E(q_M^*, q_A^*, q_H^*) > 0$ and $\partial E(q_M^*, q_A^*, q_H^*)/\partial z > 0$ with $z \in Z$. In other word, the (positive) effect of HSR entry increases with the size of the market, the time differentiator, the HSR weight on welfare relative to profits and the substitutability between the two travel products. On the other hand, when $\beta/2 < e_H/e_A < \tilde{e}$, the introduction of HSR is detrimental to the environment, i.e., $E(q_M^*, q_A^*, q_H^*) < 0$. Let $Y := \{\alpha, T, \delta\}$. It results,
\[ \partial E(q_M, q_A, q_H)/\partial h < 0, \text{ with } h \in Y, \text{ while } \partial E(q_M^*, q_A^*, q_H^*)/\partial \beta > 0. \] Thus, an increase in the size of the market, the time differentiator or the HSR weight on welfare relative to profits exacerbates the environmental damage, while an increase in the substitutability mitigates the negative effect on the environment. Finally, when \( e_H / e_A > \varepsilon \), the introduction of HSR is damaging for the environment and \( \partial E(q_M^*, q_A^*, q_H^*)/\partial z < 0 \) with \( z \in Z \), i.e., an increase in \( \beta \) exacerbates the environmental damage. The reason is that \( d\Delta q / d\beta < 0 \) while \( d\Delta q / dh > 0 \) with \( h \in Y \). Thus HSR needs to be much more polluting to cause a decrease of the quantity \( e_A q_M^* - (e_A q_A^* + e_H q_H^*) < 0 \), when we look at the case in which this decrease is driven by the substitutability between travel products.

### 3.2.2 Effects on social welfare

In this section, we seek to assess the effects of competition between HSR and air on social welfare, when the environmental impact matters for society. In particular, we define

\[
W^C = U(q_A, q_H) - (c_A + T)q_A - c_H q_H - (\varepsilon_A q_A + \varepsilon_H q_H)
\]

\[
W^M = U(q_M) - (c_A + T)q_M - (\varepsilon_A q_M)
\]  

(3.14)

where \( U(q_M) = q_M - (1/2)q_M^2 \) and \( \varepsilon_i = \phi \varepsilon_i \) is the (per-passenger) environmental cost of damage due to mode \( i \). The superscript \( C \) stands for the competition case, while the superscript (and subscript) \( M \) stands for the monopoly case. The parameter \( \varepsilon_i \) is obtained by multiplying emissions, \( e_i \), of the relevant pollutants by the cost of damage, \( \phi > 0 \), from LAP or climate change impacts. Cost estimates for \( \phi \) are provided, for instance, by Dings et al. (2002).\(^{52}\) Here, we assume that \( \varepsilon_A > \varepsilon_H \), i.e., the environmental damage due to air is greater than the damage due to HSR.

Thus, we evaluate the overall effect on the environment caused by HSR entry as

---

\(^{52}\) Schipper et al. (2001) provide a useful discussion on the evaluation of environmental externalities in air transport markets and the problem of assigning a monetary value to the damage imposed.
\[ \Delta W(q_A, q_H, q_M) = W^M(q_M) - W^C(q_A, q_H). \] When \( \Delta W(q_A, q_H, q_M) > 0 \), competition is detrimental to social welfare.\(^{53}\)

**Proposition 3.3** There exists a value \( \bar{e} > 0 \) such that \( \forall (e_A, e_H) \) with \( e_A - (2/\beta)e_H < \bar{e} \) it results \( \Delta W(q_A^*, q_H^*, q_M^*) > 0 \), that is when HSR is not clean enough, the total social welfare is higher in the monopoly case than in the competition case.

Proof: We first show that the difference in social welfare between the monopoly case and the competition case, i.e., \( \Delta W(q_A, q_H, q_M) \), is decreasing in \( e_A \), that is it reduces when the (per passenger) environmental damage due to airline increases. Indeed,

\[
\frac{\partial \Delta W(q_A^*, q_H^*, q_M^*)}{\partial e_A} = -\varphi \frac{\beta [\alpha - (c_A + T)] + 2(c_H - \alpha)}{2(\beta^2 + 2\delta - 4)} < 0
\]

since \( \beta [\alpha - (c_A + T)] + 2(c_H - \alpha) < 0 \) when \( q_H^* > 0 \) and \( (\beta^2 + 2\delta - 4) < 0 \). In particular, \( \Delta W(q_A, q_H^*, q_M^*) = 0 \) when \( e_A = \bar{e} + (2/\beta)e_H \) where

\[
\bar{e} = \frac{1}{4\beta(\beta^2 + 2\delta - 4)} \left\{ \beta(T + c_A)(20 - 3\beta^2 - 12\delta) + 2c_H(-12 + \beta^2 + 8\delta) + \alpha[24 + \beta(3\beta^2 + 12\delta - 20 - 2\beta) - 16\delta] \right\}
\]

Note that it causes \( \bar{e} > 0 \). Indeed:

\(^{53}\text{HSR entry, while expanding the catchment area and improving accessibility of areas served by stations, may actually induce some indirect benefits, like spatial labor market relocation effects, spatial labor market matching effects, international labor market effects or additional consumer benefits (Levinson, 2012). In our analysis, we abstract away from these positive externalities (and, therefore, we do not model in the social welfare function the extra-surplus that consumers may gain from these benefits). We concentrate on traffic relocation (and generation) effects over a specific route while any examination of an HSR line’s indirect benefits must consider a wider geographic area than just the cities on the line. In such a scenario, integration between transport networks, especially between the high-speed and conventional rail, should be considered. This is out of the scope of this paper, and any examination of all positive and negative externalities on the overall welfare should reserve attention in future developments.}
\[
\frac{\partial \bar{e}}{\partial \delta} = \frac{(3\beta^2 - 4)\{[\alpha - (c_A + T)]\beta + 2(c_H - \alpha)\}}{2\beta(\beta^2 + 2\delta - 4)^2} > 0
\]

since the numerator is positive because of non-negativity of \(q_H^*\). Therefore, \(\bar{e} > 0\) \(\forall \delta > 0\). Thus, \(\forall (e_A, e_H)\) such that \(e_A - (2/\beta)e_H < \bar{e}\), \(\Delta W(q_A^*, q_H^*, q_M^*) > 0\).

Q.E.D.

The intuition behind Proposition 3.3 can be derived as follows. The introduction of a new mode of transport induces an increase in the overall demand for travel. This is beneficial to the society. Indeed, there is a gain \(U(q_A^*, q_H^*) - U(q_M^*) - (c_A + T)(q_A^* - q_M^*) - c_Hq_H^* > 0\). However, competition from the new mode may be detrimental to the environment: when HSR is not clean enough, this gain – obtained from shifting former air passengers to the HSR – is not able to compensate the amount of extra pollution from newly generated demand. In this case, \(E(q_M^*, q_A^*, q_H^*) < 0\). Thus, if environment matters for welfare, this causes a cost \(q_E(q_M^*, q_A^*, q_H^*)\) that may offset the benefit for the society due to the traffic generation effect.

From the proof of Proposition 3.3 it derives that, when the environmental impact of introducing a new mode of transport matters, it may always happen that competition between the two modes is detrimental to society, whatever is the weight of welfare relative to profits chosen by HSR. In fact, for each \(\delta \in [0,1]\), there always exists a value \(\bar{e} > 0\) such that \(\forall (e_A, e_H)\) with \(e_A - (2/\beta)e_H < \bar{e}\), that is when HSR is not clean enough, the total social welfare is higher under the monopoly case than in the competition case.

Intuitively, the more HSR cares about social welfare, the more passengers will be served by the rail operator, i.e., \(dq_H^*/d\delta > 0\). However, these additional travelers are those with lower WTP: while contributing to pollution with the same amount of emissions, they contribute less to surplus.

In particular, the following corollary holds.

**Corollary 3.1** \(\forall \delta \in [0,1]\), there always exists a value \(\bar{e} > 0\) such that \(\forall (e_A, e_H)\) with \(e_A - (2/\beta)e_H < \bar{e}\) it results \(\partial \bar{e}/\partial \delta > 0\), that is the extent to which the constraint
\( e_A - (2/\beta)e_H < \bar{e} \) can be satisfied is less limited when \( \delta \) increases.

Corollary 3.1 states that the higher \( \delta \), that is the more HSR cares about social welfare, the more likely an overall loss caused by HSR entry, \( \Delta W(q_A^*, q_H^*, q_M^*) > 0 \), arises.

Proposition 3.3 shows that it is not always true to say that the introduction of HSR is beneficial to the society. This depends on the scope of benefits included in the assessment framework. Actually, whether the non-economic benefits should also be factored into the assessment is still an open question. On the one hand, widening the assessment framework to take into account non-economic externalities, such as environmental considerations, could allow competition authorities to identify and consider all the benefits of modal competition. In this case, we show that if the impact on the environment matters for society, the surplus measure of the traditional approach (when environmental effects are not taken into account when assessing social welfare) will fall short of giving a true measure of total social surplus. On the other hand, the inclusion of non-economic benefits into the assessment of the social welfare function is likely to raise a number of challenges (Button, 1990). First, assigning a monetary value to non-economic benefits is likely to be complicated and may be arbitrary. Second, as non-economic benefits may spread over several generations, this might require the forecasting of various dynamic factors such as future capacity, prices and network development. Third, introducing non-economic benefits into the assessment framework may lead to conflicts between the different policy goals (e.g., economic efficiency and environmental targets) and a greater number of challenges to regulatory decisions from stakeholders.

In this respect, it will be important for competition authorities to specify their approach towards ranking and weighting factors in the assessment of social welfare, if the incentive to modes competition is not to be chilled.

### 3.3 Extensions

In this section, we will broaden the analysis to include some characteristics that may influence strategic decisions of operators. In particular, Section 3.1 presents results for the case in which both the airline and the HSR can choose frequency. In Section 3.2, we
3.3.1 Schedule frequency

In this section, we consider a model of full prices that include both quantities and frequencies decisions. Service frequency affects passengers’ modal choice and is an important dimension in the competition between air transport and HSR (Roman et al., 2010; Behrens and Pels, 2012; González-Savignat, 2004; Yang and Zhang, 2012).

Passengers choose an alternative based on the ticket price, the total trip time and the frequency, a proxy for level of service (Adler et al., 2010) of all modes. In particular, following Flores-Fillol (2009), we introduce frequencies additively in the full price functions, while assuming that frequency of flights offered by a particular airline delivers higher value to passengers and, therefore, determines service quality as a measure of flight flexibility. Following a similar approach for frequency of HSR departures, the full prices perceived by travelers are, respectively:

\[
\theta_A = p_A - \gamma_f f_A + T
\]

\[
\theta_H = p_H - \gamma_f f_H
\]

(3.15)

where \( f_i \) is the schedule frequency of transport mode \( i \) and \( \gamma_f \) is the benefit from frequency.\(^{54}\) A similar formulation is also suggested in Heimer and Shy (2006). In addition to a reduced overall journey time, benefits from higher frequency may also include increasing choice/travel opportunity for passengers in terms of schedule coordination for multi-stops trips (Cokasova, 2006; Vespermann and Wald, 2011) or less apprehension over what happens in case of a missed connection due to low punctuality or reliability.\(^{55}\) The value of higher frequency for passenger, \( \gamma_f \), is assessed, for instance, in

\(^{54}\) We assume that the benefit from frequency is the same across the two modes of transport available to the travelers.

\(^{55}\) Reliability is a measure of how often a service is subject to severe disruption, for example due to strikes or engineering problems. Punctuality is a measure of the proportion of services which run on time, when
Behrens and Pels (2012), who estimate direct elasticity of passenger demand with respect to frequency for business and leisure passengers on the London-Paris route, when air transport and HSR compete.\textsuperscript{56} González-Savignat (2004), for instance, finds the WTP to save time when a saving is produced by an improvement in the frequency of the service timetable is 17€/hour. In other words, the expected schedule delay of transport mode \( i \) becomes now endogenous and the WTP as to save time when it is a saving produced by improvement in the frequency of the service timetable is captured by \( \gamma_f \), which, indeed, measures the benefit from frequency.\textsuperscript{57} From equations (3.5) and (3.15) it follows that:

\[
\begin{align*}
p_A(q_A, q_H, f_A) &= \alpha - T - q_A - \beta q_H + f_A \\
p_H(q_A, q_H, f_H) &= \alpha - q_H - \beta q_A + f_H
\end{align*}
\]  

(3.16)

where \( \gamma_f \) has been normalized to 1.

Turning to the supply side, the cost of operating a flight (HSR departure) is given by \( k_{il} \times f_i - k_i + c_i \times Size_i \), where \( Size_i \) measures the number of seats of the aircraft, \( i = A, \) or the train \( (i = H) \), \( c_i \) is the is the unit (per aircraft seat) variable cost and \( k_{il} \times f_i - k_i \) is the cost per departure, with \( k_i \geq 0 \) and \( k_{il} \geq 0 \). This cost consists of fuel for the duration of the flight, airport maintenance, renting the gate to board and disembark the passengers, landing and air-traffic control fees. By doing so we base our assumption on Flores-Fillol (2009) and Brueckner (2009). As in Brueckner and Flores-Fillol (2009), Brueckner (2004, 2009) and Flores-Fillol (2009), it is assumed that all seats are filled, so that load factor equals 100\% and therefore \( q_i = f_i \times Size_i \times LF_i \), i.e., aircraft size can be determined residually dividing airline’s total traffic on a route by the

\[\text{the service does run. EC (2006), for instance, compares data on a few routes where rail market share has increased due to these factors.}\]

\textsuperscript{56} In our model, the direct elasticity of passenger demand with respect to frequency for mode \( i = A, H \), that is \( e_f^i = (\partial q_i / \partial f_i) (f_i / q_i) \), is equal to \([\gamma_f / (1 - \beta^2)] (f_i / q_i)\).

\textsuperscript{57} As in the basic model, without loss of generality, in what follows, we normalize \( \bar{T}_H = 0 \). Thus, HSR operating costs, \( c_H \), and ticket price, \( p_H \), are considered net of \( \nu_a c_H + \nu_t e_H \).
number of planes. Under this specification we can write the profit of mode $i$ as follows:

$$\pi_i(q_i, q_{-i}, f_i) = \left[ p_i(q_i, q_{-i}, f_i) - c_i \right] q_i - C_i(f_i)$$  \hspace{1cm} (3.17)$$

where $C_i(f_i) = f_i(k_{ii} \times f_i - k_i) + K_i$, with $K_i$ being the fixed cost that the airline or the HSR bear in the case in which no flights (HSR departures) are operated. The existence of this term will prevent the cost from being zero when no flight (HSR departure) is operated.

We note that this formulation assumes that the vehicle size and frequency can be smoothly adjusted to suit the size of the market. In reality, such decisions involve indivisibilities such as minimum vehicle sizes and minimum viable frequencies, which may constrain actual choices (Brueckner and Zhang, 2010). Nevertheless, the size of the aircraft can be easily adjusted in the short run, since leasing practices are very common. Gavazza (2011) shows, for instance, that the share of new narrow-body and wide-body aircraft acquired by lessors and coefficient of variation of carriers’ fleet size, in the period 1970-2002, are highly correlated. Moreover, since the 1970s when the deregulation took place in the US, the airline companies invested lot of time and money in new techniques of yield management in order to achieve high load factors by optimally allocating the available resources (Ciancimino et al., 1999).

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58 We note that when $k_{ii} \times f_i - k_i \geq 0$, the cost per departure is increasing with frequency. In what follows, we assume that $k_i$ is much smaller than $k_{ii}$ such that the cost per departure is increasing with frequency $\forall f_i \geq 1$ (e.g., Flores-Fillol, 2009, and Brueckner, 2009). We note that this assumption assures that the cost per seat, that can be written as $(k_{ii} \times f_i - k_i + c_i \times \text{Size}_i)/\text{Size}_i = (k_{ii} \times f_i - k_i)/\text{Size}_i + c_i$, visibly decreases with the size, capturing the presence of economies of traffic density (i.e., economies from operating a larger aircraft) that are unequivocal in the airline industry. While other papers as Brueckner and Flores-Fillol (2009) and Brueckner (2004) consider a constant cost per flight, the assumption of non constant returns is needed to generate sensible results.

59 Greater competition as a result of the Deregulation Act increased the importance of aircraft reallocation, and, therefore, the need for trading intermediaries has become stronger. For example, GECAS - GE Capital Aviation Services - cites the following benefits of an operating lease: “Fleet flexibility to introduce new routes or aircraft types” and “Flexibility to increase or reduce capacity quickly”. Similarly, AWAS, a global leader in commercial aircraft leasing, mentions that “AWAS’ customers gain operating flexibility” (Gavazza, 2011).
In the HSR industry, where leasing practices are much less common, some operators rely on advanced scheduling and capacity management process as a key factor in increasing load factors and winning market share. For instance, Sociétè Nationale des Chemins de Fer Français (SNCF), in partnership with SABRE Technology Solutions, has implemented a set of comprehensive decision-support systems such as revenue management (*RailRev*), schedule planning (*RailPlus*), and capacity (seat control) management (*RailCap*). Some evidence shows that both the French TGV and Eurostar services, between London, Paris and Brussels, with long non-stop runs, compulsory seat reservations and sophisticated yield management systems, claim load factors similar to the 70% shown for air (Nash, 2009).

Similar to the basic model, we assume that the airline maximizes its own profit while HSR a weighted sum of its own profit and the social welfare, that is:

\[
W(q_A, q_H, f_A, f_H) = U(q_A, q_H) - (T + c_A)q_A - c_H q_H - c_A(f_A) - C_H(f_H)
\]  
(3.18)

The operators choose simultaneously the frequency of services and the quantity of passengers and, thus, solve the following decision problems:

---

60 There exists some evidence. The Italian NTV (Nuovo Trasporto Viaggiatori) ordered 25 AGV trains from Alstom, for a value of EUR 650 million, to be purchased in leasing. The contract includes the maintenance of trains for a period of 30 years and an option for 10 additional trains. Renfe, the Spanish public rail operator, has announced that 26 high-speed trains will be available for leasing to new entrants in the market. The newly formed leasing company AMF has a fleet of 51 trainsets, including 19 high speed trains. From May 2000 until December 2005, GNER leased Class 373 Regional Eurostars from Eurostar. These were used on services to York and later Leeds in United Kingdom.

61 At SNCF, the major responsibilities of *RailCap* are to monitor the reservation activity for all trains, using the latest forecasts produced by the yield management system *RailRev*, and proactively to add capacity (train sets), called *forcements*. In particular, *RailCap* may suggest the following changes to TGV train capacity: (i) add a second train unit to single-unit trains; (ii) drop empty second train units or open them to reservations on double-unit trains; (iii) open an optional train to reservations and assign it an itinerary-compatible fleet type. Capacity adjustments can be suggested from 15 to three days before the train departure (Ben-Khedher et al., 1998).

62 It is reasonable to assume that the operators may choose contextually the frequency of service since frequency can be easily adjusted in the short run. Moreover, this is consistent with the instance of: (i) uncongested airports where slots are available; (ii) uncongested rail infrastructure (i.e., the tracks and train
\[
\max_{q_A,f_A} \left[ p_A(q_A, q_H, f_A) - c_A \right] q_A - C_A(f_A) \\
\max_{q_H,f_H} (1 - \delta) \left[ (p_H(q_A, q_H, f_H) - c_H) q_H - C_H(f_H) \right] + \delta W(q_A, q_H, f_A, f_H)
\]

where \( \delta \) is the weight in welfare relative to profits, as described in the basic model. It is straightforward to derive equilibrium solutions for the quantities and frequencies (the superscript \( * \), \( f \) stands for equilibrium), which is omitted from the text due to their complex expression.\(^{63}\)

In order to analyze the impact of competition between HSR and air transport on the environment, again we refer to the benchmark case of a monopoly airline. Again we assume a linear demand function. In particular, the inverse demand with respect to full price in the market served by the monopoly airline can be written as \( \theta_M(q_M) = \alpha - q_M \). Full price is \( \theta_M = p_M + T + \gamma_f f_M \), where \( T = \nu_a a_A + \nu_t t_A \) measures the cost of access/egress and travel time for travelers when air is the only available transport mode.

The inverse demand function with respect to the ticket price can be easily obtained:

\[
p_M(q_M, f_M) = \alpha - T - q_M - \gamma_f f_M,
\]

where again we normalize \( \gamma_f \) to 1. The airline maximize its profit, that is \( \pi_M(q_M, f_M) = (p_M - c_A) q_M - C_A(f_M) \) with respect to quantity and frequency. Equilibrium results are

\[
q_{M}^{*,f} = \frac{-2k_A(T + c_A - \alpha) + k_A}{4k_A T - 1} \tag{3.20}
\]

\[
f_{M}^{*,f} = \frac{2k_A(T + c_A - \alpha)}{4k_A T - 1} \tag{3.21}
\]

**Lemma 3.2** The introduction of high speed rail in the market for travel results in lower air market share and lower frequency, compared to the monopoly case, i.e., \( q_{M A}^{*,f} < q_{M}^{*,f} \)

---

\(^{63}\) It is easy to prove that the second order conditions for unconstrained optimization are satisfied for problem (19).
and $f_{A}^* < f_{M}^*$. Moreover, it results $q_{M}^* f_{M}^* - q_{A}^* f_{A}^* > 0$. If $\beta < (4k_{AA} - 1)/2k_{AA}$, competition between the two modes leads to market expansion, i.e., $q_{M}^* - q_{A}^* < 0$.

Proof: At the equilibrium, let $D$ denote the denominator of $q_{A}^*, q_{H}^*, f_{A}^*$ and $f_{H}^*$. Moreover, let $N_{qA}$ denote the numerator of $q_{A}^*$, $N_{qH}$ the numerator of $q_{H}^*$, $N_{qM}$ the numerator of $q_{M}^*$, $N_{fA}$ the numerator of $f_{A}^*$ and $N_{fH}$ the numerator of $f_{H}^*$, $N_{fM}$ the numerator of $f_{M}^*$. Since, at the equilibrium, frequencies and quantities are non-negative, $N_{qA}, N_{qH}, N_{fA}, N_{fH}$ and $D$ share the same sign. It is easy to note that, in $q_{A}^* - q_{M}^*$, the second part of the numerator is equal to $N_{qH}$, $2k_{AA} \beta$ is positive, $-(4k_{AA} - 1)$ is negative because, at the equilibrium the second order conditions are satisfied, and the second part of the denominator is equal to $D$. Thus, the whole expression is negative. A similar conclusion follows in the case of $f_{A}^* - f_{M}^*$, given that $\beta$ is positive. The thesis related to $q_{A}^* + q_{H}^* - q_{M}^*$ follows from the same arguments, given that $[2k_{AA}(-2 + \beta) + 1]$ can be positive or negative depending on $\beta$. The thesis related to $q_{M}^* f_{M}^* - q_{A}^* f_{A}^*$ follows when noting that the second part of the numerator is equal to $N_{qH}$, $k_{AA} \beta$ is positive, the first part of the denominator is $N_{fM}$, which is positive, and the second part of the denominator is the opposite of $N_{fA}$.

Q.E.D.

Lemma 3.2 shows that competition between the two modes leads to market expansion, if the substitutability between the two modes is sufficiently low, i.e., if the two travel products are differentiated enough. Moreover, after the introduction of HSR in the market for travel, the airline carries fewer passengers and reduces the frequency of the service. When load factors are assumed to be 100%, the reduction of frequency may have an impact on the aircraft size, since $q_{j}^* f_{j}^* = \text{Size}_j$, $j = A, M$, where $\text{Size}_M$ is the size of aircrafts used by the monopoly airline. In particular, Lemma 3.2 implies that the carrier reduces the size of the aircraft, i.e., $\text{Size}_A < \text{Size}_M$. In other words, with the entry of HSR the airline loses traffic, it reduces the frequency of service and it may tend to reduce the
size of the aircraft used in order to keep load factors high while carrying less passengers. The results find a confirmation in literature. For instance, when the TGV Est began operations from Paris to Metz and Nancy, and provided attractive frequency (10 trains per day in each direction), flights between Paris and these two cities have been completely eliminated (Dobruszkes, 2011). Similarly, in Spain, before the HSR link was established between Madrid and Seville at early 1990s, the mix of air/rail passengers was 67% and 33% respectively. After the introduction of HSR, the mix changed to 16% and 84%. In China, all the flights between Zhengzhou and Xi’an were suspended in March 2010, 48 days after the opening of the HSR service, whereas daily flights on the Wuhan-Guangzhou route (1,069 km) were reduced from fifteen to nine, one year after the HSR entry (Fu et al., 2012). Recent cases of air route cancellations also include a number of Chinese domestic markets such as Nanjing-Shanghai, Changsha-Guangzhou and Wuhan-Nanjing. Givoni and Rietveld (2009) investigate airlines’ choice of aircraft size and claim that the stronger the competition the smaller the aircraft size one may expect given the importance of service frequency. In particular, they find that market concentration on certain routes leads to the choice of relatively large aircraft, since lack of competition allows carriers to reduce frequencies. Hence in a highly concentrated market aircraft size tends to be larger. In the specific case of Paris-Nantes route, the introduction of the TGV network has decreased the traffic of 30%. Air Inter, to cope with this decrease, has first restructured its service by using smaller airplanes without reducing the number of flights between the two cities (15 flights every two days, on average). The same situation is observed in other routes like Paris-Rennes or Paris-Brest (Chi, 2004). Empirical evidence also shows that the reduction of aircraft size when adjusting frequency may have an impact on the environment. For instance, Givoni and Rietveld (2010), based on three case studies, show that decreasing aircraft size, switching from a B747 (524 seats) fleet to an A320 (150 seats) fleet and adjusting the service frequency to offer similar seating capacity, would decrease LAP but increase climate change impact. When these impacts are monetized and aggregated, the analysis shows that an overall environmental detriment
would follow.\textsuperscript{64} In general, literature suggests environmental benefits can be expected from increasing aircraft size, i.e., large aircraft have lower environmental per passenger km costs than small aircraft.

Let $E_i$, with $i = A, H$ be the total level of emissions per flight or HSR departure, respectively, with $E_H < E_A$. In particular, we evaluate:

$$
\hat{E}(\mathbf{q}, \mathbf{f}) := \frac{E_A \cdot f_M^*}{q^*_M} - \frac{(E_A \cdot f_A^* + E_H \cdot f_H^*)}{q^*_A + q^*_H} \tag{3.22}
$$

where $\mathbf{q} = (q_A^*, q_H^*, q_M^*)$ and $\mathbf{f} = (f_A^*, f_H^*, f_M^*)$. $\hat{E}(\mathbf{q}, \mathbf{f})$ measures the difference between the per-passenger level of emissions observed in the case in which the market for travel is served by a monopoly airline and the case in which a new mode of transport is introduced. If $\hat{E}(\mathbf{q}, \mathbf{f}) > 0$, then competition between HSR and air transport is beneficial to the environment on a per passenger base. The following proposition holds:

**Proposition 3.4** If the market size is small enough, that is if $\alpha < \bar{\alpha} = -2k_A + k_A\beta + T + c_A$, the introduction of the high speed rail is always detrimental to the environment, i.e., $\hat{E}(\mathbf{q}, \mathbf{f}) < 0$. Otherwise, $\exists \check{\varepsilon} > 0$ such that $\forall (e_A, e_H)$ with $e_A/e_H > \check{\varepsilon}$ it results $\hat{E}(\mathbf{q}, \mathbf{f}) > 0$, that is if high speed rail is sufficiently greener than air transport, competition between the two modes of transport is beneficial to the environment.

Proof: At the equilibrium, it results:

\textsuperscript{64} The case studies are Barcelona-Madrid (BCN-MAD), Sapporo-Tokyo (CTS-HND) and Los Angeles-Chicago (LAX-ORD) routes. The increase in aircraft movements when downsizing aircraft fleet and adjusting service frequency would also increase noise pollution around airports and intensify delays - on the ground and in the sky - and therefore increase flight time leading to lower LAP and climate change impacts. Finally, reduction in the number of movements means airport capacity can be maintained or increased without constructing new runways.
\[
\frac{\partial \hat{E}(q,f)}{\partial e_A} = - \frac{[k_H(-2 + \beta) + (c_A + T - \alpha)]N_{qH}}{N_{qM}(N_{qA} + N_{qH})}
\]

Since \(N_{qH}, N_{qA}\) and \(N_{qM}\) share the same sign, the sign of the whole expression still depends on the sign of \([k_H(-2 + \beta) + (c_A + T - \alpha)]\). If this is positive, i.e., \(\alpha < [k_H(-2 + \beta) + (c_A + T)]\), then \(\hat{E}(q,f)\) is decreasing in \(e_A\). In particular, \(\partial \hat{E}(q,f)/\partial e_A = 0\) when \(e_A/e_H = \tilde{e}\) with:

\[
\tilde{e} = - \frac{N_{qM}N_{fH}}{[k_H(-2 + \beta) + (c_A + T - \alpha)]N_{qH}}
\]

Thus, if \(\alpha < [k_H(-2 + \beta) + (c_A + T)]\), that is \(\hat{E}(q,f)\) is decreasing in \(e_A\), and \(\tilde{e}\) is negative. In this case, \(\hat{E}(q,f) < 0\) always holds. In this case, the introduction of the high speed rail is always detrimental to the environment. As opposite, if \(\alpha \geq [k_H(-2 + \beta) + (c_A + T)]\), that is \(\hat{E}(q,f)\) is increasing in \(e_A\), and \(\tilde{e}\) is positive. In this case, when \(e_A/e_H > \tilde{e}\), \(\hat{E}(q,f) > 0\) holds.

We remark that the definition of \(\hat{E}(q,f)\) implies that \(E_A\), the total level of emissions per flight, is the same in the monopoly case and in the competition case, while the airline uses different types of aircrafts. In particular, let \(E_M\) denote the total level of emissions per flight in the monopoly case. We proved that when \(E_M = E_A \cdot z\), with \(z = 1\), there exists a \(\tilde{e}\) such that \(\forall e_A/e_H < \tilde{e}\) introducing HSR into the market will deteriorate environment on a per-passenger basis, as long as the market size is big enough. In particular, the larger \(z\), that is the less efficient a small aircraft is, the more likely this situation will happen, since the larger \(z\) the larger \(\hat{E}(q,f)\). This translates into the fact that a larger \(z\) will push up the threshold \(\tilde{e}\).

Q.E.D.

Proposition 3.4 shows that it is not straightforward to assert that the introduction of HSR will bring environmental benefit on a per passenger base. This depends on the market size when both modes of transport decide on frequency. The final conclusion is that when HSR enters the market, the airline carries out fewer passengers, lowers the frequency and,
accordingly, decreases the size of the aircraft. Thus, there are some gains related to less flights, i.e., a (positive) frequency effect, but these flights are carried out with small aircrafts, that are more polluting (Givoni and Rietveld, 2010), a (negative) size effect. If the airline is very polluting, i.e., if HSR is sufficiently greener than air transport, in some sense it is beneficial for the environment to carry out less flights even if with smaller aircrafts.

3.3.2 Speed

In this section, we turn back to the case in which the schedule frequency is exogenously given. We concentrate on the case in which the HSR operator may set the (maximum) train speed.

There are two reasons why it is interesting to look at this problem. First, while the aircraft speed can be considered as being constant, since it is close to the speed of sound and has been relatively stable, rail (maximum) speed can vary in practice. The rail maximum speed of a HST depends on the type of power car that is used to operate the train. Since HSTs do not follow the direct routes, HSR may have incentive to increase the speed of the vehicle to reduce travel time: as train become faster, HSR is likely to impose a significant competitive pressure on air transport over a relatively large range of distances, due to the increase of its attractiveness over travelers. Benefits from higher speed may also include the increase in the opportunities for passengers in terms of coordination with other transport modes or in the possibility to take advantage of some services when the departure time cannot be anticipated. Take the example of a traveler who is constrained to leave a city (e.g., Milan) not before a certain schedule (e.g., at the end of a business meeting) but may wish to arrive at destination (e.g., Rome) as early as possible to take the last bus or train back home (e.g., to a peripheral city), or to do some ordinary

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65 For instance, maximum commercial speed is 360 km/h for the Italian Italo ETR 575 (used by NTV), 300 km/h for the Italian ETR 500 (used by Trenitalia) and the Eurostar BR Class 373, 250 km/h for the Spanish Alvia Class, 350 km/h for the AVE Class 103, 380 km/h for the Chinese CRH380.
shopping before shops close. The traveler may not manage to catch these opportunities (e.g., he has to spend one more night in a hotel) if the train is not fast enough.

Second, the emissions from HSTs depend on two parameters - the energy consumption for the train and the emissions from the electricity generated to power the train (CfIT, 2001). Evidence shows that HSR energy consumption, i.e., quantity of energy per unit of output - kWh/pkm, increases with the speed of the train (Kemp, 2004; Garcia, 2010; Andersson and Lukaszewicz, 2006; Bousquet et al., 2013). Therefore, when HSR is able to decide on the speed of the vehicle, there can be a trade-off between the attractiveness of the service and the effects on the environment.

We first examine the demand side. In our formulation, we assume that higher train speed delivers higher value to HSR passengers and, therefore, determines service quality. Let $s_H > 0$ denote the commercial speed of the HST. In this framework, we model the full prices perceived by travelers as, respectively:

$$\theta_A = p_A + T$$
$$\theta_H = p_H - \gamma_S s_H$$

(3.23)

The parameter $\gamma_S$ measures the benefit for HSR passengers’ from train speed. In some sense, the formulation is similar to the one adopted to model the impact of frequency on passengers’ full prices. Introducing speed additively in the full prices, simplifies the analysis, where higher speed reduce the cost of travel time and increases travelers’ WTP.

For the sake of notation, in what follows we shall refer to $\tilde{T}_A = a_A + t_A + d_A$, $\tilde{T}_H = a_H + d_H$ and $T = \nu_a (a_A - a_H) + \nu_f (d_A - d_H)$, where $\nu_f$ represents the value of WTP for a saving due to improvement in schedule frequency.66 The WTP of HSR passengers for a

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66 As in the basic model, without loss of generality, in what follows, we normalize $\tilde{T}_H = 0$. Thus, HSR operating costs, $c_H$, and ticket price, $p_H$, are considered net of $\nu_a a_H + \nu_f d_H$. We also note that $s_A$ is assumed to be constant. Thus, $t_A = l_A / s_A$ with $l_A$ being the length of the air route (as the crown flies) is constant and included, as $\nu_f t_A$, in $T$. 

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saving in the travel time is now captured by $\gamma_s$ which, indeed, includes the benefits from higher speed.

From equations (3.5) and (3.15), it follows that:

$$p_A(q_A, q_H) = \alpha - T - q_A - \beta q_H$$
$$p_H(q_A, q_H) = \alpha + s_H - q_H - \beta q_A$$

(3.24)

where $\gamma_s$ has been normalized to 1 (an assumption that will be relaxed in Section 3.4).

Turning to the supply side, the profit of the airline is $\pi_A(q_A, q_H) = [p_A(q_A, q_H) - c_A] q_A$, $c_A$ is the unit (per aircraft seat) variable cost. The profit of HSR is given by $\pi_H(q_A, q_H) = [p_H(q_A, q_H) - c_H - C_s(s_H)] q_H$, where $c_H$ is the variable (operation) cost per train seat and $C_s = C_s(s_H)$ is the electricity cost per kmh/per train seat (i.e., it is proportional to the energy consumption). Consequently, in this model, HSR operation costs per seat are all the basic model’s costs other than the electricity costs per seat. We assume that $\partial C_s / \partial s_H > 0$, that is higher speed leads to higher unit electricity cost per kmh. This is confirmed by several empirical researches (e.g., Kemp, 2004; Garcia, 2010; Andersson and Lukaszewicz, 2006; Bousquet et al., 2013) and adopted in a theoretical model by Yang and Zhang (2012). In particular, in this paper we assume that unit electricity cost per kmh is constant, that is, the electricity cost increases linearly with speed. Janic (2003) finds that HSR energy consumption (quantity of energy per unit of output - kWh/pkm) is mainly proportional to cruising speed: it is lower during the accelerating/ decelerating phase of a trip and higher but reasonably constant during cruising at constant speed (of about 250 km/h). Lukaszewicz and Andersson (2009)’s estimations on the Swedish case show that the energy consumption increases by a power of 1.1-1.3 of the cruising speed for the trains running on the dedicated very-high-speed line. For example, if the speed is increased from 250 to 280 km/h (12 %), energy consumption increases by 13-16%. Garcia (2010) reports the relationship, based on estimates on some Spanish routes, between each train vehicle’s output (in kilowatts) and
its maximum speed showing a curve that confirms the power of 1.3.

Let $\mu$ be the constant unit electricity cost per kmh of HSR.\(^67\) The profit of HSR is given by:

$$\pi_H(q_A, q_H) = (p_H(q_A, q_H) - c_H - \mu s_H) q_H$$ \hspace{1cm} (3.25)

where $\mu < \gamma_s$, that is the unit electricity cost of a marginal increase of speed is lower than the passengers’ WTP for that marginal increase of speed. We assume that $0 < s_H \leq \bar{s}_H$, where $\bar{s}_H > 0$ is the maximum train speed which can be achieved given the technology of the power car, legal requirements, e.g., the percentage of the line on which maximum speed can be achieved, and the number of stops on the HSR line.\(^68\) For instance, each additional stop (station) can cost 5–10 min and often trains must slow-down through cities, even if they are not stopping there (Givoni and Banister, 2012).\(^69\)

Similar to previous sections, we assume that the airline maximizes his own profit while HSR a weighted sum of his own profit and social welfare, that is:

$$W(q_A, q_H, s_H) = U(q_A, q_H) - (c_A + T)q_A - (c_H + \mu s_H)q_H$$ \hspace{1cm} (3.26)

The interaction between the airline and the HSR operator is modeled as a sequential game. In the first stage the HSR decides on speed. In the second stage, the two modes compete

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\(^67\) For instance, Kemp (2004) provides the average energy consumption per kmh/per seat of HSR, that is $0.15 kWh/kmh \cdot seat$. The average cost is 0.096 €/kwh according to Eurostat (2013).

\(^68\) For instance, from May 2000 until December 2005, Class 373 Regional Eurostar were used in Britain by GNER on services to York and later Leeds but were restricted to 110 mph between Grantham and Doncaster because of problems with the overhead wire and pantograph interface. Due to gauging restrictions, they were not permitted to operate north of York to Newcastle, Glasgow or Edinburgh.

\(^69\) While maximum speed of 350 kmh is considered the new standard for HSR, most HST services are provided at a much lower average speed. The world record for average speed of a commercial HST service is 313 kmh, held by a non-stop service between Wuhan and Guangzhou in China. Since then, the speed on this route was reduced and a station added, reducing the average speed. Before that a French TGV service held the record with an average speed of 279 kmh (Givoni and Banister, 2012).
on quantities.\textsuperscript{70} We solve the game by backward induction. In the second stage, the operators solve simultaneously the following decision problems:

\[
\max_{q_A} \left[ p_A(q_A, q_H) - c_A \right] q_A
\]

\[
\max_{q_H} (1 - \delta) \left[ (p_H(q_A, q_H, s_H) - c_H - \mu s_H) q_H \right] + \delta W(q_A, q_H, s_H)
\]

where \( \delta \) is the weight on welfare relative to profit as defined in the basic model. In other words, the airline observes the speed at which HSR operates and compete simultaneously with the HSR operator in maximizing their profit with respect to the number of carried travelers. We thus find the best response functions for \( q_A(s_H) \) and \( q_H(s_H) \):

\[
q_A(s_H) = \frac{[c_H - s_H(1 - \mu)]\beta + (\delta - 2)(T + c_A - \alpha) - \alpha \beta}{\beta^2 + 2(\delta - 2)}
\]

\[
q_H(s_H) = \frac{\alpha(-2 + \beta) - 2s_H(1 - \mu) + 2c_H - (c_A + T)\beta}{\beta^2 + 2(\delta - 2)}
\]

In the first stage, the HSR operator chooses the speed of the vehicle in order to maximize its objective function. The following decision problem results:

\textsuperscript{70} As noted, leasing practices are much less common in the HSR industry than in the aviation industry, though some evidence exists. In most of the cases, HSR operators own their own fleet and, therefore, the decision on the type of the locomotive used to operate the service on a route imply a sunk cost in the short run. Consequently, the decision on the speed of the vehicle can be seen as a long run decision, since it cannot be easily adjusted in the short run once that the rolling stock, and so the power car, has been acquired. For instance, Trenitalia invested in 2013 approximately € 552 million, of which 56% is used to purchase new rolling stock (FSI, 2014). In particular, the investments involve the purchase of the new electric trains AV "Frecciarossa 1000". Similarly, in 2004 The European Investment Bank (EIB) granted a € 200 million loan to SNCF for purchasing 18 Duplex (double-deck) train sets. The project represented the second phase of a vast SNCF programme to expand its TGV fleet, which has followed a previous operation in 2002 when SNCF purchased 22 Duplex train sets, which are now in use.
$$\max_{s_H} (1 - \delta)[(p_H(q_A(s_H), q_h(s_H), s_H) - c_H - \mu s_H)q_H(s_H)]$$

$$+ \delta W[q_A(s_H), q_h(s_H), s_H]$$

In particular, it is easy to demonstrate that\(^71\)

$$\partial \{(1 - \delta)[(p_H(q_A(s_H), q_h(s_H), s_H) - c_H - \mu s_H)q_H(s_H)] + \delta W(q_A(s_H), q_h(s_H), s_H)} / \partial s_H > 0$$

Thus, HSR always has incentive to raise its speed. It results (the superscript \(s^*\), \(s\) stands for equilibrium):

$$s_H^{s^*} = \bar{s}_H$$

Consequently, equilibrium quantities are found, i.e., \(q_A^{s^*} = q_A(\bar{s}_H)\) and \(q_H^{s^*} = q_H(\bar{s}_H)\).

In order to analyze the impact on the environment of competition between air and HSR, we refer to the benchmark case of a monopoly airline. Expression for equilibrium result for \(q_M\) is the same as in the basic case model, i.e., \(q_M^{s^*} = (\alpha - T - c_A)/2\). Again, it is easy to check that competition between the two modes leads to market expansion, i.e., \(q_M^{s^*} - q_H^{s^*} - q_A^{s^*} < 0\).

We shall consider, then, the overall environmental impact of market expansion. In electrically powered high-speed trains, emissions mostly depend on the energy consumption (CfIT, 2010).\(^72\) However, we can distinguish between direct and indirect energy consumption. The former mostly includes the energy required to overcome the train’s resistance to movement. It also includes the energy lost due to inefficiencies in the traction system between pantograph and wheel, the energy used for on-board passenger

\(^71\) We have \(\partial^2 \{(1 - \delta)[(p_H(q_A(s_H), q_h(s_H), s_H) - c_H - \mu s_H)q_H(s_H)] + \delta W(q_A(s_H), q_h(s_H), s_H)] / \partial s_H \partial \delta > 0\) in the feasible region and \(\lim_{\delta \to 0}\{(1 - \delta)[(p_H(q_A(s_H), q_h(s_H), s_H) - c_H - \mu s_H)q_H(s_H)] + \delta W(q_A(s_H), q_h(s_H), s_H)] / \partial s_H \partial \delta\} = 0\).

\(^72\) See Pérez-Arriaga (2013) for the analysis of the environmental impact of electricity by fuel type (pg. 541-542).
comfort functions, the losses in the electrical supply system between the substation and pantograph. The latter includes energy used for in-service maintenance of rail rolling stock (Network Rail, 2009). In particular, emissions from indirect energy consumption do not increase with the speed as well as emissions from direct energy consumption for on-board passenger comfort functions. We let $e_H^f$ denote this type of emissions (the superscript $f$ denotes fixed with respect to speed). We let $e_H^v$ denote all emissions other than $e_H^f$, that is those which reasonably increase with the speed of the vehicle (the superscript $v$ denotes variable with respect to speed). In other words, $e_H^v$ is the marginal increase in the level of emissions per seat due to the energy consumption per kmh, while $e_H^f$ is the marginal increase in emissions per seat that is fixed per kmh.

Let $\hat{E}$ denote the difference between the total pollution before and after the introduction of HSR. We define $\hat{E}$ as:

$$\hat{E}(q, s_H^{*s}) := e_A - \frac{(e_A q_A^{*s} + e_H^f q_H^{*s} + e_H^v s_H^{*s})}{q_A^{*s} + q_H^{*s}}$$

(3.29)

where $q = (q_M^{*s}, q_H^{*s}, q_A^{*s})$. The following proposition hold.

**Proposition 3.5** There exists a value $e_H^f > 0$ such that, $\forall (e_A, e_H^f, e_H^v)$ with $e_H^v > (e_A - e_H^f)/(\omega s_H)$, it results $\hat{E}(q, s_H^{*s}) < 0$, that is when the increase in the emissions of high speed rail due to the increase in the speed of the train is sufficiently high, the overall level of emissions after the introduction of the high speed rail is always higher than the level of emissions in the monopoly case.

Proof: At the equilibrium, $\hat{E}(q, s_H^{*s})$ is always increasing in $e_A$, that is:

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73 Comfort functions include lighting, heating and ventilating coaches for passenger comfort. Whilst this is mainly required during operation there is demand during stabled hours for cleaning and maintenance and to ensure a comfortable temperature when the train begins operation. Comfort function energy demand depends strongly on ambient temperature (Network rail, 2009). Evidence shows that such energy consumption accounts for the 22% of the direct energy consumption (Network Rail, 2009).
Indeed, \( \frac{\partial \bar{E}(q, s_{H}^{*})}{\partial e_{A}} \) is always increasing in \( c_{H} \):

\[
\frac{\partial^{2} \bar{E}(q, s_{H}^{*})}{\partial e_{A} \partial c_{H}} = \frac{(c_{A} + T - \alpha)(\beta^{2} - 4 + 2\delta)}{[(T + c_{A} + c_{H} + \bar{s}_{H}(-1 + \mu) - 2\alpha)(\beta - 2) + (c_{A} + T - \alpha)\delta]^{2}} > 0
\]

since \( \alpha > c_{A} + T \), \( 0 < \beta < 1 \) and \( \mu < 1 \). Moreover, when \( c_{H} = 0 \), it results:

\[
\frac{\partial \bar{E}(q, s_{H}^{*})}{\partial e_{A}} \bigg|_{c_{H}=0} = \frac{\alpha(2 - \beta) + 2\bar{s}_{H}(1 - \mu) - 2c_{H} + (c_{A} + T)\beta}{(c_{A} + T - \alpha)(\delta - 2 + \beta) + (\beta - 2)(\bar{s}_{H}(-1 + \mu) - \alpha)} > 0
\]

In particular, \( \bar{E}(q, s_{H}^{*}) = 0 \) when:

\[
e_{A} = e_{H}^{f} + e_{H}^{d}\bar{s}_{H}(\beta^{2} - 4 + 2\delta)/\alpha(-2 + \beta) - 2s_{H}(1 - \mu) + 2c_{H} - (c_{A} + T)\beta
\]

Where

\[
\omega = (\beta^{2} - 4 + 2\delta)/\alpha(-2 + \beta) - 2s_{H}(1 - \mu) + 2c_{H} - (c_{A} + T)\beta > 0
\]

Therefore, \( \forall (e_{A}, e_{H}^{f}, e_{H}^{d}) \) with \( e_{A} < e_{H}^{f} + e_{H}^{d}\omega\bar{s}_{H} \), it results \( \bar{E}(q, s_{H}^{*}) < 0 \).

Q.E.D.

Proposition 3.5 shows that when HSR is able to decide on the speed of the vehicle, there can be a trade-off between the attractiveness of the service due to reduced travel time and the effects on the environment. Indeed, \( \partial q_{A}^{*}/\partial s_{H} < 0 \) while \( \partial q_{H}^{*}/\partial s_{H} > 0 \), that is the number of passengers traveling by air decreases as HSR become faster, while the number of passengers traveling by HSR increases. However, when HSR increases the speed of the vehicle and the subsequent increase in the emissions of HSR is sufficiently high, the competition between the two modes of transport may be detrimental to the environment. Thus, energy efficiency technologies and strategies should be promoted in order to increase the environmental friendliness of HSR when compared to air transport (UIC, 2003). Low energy consumption at increased speeds requires a new train concept and
design, using the most modern technologies and knowledge available. The Swedish research and development program ‘Gröna Tåget’ (the Green Train) can be taken as an example. Other than increasing speed and reducing travel time, environmental performance and energy efficiency are also among the major goals (Lukaszewicz and Andersson, 2009).

3.5 Concluding Remarks

In this paper, we propose a duopoly model to shed light on the impact of air transport and HSR competition on the environment and social welfare when new travel demand is induced. Although evidence shows that HSR is more environmentally friendly than air transport on a per-seat base, its introduction may not necessarily lead to environmental advantages. The net environmental effect depends on the balance between the substitution effect (how many passengers using the HST are shifted from the aircraft) and the traffic generation effect (how much new demand is generated by the HSR).

First, our findings show that, when the pollution level of HSR is not sufficiently lower than that of the airline, the gain from shifting former air passengers to a cleaner mode of transport is not able to compensate the amount of pollution due to newly generated traffic. Moreover, if the impact on the environment is taken into account when assessing social welfare, the surplus measure may be higher in the monopoly case than in the competition case. In this case, when HSR is owned by both public and private sectors and maximizes a weighted sum of its profit and social surplus excluding environment impacts, the more HSR cares about social surplus, the more it is detrimental to social welfare including environmental impacts. The reason is that a proportion of the additional travelers are those with lower willingness to pay: while contributing to pollution with the same amount of emissions, they contribute less to surplus.

Second, the decisions on the frequency of flights (HSR departures) or on the speed of trains may also affect the environment. On the one hand, when a new mode of transport is introduced in the market, we show that airlines may tend to reduce the size of their aircrafts in order to maintain high frequency services. Decreasing the aircraft size and
adjusting the service frequency to offer similar seating capacity will increase the environmental impact since smaller aircrafts generally incur more environmental impacts on a per-seat base. If the market size is small, we show that reduced aircraft size may make the introduction of HSR detrimental to environment even on a per-passenger base.

HSR may have incentive to increase the speed of trains, in order to reduce travel time and increase its attractiveness to travelers when competing with air transport. This induces a higher cost for the HSR operator but it also affects the environment, since the HSR impacts on LAP and climate change depend on the energy consumption, which rises when the speed of the vehicle increases. When HSR decides on the train speed, the operator will choose the maximum level of speed given the technology of the power car, the legal requirements and the number of stops on the HSR line. When the increase in the emissions of HSR due to the increase in the speed of the train is sufficiently high, the overall level of emissions after the introduction of the HSR will be higher than in the monopoly case. Therefore, there can also be a trade-off between the attractiveness of the service due to reduced travel time and the effects on the environment.

The paper has raised some important issues within the policy debate around HSR versus air transport. First, the argument that introducing HSR as a substitute for air transport will doubtlessly benefit the environment may have led to potential bias amongst policy makers when considering future transport policy. Indeed, it is not always true to say that the introduction of HSR is beneficial to the society. Though the inclusion of non-economic benefits into the assessment of the social welfare function is likely to raise a number of challenges, widening the assessment framework to take into account environmental considerations could allow competition authorities to identify and consider all of the benefits of intermodal competition. In this case, we show that if the impact on the environment matters for society, the surplus measure of the traditional approach (that is when environmental effects are not taken into account when assessing social welfare) will fall short of giving a true measure of total social surplus.

Second, our analysis suggests that it is crucial to analyze the implications of the introduction of HSR on social welfare and environment on a case-by-case basis, since
benefits depend on the environmental friendliness of HSR. This, in turn, hinges on the mix of energy sources used to generate the electricity. Thus, policy makers should carefully assess the implications of HSR introduction in the market for travel taking into account the potential impact of policy targets for renewable resources for energy production. In fact, whilst airlines have the opportunity to switch to non-conventional jet fuels, e.g. biofuels, in order to reduce their own environmental footprint, the generation mix for electricity is heavily constrained from the country in which HSR operates – the availability of electricity sources, dispatch merit rules, topology of the electricity grid. Consequently, the set of mitigation strategies that might be implemented by HSR is much more limited when compared to air transport. This is something that should be taken into account by policy makers in the design of environmental regulation.

The paper has also raised some avenues for further research. First, we have considered the case of a single airline and a single HSR operator. In reality, with respect to the airline industry, more firms may compete in any particular market. Extending the analysis to a framework with more competitors would be an insightful future study. Second, phases other than operation in the HSR life-cycle analysis (construction/production, maintenance and disposal) can be responsible for significant environmental impact. The effects related to the construction of rail infrastructure, for instance, include emissions from building a new HSR line as well as land take, affecting landscape, townscape, biodiversity and heritage. Further developments of this work may investigate the effect of modes competition and environment when capacity investments in building a new line are considered. Third, it can be interesting to include the environmental dimension in the analysis of demand (rather than of the supply side only). Its importance is suggested by some stylized facts. For instance, Trenitalia sponsored EcoPassenger, a tool which calculates the energy consumption and emissions of the major atmospheric pollutants per passenger travelling by plane, by train or by car. The aim of the system is to increase user awareness of the cost of their selected mode of transport. The system has been developed by Union Internationale des Chemins de Fer (UIC) and approved by the European Environmental Agency and the European Commission.
4 Airline Network Choice and Market Coverage under High-speed Rail Competition

4.1 Introduction

Over the past decades, high-speed rail (HSR) has become a growing phenomenon all over the world. In countries like Japan, United Kingdom, France, Spain, Germany, Italy, Belgium, the Netherlands and South Korea, HSR is already a common transport mode for millions of passengers every day. In particular, with its first HSR line being introduced in 2007, China has since developed the most extensive and most heavily used HSR network in the world. Many countries including United States, India, Malaysia (and Singapore), Thailand, Russia and Brazil, are seriously considering their HSR development. Some of them even have a clear schedule on the table.

Other than passengers, airlines are another party that is strongly affected by the rapid development of HSR. With increased train speed, HSR has become a de facto substitute and effective competitor of air transport, especially for routes with distances less than 1,000 km (e.g., Janic, 1993; Rothengatter, 2011). Examples abound where airlines have been forced to withdraw from, or cut back on, short-haul routes. Recent cases of air route cancellations include a number of Chinese domestic markets such as Nanjing-Shanghai, Zhengzhou-Xi’an, Changsha-Guangzhou and Wuhan-Nanjing. Deep cuts of airfares after the entry of HSR service are also very common. For example, the market between Wuhan and Xiamen, two Chinese cities recently linked by HSR, saw an 80% drop in air ticket price. As a result, the three major Chinese airlines all posted miserable financial reports in 2013 (net profits dropped 32 percent for Air China, 25 percent for China Eastern Airlines, and 24 percent for China Southern Airlines). In fact, China's HSR now moves twice as many passengers as its airline industry. The Chinese carriers are not alone in this gloomy weather. For the first time ever, HSR has outpaced air travel in Spain. Figures released by the National Statistics Institute (INE) in 2014 show that 1.9 million people used the country's extensive AVE network in January compared with 1.8 million people who bought plane tickets. This represents a 7.3-percent year-on-year drop for airplane travel and a 22-percent rise in HSR journeys.
Capacity reduction and price cut are both short-term responses by airlines when they confront the direct competition from HSR. Virtually all of the existing literature on the air transport–HSR interaction has focused on such short-run impacts. For example, Gonzalez-Savignat (2004) indicates that HSR service significantly reduces the market share of air transport when the two modes compete head-on. Park and Ha (2006) find that the opening of the first HSR line in South Korea has a significant (negative) impact on the domestic air transport industry. Adler et al. (2010) use a game theory setting to analyze aviation-HSR competition in the medium- to long- distance transport markets. With a short-run model focusing on traffic and price, they conclude that the European Union should encourage development of the HSR network across Europe. Yang and Zhang (2012) show that if the objective of HSR operator is to maximize a weighted sum of welfare and profit, both airfare and HSR fare fall as the weight on welfare rises; furthermore, airfare decreases, but HSR fare increases, in the airport access time. Jiang and Zhang (2014) show that cooperation between airline and HSR reduces traffic in markets where prior modal competition occurs, but may increase traffic in other markets of the network.

However, once established, competition from HSR will likely stay; therefore, airlines need to come up with strategies to compete against HSR in the long run. In this paper, we examine, analytically, two long-term airline strategies: (1) network structure; (2) market coverage. Consider network structure first, which involves a large amount of initial investment and once established, is hard to change. On the other hand, some airlines may still be able to restructure their network structure, in particular, from fully connected (FC) to hub-and-spoke (HS). Usually, network structure is relatively constant unless some major events, such as airline deregulation, happen.74 Many carriers in the world, such as the Chinese airlines, are still using the fully connected network. The fierce competition

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74 The Airline Deregulation Act of 1978 has led most of major US airlines to shift from a fully connected network to a hub-and-spoke network (e.g., Levine, 1987; Borenstein, 1992; Zhang et al., 2011). The deregulation of European airlines in between 1993 and 1997 played a similar role.
from HSR is likely to be a major event that causes changes in airline network structure. As for the decision on market coverage, one of the most important features of aviation is its extensive network coverage. Unlike HSR, which is economically viable only for certain trunk markets due to substantial fixed costs involved in infrastructure building, airlines can serve many smaller markets with positive margins, hence creating a much more extensive network from which some network-specific benefits (such as higher service frequency and economies of traffic density) are available. One possible competitive strategy by airlines is to target markets that they have previously ignored. The small local markets and the international markets may be less profitable or more costly to serve than the domestic trunk markets, but these markets may help airlines avoid the cutthroat competition from HSR.\textsuperscript{75}

In this paper, we study the long-run response of an airline when facing the entrance of HSR into its domestic trunk market, with network structure and market coverage as its two potential strategies. In our analysis, we specifically incorporate the possible diminishing returns of the benefits from higher traffic density. Literature has pointed out that the benefits of higher traffic density on a particular route from both the demand side (increased service frequencies) and the cost side (economies of traffic density). However, the fact that these benefits are likely to diminish as the airline’s total traffic on the route increases is usually downplayed. In this paper we take into account this factor. We find that for a given network structure, when HSR enters the trunk route or there is an increase of HSR competitiveness, the airline will have a higher incentive to cover more regional (foreign) markets if the trunk market is larger or the network of the airline is closer to hub-and-spoke. And this effect is more prominent when the diminishing rate of the benefits from higher air traffic density is higher. On the other hand, for any given market

\textsuperscript{75} CAPA (2013) suggests that for Chinese airlines, international yields are often significantly lower than domestic yields, and international services are often unprofitable. This is mainly due to the fact that Chinese airlines are not as competitive as other airlines in the international markets. So far there is not any HSR service between China and other countries.
coverage level, it would be more likely for the airline to move towards hub-and-spoke network as a response to the entry or competitiveness increase of HSR when the trunk market is larger, or when the airline covers more regional (foreign) markets. This effect is also more prominent when the diminishing rate of the benefits from higher air traffic density is higher. These findings should provide helpful guidelines for airlines facing competition from HSR. In fact, some of the theoretical predictions have been observed in reality.\textsuperscript{76}

The paper is organized as follows. Section 4.2 sets up the basic model. Section 4.3 analyzes airlines’ long-term decisions of network structure and market coverage under HSR competition. Section 4.4 contains concluding remarks.

4.2 Model

We consider a network that is probably the simplest in which the issues can be addressed. As depicted in Figure 4.1, the transportation network has two major domestic cities $H$ and $K$ and a number of homogeneous cities $C_i$.\textsuperscript{77} Assume that there is only one airline and one HSR operator, both of which can serve the “trunk” route $HK$. Meanwhile, the other cities can be linked with $H$ and $K$ by the airline only. In this setting, $C_i$ can be either small domestic cities or foreign cities.\textsuperscript{78} When linked with the two major cities, a specific city $C_i$ will generate two markets $C_iH$ and $C_iK$. To keep our discussion consistent, we refer to

\textsuperscript{76} This paper is the first analytical attempt to study the long-term strategies of airlines in the era of HSR competition. Focusing on the Chinese market, Fu et al. (2012) argue, qualitatively, that facing the competitive pressure from HSR, the Chinese airlines need to transform their current fully connected networks to effective hub-and-spoke networks in order to expand network coverage, and rely more on demands from small- and medium-size airports as well as international markets.

\textsuperscript{77} Throughout this paper, we assume that there are a very large number of such cities.

\textsuperscript{78} In the case of small cities, HSR cannot serve $C_i$ because the fixed cost to serve a market is much higher for the HSR than for the airline. In particular, it is more costly for the HSR to build its infrastructure (tracks, etc.). Therefore, it requires a larger market for the HSR to enter a particular market. Airlines, on the other hand, are more flexible and nimble. Since they normally do not need to pay for the infrastructure (airports, air traffic control, etc.) it is relatively easy for them to enter or exit a particular market. In the case of foreign cities, HSR cannot reach $C_i$ mainly due to geographical or political reasons.
these markets as fringe markets in the following text. For simplicity, we assume that there is no travel demand between \( C_i \) and \( C_j \), \( \forall i, j \). Examples for this setting include China where \( H \) and \( K \) denote Beijing and Shanghai, as well as Spain where \( H \) and \( K \) denote Madrid and Barcelona.

**Figure 4.1 Network Structure**

Following, e.g., Brueckner (2004), Brueckner and Flores-Fillol (2007) and Flores-Fillol (2009), we assume that the “full price” of travelling is given by:

\[
p_o^k = p_o^k + D(f_o^k) + t_o^k
\]

with subscripts \( o = A \) or \( R \) indicating the transport operator (A for airline and R for rail), and superscripts \( k \) indicating the market (\( HK, CiH \) or \( C_iK \)). \( p_o^k \) is the ticket price. \( f_o^k \) is the service frequency, whereas \( D(f_o^k) \) is the schedule delay cost with \( D(f_o^k) > 0 \) and \( D'(f_o^k) < 0 \) and \( D''(f_o^k) \geq 0 \). It should be noted that the second order derivative

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79 This assumption is reasonable because the demand between any two small domestic cities is usually very low or negligible, and the route between two foreign cities may not be served by the airline directly due to lack of freedom of air.

80 “Schedule delay” is defined as the difference between the actual and the preferred departure/arrival time, which is negatively related with the frequency of the transport mode taken, because the higher the frequency, the closer an average passenger can schedule his/her actual arrival time to the preferred point. It should be noted that to achieve \( D'(f_o^k) < 0 \), we need to assume that passengers must commit to travel before knowing their preferred departure/arrival times, which are uniformly distributed around a circle, following papers like Brueckner (2004) and Brueckner and Flores-Fillol (2007). If we adopt a different assumption, this first order characteristic of the schedule delay cost may not hold anymore. For example, if the passengers have similar time-of-day preferences, adding flights/train trips at the beginning or end of the
condition of \( D_o(f_o^k) \) is largely ignored by literature, due to the fact that most of the results only rely on the first order derivative. However, a few papers have realized that the decrease of schedule delay cost should not be linear. For example, Hansen (1990) uses a logarithmic form for the benefit of service frequency because “one would expect diminishing returns with respect to the gain in service attractiveness from adding additional flights.” \( t_o^k \) is the remaining part of the total passenger travel cost and assumed to be uniform and also normalized to 0. For simplicity we assume that the load factors for both the airline and the HSR are always 100%, and both modes only utilize one type of vehicle. In other words, we have \( f_o^k = Q_o^k / s_o \), with a fixed number \( s_o \) denoting the number of passengers a full vehicle (aircraft or high-speed train) can take. Therefore, we have \( D(f_o^k) = D_o(Q_o^k) \) with \( D_o(Q_o^k) > 0 \), \( D_o'(Q_o^k) < 0 \) and \( D_o''(Q_o^k) \geq 0 \). In this case, equation (4.1) becomes

\[
P_o^k = p_o^k + D_o(Q_o^k)
\]

Consider first the fringe markets that are not subject to the HSR competition. We assume that the markets are facing the same downward sloping demand, i.e., \( P_{li}^{ui}((q_{li}^{ui})) = P_{li}^f((q_{li}^{ui})) \), where \( l = H \) or \( K \), \( i \) denotes city \( C_i \), and \( P_{li}^f((q_{li}^{ui})) < 0 \). The small cities can be served by the airline in two different types of network structure: fully connected (FC) or hub-and-spoke (HS). When congestion at airports \( H \) and \( K \) is not an issue (as is the case for the present paper), it is easy to see that the airline will only use one of the two major cities as its hub. For simplicity (and without loss of generality) we assume that the hub airport is \( H \) if the HS network is adopted. For simplicity, we assume that if a small city is covered, it will be linked with both \( H \) and \( K \) and the resulting two markets are symmetric. We depict these two airline network structures in Figure 4.2.
Given the symmetry, in the FC network the airfare is equivalent for both markets and equals to:

$$p_A^{i_l} = P^F_A(q_A^{i_l}) - D_A(q_A^{i_l})$$  \hspace{1cm} (4.2)$$

On the other hand, in the HS network, the $C_iH$ and $C_iK$ markets are no longer symmetric. Here we assume that the schedule delay cost of a connecting flight equals the sum of the two schedule delay costs (Fageda and Flores-Fillol, 2013).\textsuperscript{81} So the ticket prices are:

\textsuperscript{81} It should be noted that other ways of modeling may exist, such as assuming that the schedule delay cost
\[ p_{ij}^{iH} = p^{iF}_{A}(q^{iI}_{A}) - D_{A}(q^{iH}_{A} + \sum_{l=1}^{N} q^{lK}_{A}) \]  
(4.3)

\[ p_{ij}^{iK} = p^{iF}_{A}(q^{iI}_{A}) - D_{A}(q^{iK}_{A}) - D_{A}(q^{T}_{A} + q^{lK}_{A}) \]  
(4.4)

where \( N \) denotes the number of fringe markets that are covered in the HS network. Naturally \( N \) must be smaller than the total number of potential fringe markets.

The operating cost per passenger of a route, \( c_{o}(Q^{k}_{o}) \), also depends on the traffic level, with \( c_{o}(Q^{k}_{o}) > 0 \), \( c_{o}'(Q^{k}_{o}) < 0 \) and also \( c_{o}''(Q^{k}_{o}) \geq 0 \). The first order conditions are descriptions of the economies of traffic density in both the air transport and the rail transport sectors (see Jiang and Zhang, 2014, and the references cited there). And the second order condition is an explicit modeling of the decreasing density economies, i.e., the per-passenger operating cost on a route is a convex downward function of the traffic volume on this route (e.g., Brueckner and Spiller, 1994).\(^82\) In other words, we can denote \( C_{o}(Q^{k}_{o}) = c_{o}(Q^{k}_{o}) + D_{o}(Q^{k}_{o}) \), and we still have \( C_{o}(Q^{k}_{o}) > 0 \), \( C_{o}'(Q^{k}_{o}) < 0 \) and \( C_{o}''(Q^{k}_{o}) \geq 0 \). Throughout the following context, we’ll refer to the increasing returns to traffic density as the traffic density benefits, and according to our setting the benefits might have a diminishing rate. It should be noted that regularity conditions discussed in papers like Zhang (1996) and Brueckner (2001) need to be satisfied to ensure that the cost function is well behaved. For analytical clarity, we further assume that \( C_{A}''(Q) \) is constant.\(^83\) In other words, we have \( C_{A}'(Q) = -\beta + \theta Q \), as well as \( C_{A}(Q) = \alpha - \left( \beta - \frac{\theta}{2} Q \right) Q \), where \( \theta \) can be interpreted as the decreasing rate of the density economies.

Note that this functional form is not necessary for many of the analytical results, but will

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\(^{82}\) Brueckner and Spiller (1994) test a few specifications for the marginal cost of US airlines on a particular spoke, including a quadratic function of the spoke traffic level. This specification has the highest log likelihood value (indicating best fit), and the coefficient of the quadratic term is, although quite small, significantly positive.

\(^{83}\) For simplicity, we’ll use \( C_{A}'' \) instead of \( C_{A}'''(Q) \) in the following text.
be helpful for the clarity of the economic interpretation. Since the airline traffic in the fringe markets is small, we can reasonably assume that $2C_A'(q_A^{iH} + q_A^{iK}) + (q_A^{iH} + q_A^{iK})C_A'' < 0, \forall i$. But this might not be applicable to the trunk market when the market size is large, in which case we might have $C_A'(q_A^T + \sum_{i=1}^N q_A^{iK}) < 0$ but $2C_A'(q_A^T + \sum_{i=1}^N q_A^{iK}) + (q_A^T + \sum_{i=1}^N q_A^{iK})C_A'' > 0$.  

Now turn to the trunk market $HK$. This market is subject to the potential competition from an HSR operator. Therefore, the inverse demand is a function of both the air traffic and the HSR traffic $P_A^T = P_A^T(q_A^T, q_R^T)$, with $\frac{\partial P_A^T}{\partial q_A^T} < 0$, $\frac{\partial P_A^T}{\partial q_R^T} < 0$ as well as $\frac{\partial P_A^T}{\partial q_A^T} < \frac{\partial P_A^T}{\partial q_R^T}$. We use $T$ to denote the market size parameter, and we have $\frac{\partial q_A^T}{\partial T} > 0$ given all other parameters.

Following Oum et al. (1995), we consider hubbing as a continuous decision denoted by the “infinitesimal hubbing” parameter $\delta$. $\delta$ is bounded by 0 and 1. In particular, when $\delta = 0$, the airline adopts a pure FC network; while when $\delta = 1$, the airline network is purely HS. In our setting, $\delta$ can be interpreted as the percentage of traffic in fringe cities that are connected with the major cities with a HS network. So the final profit function of the airline is:

$$\pi_A = q_A^T P_A^T(q_A^T, q_R^T) + \sum_{i=1}^N [q_A^{iH} P_A^F(q_A^{iH}) + q_A^{iK} P_A^F(q_A^{iK})]$$

$$- \left( q_A^T + \delta \sum_{i=1}^N q_A^{iK} \right) C_A(q_A^T + \delta \sum_{i=1}^N q_A^{iK})$$

$$- \sum_{i=1}^N \left( q_A^{iH} + \delta q_A^{iK} \right) C_A(q_A^{iH} + \delta q_A^{iK}) - (1 - \delta) \sum_{i=1}^N q_A^{iK} C_A(q_A^{iK}) \quad (4.5)$$

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84 These two assumptions are needed for the following analysis.

85 Another way to interpret $\delta$ is the percentage of fringe markets that are connected to the major cities with the HS network. Under this interpretation the profit function of the airline will be a bit different, but all the qualitative results will still hold given the assumption of indistinguishable fringe markets.
The airline first makes long-term decisions, i.e., the network structure \( \delta \) and the market coverage \( N \). Given these long-term decisions, the airline then decides on the traffic offered to different markets. If the HSR is also in the trunk market \( HK \), the two companies would engage in Cournot competition.

### 4.3 Airline Decisions

#### 4.3.1 Airline traffic

Let’s first consider the last stage of the airline’s decision-making. The first order conditions with respect to the traffic levels for the airline in the trunk market as well as the fringe markets are given by equations (4.6)-(4.8):

\[
P_A^T(q^T_A, q^T_K) + q^T_A \frac{\partial P_A^T}{\partial q_A} - \frac{C_A(q^T_A + \delta \sum_{i=1}^{N} q^iK_A^*)}{C_A'}(q^T_A + \delta \sum_{i=1}^{N} q^iK_A^*) = 0
\]  
(4.6)

\[
P_A^K(q^K_A^H) + q^K_A^H P_A^H(q^K_A^H) - \left[C_A(q^H_A + \delta q^iK_A^*) + (q^H_A + \delta q^iK_A^*)C_A'(q^H_A + \delta q^iK_A^*)\right] = 0
\]  
(4.7)

\[
P_A^K(q^K_A^K) + q^K_A^K P_A^K(q^K_A^K) - \delta C_A(q^K_A + \delta \sum_{i=1}^{N} q^iK_A^*)
- \delta \left[C_A(q^H_A + \delta q^iK_A^*) + (q^H_A + \delta q^iK_A^*)C_A'(q^H_A + \delta q^iK_A^*)\right]
- (1 - \delta)\left[C_A(q^iK_A^*) + q^iK_A^*C_A'(q^iK_A^*)\right] = 0
\]  
(4.8)

The * in the superscripts denotes the equilibrium status. Note that due to homogeneity of the fringe markets, we will have \( q^H_A = q^iA^H \) and \( q^iK_A^* = q^iK_A^*, \forall i \). Therefore, equations (4.6) to (4.8) can be written as:
\[ P_A^T(q_A^*, q_K^*) + q_A^* \frac{\partial P_A^T}{\partial q_A^*} - C_A(q_A^* + \delta N q_A^K) - (q_A^* + \delta N q_A^K)C'_A(q_A^* + \delta N q_A^K) = 0 \]  
(4.6')

\[ P_A^H(q_A^H) + q_A^H P_A^H(q_A^H) - [C_A(q_A^H + \delta q_A^K) + (q_A^H + \delta q_A^K)C'_A(q_A^H + \delta q_A^K)] = 0 \]  
(4.7')

\[ P_A^K(q_A^K) + q_A^K P_A^K(q_A^K) - \delta [C_A(q_A^K + \delta N q_A^K) - (q_A^K + \delta N q_A^K)C'_A(q_A^* + \delta N q_A^K)] - \delta [C_A(q_A^K + \delta q_A^K) + (q_A^K + \delta q_A^K)C'_A(q_A^K + \delta q_A^K)] - (1 - \delta) [C_A(q_A^K) + q_A^K C'_A(q_A^K)] = 0 \]  
(4.8')

The second order condition is assumed to hold.\(^{86}\) This requires the Hessian Matrix of the airline profit with respect to the airline traffic levels in different markets to be negative semi-definite. From equations (4.6')-(4.8'), we can find out the relationships between the equilibrium traffic levels in the trunk market and the fringe markets, which are summarized in Lemma 4.1 as follows.

**Lemma 4.1** If the trunk route traffic has reached a level of weak density benefit, the increase of traffic for the trunk market will decrease both types of fringe market traffic, for any given network structure and market coverage.

Proof: Taking derivative of (4.6') with respect to \(q_A^T\), we have

\[
\frac{\partial^2 \pi_A}{\partial q_A^T^2} - \delta N \left[ 2C'_A(q_A^* + \delta N q_A^K) + (q_A^* + \delta N q_A^K)C''_A(q_A^* + \delta N q_A^K) \right] \frac{\partial q_A^K}{\partial q_A^T} = 0
\]

Given that \(\frac{\partial^2 \pi_A}{\partial q_A^T^2} \leq 0\) due to the second order condition, if \(2C'_A(q_A^* + \delta N q_A^K) + (q_A^* + \delta N q_A^K)C''_A(q_A^* + \delta N q_A^K) \geq 0\), we have \(\frac{\partial q_A^K}{\partial q_A^T} \leq 0\).

---

\(^{86}\) This condition doesn’t hold automatically due to the cubic nature of the cost function.
Similarly, taking derivative of (4.7') with respect to \( q_{A}^{*} \), we have
\[
\frac{\partial^{2} \pi_{A}}{\partial q_{A}^{H^{2}}} - \delta [2C_{A}'(q_{A}^{H^{*}} + \delta q_{A}^{K^{*}}) + (q_{A}^{H^{*}} + \delta q_{A}^{K^{*}})C_{A}''] \frac{\partial q_{A}^{K^{*}}}{\partial q_{A}^{H^{*}}} = 0
\]
Since \( \frac{\partial^{2} \pi_{A}}{\partial q_{A}^{H^{2}}} \leq 0 \) due to the second order condition and \( 2C_{A}'(q_{A}^{H^{*}} + \delta q_{A}^{K^{*}}) + (q_{A}^{H^{*}} + q_{A}^{K^{*}})C_{A}'' < 0 \), we have \( \frac{\partial q_{A}^{K^{*}}}{\partial q_{A}^{H^{*}}} > 0 \). Reciprocally, we should always have \( \frac{\partial q_{A}^{H^{*}}}{\partial q_{A}^{K^{*}}} > 0 \).

Therefore, if \( 2C_{A}'(q_{A}^{H^{*}} + \delta N q_{A}^{K^{*}}) + (q_{A}^{H^{*}} + \delta N q_{A}^{K^{*}})C_{A}'' \geq 0 \), we also have \( \frac{\partial q_{A}^{H^{*}}}{\partial q_{A}^{K^{*}}} \leq 0 \).

Q.E.D.

Lemma 4.1 reveals the relationship between different markets. The trunk market \( HK \) is only linked with the \( C_{i}K \) markets through the (partial) HS network, while its impact on the \( C_{i}H \) markets will have to go through the \( C_{i}K \) markets. We can easily see that if the airline adopts a pure FC network, the three types of markets are independent from each other. The traffic density benefit plays a crucial role in the relationship between markets. When it is strong, an increase of \( HK \) market traffic will be able to significantly reduce the unit cost on the trunk route, enhancing the incentive of the airline to increase also the \( C_{i}K \) markets traffic which also (partially) go through the trunk route. However, if the density benefit already quite weak on the trunk route due to the huge amount of traffic that has existed, adding more traffic will no longer be able to reduce unit cost of serving this route significantly. In this case, the airline may decrease the traffic of the \( C_{i}K \) markets instead to balance the increase of traffic in the \( HK \) market. For the \( C_{i}H \) routes, the traffic density benefit is relatively large due to the small amount of traffic, so the equilibrium traffic in the \( C_{i}H \) markets will always move towards the same direction as the corresponding \( C_{i}K \) markets equilibrium traffic.

4.3.2 Long-term decisions

Now let’s turn to the long-term decisions. In this paper we consider the two long-term
strategies, network structure and market coverage, to be independently decided. In other words, when we consider one decision, we assumed the other is held constant. It should be noted that the results that we obtain in this section not only give hints for the circumstances when one strategy is not readily available but also largely hold even if these two long-term decisions are made simultaneously. According to the Envelope Theorem, we can derive the first order conditions of the airline with respect to $N$ and $\delta$, which are given by:

$$
[q_H^* P_A^F(q_H^*) + q_K^* P_A^F(q_K^*)] - \delta q_K^* C_A(q_A^T + \delta N^* q_A^K) \\
- \delta q_A^* (q_A^T + \delta N^* q_A^K) C_A(q_A^T + \delta N^* q_A^K) - (q_A^H) \\
+ \delta q_K^* C_A(q_A^H + \delta q_A^K) - (1 - \delta)(q_K^* C_A(q_A^K)) = 0
$$

(4.9)

$$
-N q_K^* C_A(q_A^T + \delta N q_A^K) - N q_A^K (q_A^T + \delta N q_A^K) C_A(q_A^T + \delta N q_A^K) \\
+ N q_K^* [C_A(q_A^K) - C_A(q_A^H + \delta q_A^K)] \\
- (q_A^H + \delta q_A^K) C_A(q_A^H + \delta q_A^K)] = 0
$$

(4.10)

Again, second order conditions are assumed to hold. In particular, we need to assume that $\frac{\partial^2 \pi_A}{\partial N^2} \leq 0$ and $\frac{\partial^2 \pi_A}{\partial \delta^2} \leq 0$, respectively.

Next let’s focus on the impact of HSR competition on the airline’s network decision and market coverage. Denote the competitiveness of HSR with a continuous parameter $\gamma$, with $\gamma \geq 0$. When $\gamma = 0$, HSR is very uncompetitive and thus excluded from the trunk market. The larger $\gamma$ is, the more competitive the HSR is in the trunk market. In other word, the increase of $\gamma$ from 0 to any positive number can also be interpreted as the entry

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87 It can also be interpreted as the case when no HSR project is viable in the trunk market due to various reasons such as technology and politics.

88 For a particular HSR, the increase of $\gamma$ may be due to improvements in technology, operation or management. For example, due to safety concern, many of the HSR lines in China are running at a speed far below the maximum design level, which means that it is feasible to increase the attractiveness of rail travel by increasing operating speed.
of HSR into the trunk market. Therefore, other things equal, we should have \( \frac{\partial q^T_R}{\partial y} > 0 \) and \( \frac{\partial q^T_A}{\partial y} < 0 \).

From equations (4.9) and (4.10), it is straightforward to obtain the following propositions 4.1 and 4.2.

**Proposition 4.1** If the network structure of the airline is exogenously given, an increase of HSR competitiveness will more likely push the airline to cover more fringe markets when the trunk market is larger, or when the network of the airline is closer to hub-and-spoke. And this effect is more prominent when the diminishing rate of the airline’s traffic density benefit is higher.

Proof: Taking derivative of (4.9) with respect to \( \gamma \), we have

\[
-\delta q_A^K \left[ 2C_A(q_A^T + \delta N^* q_A^K) + (q_A^T + \delta N^* q_A^K)C_A' + \hat{x} \frac{\partial q_A^{H*}}{\partial q_A^T} + \hat{y} \frac{\partial q_A^{K*}}{\partial q_A^T} \right] \frac{\partial q_A^T}{\partial y} + \frac{\partial^2 \pi_A}{\partial N^* \partial y} = 0
\]

where

\[
\hat{x} = P_A^F(q_A^{H*}) + q_A^{H*} P_A^{F*}(q_A^{H*}) - C_A(q_A^{H*} + \delta q_A^K) - (q_A^{H*} + \delta q_A^K)C_A'(q_A^{H*} + \delta q_A^K) = 0
\]

according to equation (4.7').

\[
\hat{y} = P_A^F(q_A^{K*}) + q_A^{K*} P_A^{F*}(q_A^{K*}) - \delta C_A(q_A^{H*} + \delta N q_A^K)
- \delta(q_A^{T*} + 3 \delta N q_A^K)C_A'(q_A^{T*} + \delta N q_A^K) - \delta^2 N^* q_A^K (q_A^{T*} + \delta N^* q_A^K)C_A''
- \delta C_A(q_A^{H*} + \delta q_A^K) - \delta(q_A^{H*} + \delta q_A^K)C_A'(q_A^{H*} + \delta q_A^K)
- (1 - \delta)[C_A(q_A^{K*}) + q_A^{H*} C_A'(q_A^{K*})]
= -\delta(q_A^{T*} + 2 \delta N^* q_A^K)C_A'(q_A^{T*} + \delta N^* q_A^K)
- \delta^2 N^* q_A^K (q_A^{T*} + \delta N^* q_A^K)C_A''
\]
According to equation (4.8').

Given that \( \frac{\partial^2 \pi_A}{\partial N^2} \leq 0 \), we have \( \frac{\partial N^*}{\partial \gamma} > 0 \) as long as

\[
2C_A'(q_A^T + \delta N^* q_A^K) + (q_A^T + \delta N^* q_A^K)C_A'' + \gamma \frac{\partial q_A^K}{\partial q_A^T} > 0
\]

According to Lemma 4.1, \( \frac{\partial q_A^K}{\partial q_A^T} \leq 0 \) if \( 2C_A' \left( q_A^T + \delta N^* q_A^K \right) + (q_A^T + \delta N^* q_A^K)C_A'' \geq 0 \).

In order to get a more clear result, we impose the functional form of \( C_A(Q) = \alpha - \left( \beta - \frac{\theta}{2} Q \right) Q \) and have:

\[
2C_A' \left( q_A^T + \delta N^* q_A^K \right) + (q_A^T + \delta N^* q_A^K)C_A'' = -2\beta + 3(q_A^T + \delta N^* q_A^K)\theta
\]

\[
\hat{y} = -\delta\left[ (q_A^T + 2\delta N^* q_A^K)C_A' \left( q_A^T + \delta N^* q_A^K \right) + \delta N^* q_A^K (q_A^T + \delta N^* q_A^K)C_A'' \right]
\]

\[
= -\delta\left[ -(q_A^T + 2\delta N^* q_A^K)\beta + (q_A^T + \delta N^* q_A^K)(q_A^T + 3\delta N^* q_A^K)\theta \right]
\]

It is clear that when \( q_A^T \) or \( \delta \) is larger, it is more likely for \( 2C_A' \left( q_A^T + \delta N^* q_A^K \right) \) + \( (q_A^T + \delta N^* q_A^K)C_A'' > 0 \) as well as \( \hat{y} < 0 \). In other words, it is more likely that \( \frac{\partial N^*}{\partial \gamma} > 0 \).

Other things equal, the larger the trunk market size \( T \) is, the larger \( q_A^T \) will be.

On the other hand, the larger \( \theta \) is, the stronger this result holds, since \( \theta \) is a multiplicative term to both \( q_A^T \) and \( \delta \).

Q.E.D.

**Proposition 4.2** If the market coverage of the airline is exogenously given, an increase of the HSR competitiveness will more likely move the airline towards hub-and-spoke network when the trunk market is larger, or when more fringe markets are covered. And this effect is more prominent when the diminishing rate of the airline’s traffic density benefit is higher.
Proof: Taking derivative of (4.10) with respect to $ߛ$, we have

$$-Nq_A^{K^*} \left[ 2C'_A(q_A^{T^*} + \delta^* Nq_A^{K^*}) + (q_A^{T^*} + \delta^* Nq_A^{K^*})C''_A + \bar{x} \frac{\partial q_A^{H^*}}{\partial q_A^{T^*}} + \bar{y} \frac{\partial q_A^{K^*}}{\partial q_A^{T^*}} \right] \frac{\partial q_A^{T^*}}{\partial y}$$

$$+ \frac{\partial^2 \pi_A}{\partial \delta^2} \frac{\partial \delta^*}{\partial y} = 0$$

where

$$\bar{x} = -Nq_A^{K^*} \left[ 2C'_A(q_A^{H^*} + \delta^* q_A^{K^*}) + (q_A^{H^*} + \delta^* q_A^{K^*})C''_A \right] > 0$$

$$\bar{y} = -\delta^* N \left[ 2C'_A(q_A^{T^*} + \delta^* Nq_A^{K^*}) + (q_A^{T^*} + \delta^* Nq_A^{K^*})C''_A \right] - \delta^* \left[ 2C'_A(q_A^{H^*} + \delta^* q_A^{K^*})C''_A \right] + (q_A^{H^*} + \delta^* q_A^{K^*})C''_A + C'_A(q_A^{K^*})$$

Given that $\frac{\partial^2 \pi_A}{\partial \delta^2} \leq 0$, we have $\frac{\partial \delta^*}{\partial y} > 0$ as long as

$$2C'_A(q_A^{T^*} + \delta^* Nq_A^{K^*}) + (q_A^{T^*} + \delta^* Nq_A^{K^*})C''_A + \bar{x} \frac{\partial q_A^{H^*}}{\partial q_A^{T^*}} + \bar{y} \frac{\partial q_A^{K^*}}{\partial q_A^{T^*}} > 0$$

In order to get a more clear result, we impose the functional form of $C_A(Q) = \alpha - \left( \beta - \frac{\theta}{2} Q \right) Q$ and have:

$$2C'_A(q_A^{T^*} + \delta^* Nq_A^{K^*}) + (q_A^{T^*} + \delta^* Nq_A^{K^*})C''_A = -2\beta + 3(q_A^{T^*} + \delta^* Nq_A^{K^*})\theta$$

$$\bar{y} = -\delta^* N \left[ -2\beta + 3(q_A^{T^*} + \delta^* Nq_A^{K^*})\theta \right] - \delta^* \left[ -2\beta + 3(q_A^{H^*} + \delta^* q_A^{K^*})\theta \right] + \left[ -\beta + q_A^{K^*} \theta \right]$$

It is clear that when $q_A^{T^*}$ or $N$ is larger, it is more likely for $2C'_A(q_A^{T^*} + \delta^* Nq_A^{K^*}) + (q_A^{T^*} + \delta^* Nq_A^{K^*})C''_A$ as well as $\bar{y} < 0$. In other words, it is more likely that $\frac{\partial \delta^*}{\partial y} > 0$.

Other things equal, the larger the trunk market size $T$ is, the larger $q_A^{T^*}$ will be.

On the other hand, the larger $\theta$ is, the stronger this result holds, since $\theta$ is a multiplicative
term to both \( q^*_a \) and \( \delta \).

\[Q.E.D.\]

Proposition 4.2 provides another explanation for why HS network system doesn’t exist in some of the major aviation markets in the world. On the one hand, when an airline is facing large trunk markets, it might lack the incentive to work very hard to develop a HS system and to cover more fringe markets, given that these will only bring relatively minor benefits. On the other hand, if the traffic density benefit diminishes quickly, it will not be worthwhile for the airline to adopt a HS network or to cover more fringe markets, because concentrating traffic from the fringe markets to the trunk route will not decrease the marginal operating cost very much, particularly when the trunk market is in itself sufficiently large to realize the density benefit. These two features describe the Chinese aviation market well. First, it has big fat trunk markets such as Beijing-Shanghai, Shanghai-Guangzhou, and Beijing-Shenzhen. Meanwhile, due to regulations, most of the Chinese domestic markets are still dominated by one or two airlines, which means that these dominant airlines can obtain the traffic density benefit on the trunk routes to a very high degree. Second, airspace control by the military that frequently grounds air flights is an important feature of the Chinese aviation industry. It significantly limits the potential of the Chinese airlines to utilize the density benefit. Therefore, all of the Chinese airlines are still in \textit{de facto} FC networks.

The two propositions describe how an airline will respond to the entry or competitiveness increase of HSR in its trunk market. When the diminishing rate of the airline’s traffic density benefit is high, the decrease of airline traffic in the trunk route due to the entry or competitiveness increase of the HSR can possibly lower the air traffic to a level that can

\[89\] Among the 50 busiest routes based on total number of seats per month flown in both directions as of April 2014, 8 are domestic routes in China.

\[90\] In fact, China’s major airports have earned the title of the most-delayed in the world, where passengers sometimes riot to protest long waits and miserable customer service.
better realize the benefit of traffic density, thus increasing the incentive of the airline to concentrate more traffic on the trunk route. Besides, the larger the trunk market is, the more important it is to the airline. Therefore, the airline will have a higher incentive to shift to HS network and cover more fringe markets, so that it can boost up the traffic on the trunk route to compete with the HSR. From the propositions we can also see that the two strategies are mutually reinforcing, because when more fringe markets are covered, to move closer to the HS network will direct more traffic to the trunk route; while when the network is closer to the HS system, covering one more fringe market can also play the same role.

In fact, the theoretical prediction of Proposition 4.1 fits the case of China quite well. Facing the competition pressure from a rapidly growing HSR sector, most of the Chinese airlines are now seeking opportunities abroad and avidly developing their international markets. It is argued that among all the major airlines in China, Air China should be the least affected by HSR, since it has the highest exposure to the international markets (Wu and Ross, 2013). Other examples include Spain, where Iberia Airline increased its market coverage and its shares in other domestic markets after the opening of Madrid-Barcelona HSR link (Jiménez and Betancor, 2011); as well as Japan, where both All Nippon Airways and Japanese Airlines paid more attention to the international markets when facing the fierce competition of Shinkansen.

It has been reported that the high-speed market share in routes where air competition is very strong does not reach the levels usually obtained in previous European high-speed links where competition from air transport was less important (Lopez Pita et al., 2012). One possible explanation for this observation is that the predictions all focused on the short-run decisions such as traffic and price, but the airlines have adopted long-run strategies to battle HSR in important trunk routes. In other words, this paper suggests that

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91 In Oct 2013, international traffic at the Chinese “Big Three” -- Air China, China Southern Airlines and China Eastern Airlines, increased to 23% (compared with 18% one year earlier), outpacing mid-single-digit growth in domestic traffic (Chiu, 2013). And a lot of new international routes have been opened by the Chinese airlines in the past few years.
in order to predict or evaluate the impacts of HSR on the air sector and also the total social welfare level, longer-term analysis is also needed.

We can see a clear difference that HS network makes for the airline from the comparison between European and Asian cases. Despite a short flying distance of only 500 km, half of the travellers on the Madrid-Barcelona route fly. This is in contrast to only airline’s 20% market share in the Tokyo-Osaka route (515 km) and 38% in the Guangzhou-Changsha route (550 km). The distance from London to Paris is only 322 km, but air transport has preserved 25% market share. In contrast, airlines in Asia are unable to compete with HSR in a short-haul route like this and completely exited the market. This significant difference is partially due to the fact that European airlines have developed mature HS system, while most of the Asian airlines (especially in Japan and China) are still using FC networks.

4.4 Concluding Remarks

In this paper we investigate the long-term impacts of high-speed rail (HSR) competition on airlines. A theoretical model has been developed to study how the market coverage and the network choice of an airline will respond to HSR competition on origin-destination trunk routes. We find that when HSR enters or has a competitiveness increase in the trunk market of an airline, the airline will have a greater incentive to cover more regional (or foreign) markets if the trunk market is larger or the airline network is closer to a hub-and-spoke system. This effect is more prominent when the diminishing rate of the airline traffic density benefits is higher. Furthermore, for any given market coverage level, it is more likely for the airline to move towards hub-and-spoke network (from fully connected network) when the trunk market is larger, or when the airline covers more regional (or foreign) markets. This effect is also more prominent when the diminishing rate of the airline traffic density benefits is higher.

These findings might offer important insights for airlines that are struggling with the competition from HSR. Network structure can be a powerful weapon in the long run. Nowadays it has almost been a norm for the full-service carriers to adopt HS system fully.
or partially. However, many carriers in the world, such as the Chinese airlines, are still using the fully connected network. The fierce competition from HSR may be a trigger for these airlines to change their network structures. On the other hand, we might also expect to see some airlines in hub-and-spoke network to move a bit back to fully connected network under certain circumstances. Furthermore, these results may also have significant policy implications to the government. Airline network choice is highly related to government regulations. Policy makers might reach different conclusions for airline regulations when they also take into account the impacts of HSR competition.

A few assumptions have been made to simplify the analysis. It would be interesting to see whether the predictions of this model still hold if this assumption is relaxed in one way or another. Besides, given that HSR has existed in a few countries for a while, it would also be an interesting venue for future study to empirically test some of the predictions of this paper.

In this paper, we consider the network of the airline but not the HSR. This generally describes the current situation truthfully: it is easier and more flexible for the airlines to cover a larger network. However, nowadays in China (and some European countries like Spain to a lesser extent), we can also see the network of HSR. This network has some distinctive features compared with the aviation network, and might also play a role in affecting the airlines’ long-term network choice and market coverage. This can be an interesting research venue in the future.
5 Strategic Choice of Alliance Membership under Local Competition and Global Networks

5.1 Introduction

On June 21st, 2011, China Eastern Airlines officially joined the SkyTeam global airline alliance. It is the second major Chinese carrier in SkyTeam after Guangzhou-based China Southern Airlines. This decision came as a disappointment to Star Alliance and oneworld, the other two major global airline alliances, which had invited the Shanghai-based carrier as well. Air China, the other major Chinese airline, is a member of Star Alliance. It leaves oneworld without a partner in one of the world's fastest growing aviation markets.

Airline alliances play a crucial role in defining the modern aviation industry. Ever since the formation of the first major international alliance between Northwest Airlines and KLM in the early 1990s, the sizes of the wide-ranging airline alliances have been growing. At present, almost every major airline belongs to one of the three global alliances: Star Alliance, SkyTeam and oneworld, which together account for 70% of the world’s revenue passenger kilometers.

Interestingly, while whether an airline should seek membership in one of the global alliances has been heatedly discussed, a natural extension of the question, i.e., “which alliance to join”, seems to be largely ignored by the literature. Given that there are three major global alliances, after deciding to join an alliance, it must be a crucial step for the airline to determine which alliance partner to choose. For the airlines, the decision to join an alliance means not only potential gains but also substantial investments in

92 A version of this chapter has been accepted by and will be forthcoming in Journal of Transport Economics and Policy.

93 Cathay Pacific, a carrier based in Hong Kong, is a member of oneworld. However, although Hong Kong is officially a part of China, it is currently still under an independent administration due to historical reasons. Till now only a proportion of the Mainland Chinese are allowed to visit Hong Kong with permission. Therefore, Cathay Pacific has very limited access to the Mainland Chinese markets (only 20 cities in Mainland China are covered by its network as of August, 2014).
infrastructure and service in order to meet the requirements of the alliance and guarantee compatibility. These investments may be unredeemable once the relationship breaks down. On the other hand, the decision making of the global alliances has been neglected to an even more surprising level. Apparently, to get access to a larger market and fully utilize the power of network, it is also essential for the global airline alliances to attract the most suitable local partners and retain the relationship. In other words, a similar question, “which airline to take”, is also crucial from the alliances’ point of view. With respect to the Mainland Chinese market, oneworld is clearly in a weak position due to a lack of local partners.

What makes the problem more complicated and interesting is the fierce local and international competition after deregulation of the airline industry in many countries. It is clear that the alliance-joining decision of an airline will be affected not only by its complementarities with different alliances, but also by the reactions of its local competitors and their relationships with the alliances. Meanwhile, global alliances as “systems” are facing a certain level of direct (in attracting passengers in overlapped markets) and indirect (in attracting local partners for instance) competitions from each other (Zhang and Zhang, 2006; Reitzes and Moss, 2008). The “Big Three” legacy airlines in the United States (Delta Air Lines, United Airlines and American Airlines) belong to different global alliances (SkyTeam, Star Alliance and oneworld, respectively), while the “Big Three” in China (Air China, China Eastern Airlines and China Southern Airlines) only join two of the three major alliances (Star Alliance and Skyteam). These anecdotal facts suggest that airlines and alliances may not follow a unique pattern in forming partnerships. A guideline for analyzing these different scenarios is necessary and of significant importance.

In this paper, we propose a game theoretic model to analyze the partnership formation for local airlines and global alliances. Specifically, we consider two local airlines and two global alliances. Meanwhile, we allow each airline to join any of the two alliances and each alliance to take either or both airlines. We find that multiple equilibrium outcomes may exist if these four players are involved in a simultaneous game, but the number of possible equilibrium outcomes will decrease when the market size or the product
substitutability increases. On the other hand, if a sequential game is played, we show that when either the market size or the substitutability is relatively small, both local airlines will join the same alliance in equilibrium. Otherwise, both local airlines will stay independent.

Numerous studies have been dedicated to investigating the impact of airline alliances. A majority of the studies focus on the impacts of airline alliance on social welfare and related factors such as the equilibrium fares (e.g., Park, 1997; Park and Zhang, 1998, 2000; Park et al., 2001; Brueckner, 2001; Bilotkach, 2005). Little attention has been paid to the decision making of airlines on joining alliance and which alliance to join, not to mention the other end of the problem which is the decision making of alliances. As far as we know, Zhang and Zhang (2006) and Flores-Fillol and Moner-Colonques (2007) are the only attempts to focus on airlines’ decisions from an analytical perspective. In addition, Bilotkach (2005) offers some discussion about airlines’ incentives to form international alliances, while Gaggero and Bartolini (2012) empirically investigate the determinants of airline alliances. With a more general setting, Zhang and Zhang (2006) show that airlines will have an incentive to form complementary alliance with a degree of cooperation as high as possible, due to the within-alliance complementarity and the cross-alliance substitutability. Flores-Fillol and Moner-Colonques (2007) adopt a two-stage game in which airlines first decide whether to form an alliance and then determine the fare level. They show that partners sharing the same hub have an incentive to form a complementary alliance only if both product differentiation and economies of traffic density are sufficiently high. Bilotkach (2005) analyzes the effects of alliance formation (with or without antitrust immunity) on airfares and airline profits in a differentiated Bertrand model, based on which he provides a rationale for carriers’ incentives to form international alliances. In particular, he argues that even though it is possible for an airline’s profit to decrease after joining an alliance, airlines are still inclined to enter alliances due to Prisoners’ Dilemma. With a discrete choice model, Gaggero and Bartolini (2012) show that old, well-established airlines with large passenger volumes are more likely to participate in an alliance, and these airlines are also essential for the sustainability of the alliance. See Zhang and Czerny (2012) for a recent survey of the
relevant literature.

This paper goes one step further than Flores-Fillol and Moner-Colonques (2007). We study the decision-makings of airlines as well as alliances under more flexible interactive schemes. We try to identify all the possible pure-strategy Nash equilibria (for the simultaneous game) and sub-game perfect Nash equilibria (for the sequential game) so as to offer some insights for the real-world experiences and explain why some situations are more common than the others.

We make a few innovations in the modeling. First of all, we remove the constraint that partnership is only possible between certain pairs (Zhang and Zhang, 2006; Flores-Fillol and Moner-Colonques, 2007). Instead, we allow the possibility of all potential partnerships between local airlines and global alliances. In particular, the local airlines can join either alliance and the alliances can recruit either or both airlines. In other words, we are able to investigate more complicated interactions of the 4 players. Second, we treat local airlines and global alliances differently instead of simply imposing symmetry on them. Third, we examine a network that is more complex than the one adopted by Flores-Fillol and Moner-Colonques (2007), thus avoiding the possibility that some of the potential impacts of alliance partnership are ignored. All in all, our modeling captures many realistic features that have been simplified away by previous studies and thus has the potential to offer results that fit the reality better.

The paper is organized as follows. Section 5.2 sets up the basic model. Section 5.3 categorizes the potential equilibrium outcomes and presents comparisons of prices and profits between various equilibrium outcomes. Section 5.4 presents the equilibrium outcomes under various conditions in both a simultaneous game setting and a sequential game setting. Section 5.5 contains concluding remarks.

5.2 Model

Consider a network structure like Figure 5.1. The dashed line is a national borderline, i.e., points 1 and 2 denote domestic regions within a country, while points 3, 4 and 5 represent...
regions out of that country. There are two domestic local airlines, A and B, and two global airline alliances, H and K. We assume that due to freedoms of the air, flights between points 1 and 2 can only be operated by airlines A and B, while flights between points 3 and 4 (3 and 5) can only be served by alliance H (K). But all the 4 players can fly between points 2 and 3. In other words, the routes operated by A and B are totally overlapped, while the routes operated by H and K are only partially overlapped. Furthermore, the alliances need to work with the local airlines to enter the domestic market, and vice versa.

Figure 5. 1 Airline market network

This setting is representative. On the one hand, point 2 represents one or more domestic hub cities that are used by both local airlines as gateways to the outside world, while point 1 represents all the peripheral regions within the country. On the other hand, point 3 is an important international hub, or a collection of such international hubs, with the presence of both global alliances, while points 4 and 5 denote the regions specialized by one alliance only. An example of this setting is given as follows. Point 2 may represent New York JFK International Airport, used by American Airlines (airline A) and Delta Air Lines (airline B) as domestic hub; point 1 may represent a peripheral region within

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94 The network is a simplified version of the reality. There are multiple airlines in each global airline alliance, which thus operates a larger network than any local airline. In other words, our setting downplays the importance of global alliance. Therefore, we expect that compared with our model prediction, the local airlines might have a higher incentive while the global alliances will have a lower incentive in forging partnership in reality. But the qualitative conclusions should not be affected.
the United States, for instance Arizona (Phoenix Sky Harbor International Airport); Point 3 is London Heathrow International Airport, with the presence of both oneworld (to which airline A – American Airlines – belongs) and SkyTeam (to which airline B – Delta Air Lines – belongs). Assume that points 4 and 5 denote the regions specialized by one alliance only, e.g., Japan and Mainland China respectively. Japan Airlines belongs to oneworld, while no Chinese carrier is in this alliance; on the other hand, China Eastern Airlines (or China Southern Airlines) belongs to SkyTeam, while no Japanese carrier is in this alliance. In this setting, the routes operated by American Airlines and Delta Air Lines between Phoenix Sky Harbor International and New York JFK International Airport are totally overlapped while the routes operated by operators in oneworld and SkyTeam are only partially overlapped. Furthermore, the alliances need to work with the American local airlines to enter the U.S. domestic market, and vice versa.

Note that some simplifications have been made to avoid unnecessary complexity. Firstly, airlines within the same country do not always have fully overlapped networks. It is more likely that they compete fiercely in some parts of the country while act almost like local monopoly in others. However, it is undeniable that the main relationship between two airlines within one country is competition. Secondly, we largely ignore the inner network of a global alliance. Different from previous works, we specifically treat alliances as players. Therefore, the inner structure of the alliances is not our concern. This setting reflects arguably the most important reason for the existence of global alliances (Park, 1997; Wan et al., 2009): alliances allow airlines to expand their networks internationally while circumventing the regulatory and legal barriers that preclude airlines from actually operating in or between foreign countries.

Following Hackner (2000), we assume that passengers have a quadratic utility function:

$$
U = \sum_{m \in M} \left( \sum_{i \in I(m)} \alpha_i^m q_i^m \right) - \frac{1}{2} \left( \sum_{i \in I(m)} \beta_i^m \left(q_i^m\right)^2 + \gamma \sum_{i \in I(m)} \sum_{j \neq i} q_i^m q_j^m \right) \quad (5.1)
$$

Here we use superscript $m$ to denote round-trip markets. There is a set of nine possible markets: $M = \{12, 23, 34, 35, 13, 24, 25, 14, 15\}$. Each market has one and only one path.
and the notion of market and path are interchangeable in our setting. For example, market 15 needs to go through path 1-2-3-5. The subscript \( i \) is used to define itineraries (i.e., products in the round-trip markets; hereafter the terms ‘product’ and ‘itinerary’ will be used interchangeably), i.e., the combination of a series of links and their operators. \( I(m) \) is the set of possible itineraries for market \( m \). Given that for a particular market there is one and only one path, we’ll only need to denote who operates which part of the path. For example, market 14 has four possible itineraries: \( I(14) = \{AAH, AHH, BBH, BHH\} \), where AAH represents an itinerary with the local airline A operates flights from point 1 to point 2 as well as from point 2 to point 3, and the alliance H operates the flight from point 3 to point 4.

For simplicity, we assume \( \alpha_i^m = \alpha \) and \( \beta_i^m = 1 \) across all \( i \)'s and \( m \)'s. We also assume that if an itinerary can be operated by one single airline or alliance, passengers will not choose the itinerary operated by two different players. In other words, vertical quality differentiation will drive out some itineraries completely, and the itineraries remaining in the market are horizontally differentiated only. The parameter \( \gamma \), which ranges between 0 and 1, captures the degree of horizontal differentiation between itineraries in the same market. This product differentiation can be viewed as the result of brand loyalty (Brueckner and Whalen, 2000), which is assumed to be identical across markets. Therefore, connecting flights with any leg operated by different airlines will still be horizontally differentiated even if they are marketed by one single airline/alliance.

From (1), it is straightforward to derive the demand function for itinerary \( i \) in market \( m \):

\[
q_i^m = \frac{(\alpha - p_i^m)[(n_m - 2)\gamma + 1] - \sum_j\gamma^{\alpha - p_j^m}}{(1 - \gamma)[1 + (n_m - 1)\gamma]}
\]

where \( n_m \) denotes the number of itineraries available in market \( m \). We examine price instead of quantity competition. In this case, the two longest connecting markets (markets 14 and 15) require extra attention because the demand functions of the corresponding itineraries may be determined not by single prices but sums of “sub-fares” (Brueckner, 2001). For instance, when no partnership is formed between local airline and global
alliance, the price of itinerary AAH is a combination of two sub-fares \( p_{AAH}^{14} = p_{AA}^{13} + p_{H}^{34} \). On the other hand, if airline A joins alliance H, \( p_{AAH}^{14} \) will be endogenously determined by the joint venture of the two partners.

With respect to cost, to make the analysis simple, we’ll only discuss results under constant returns to traffic density in the main text. Specifically, we assume away the fixed cost and set the marginal operating cost of each player involved to be constant and – without loss of generality – equal to 1. However, a number of empirical studies, including Caves et al. (1984) and Brueckner and Spiller (1994), have established that economies of traffic density are significant in the airline industry. Accounting for this feature, we have also analyzed the model with economies of traffic density. In particular, if an airline joins an alliance, their traffic on a specific route will be pooled together to exhibit economies of traffic density. We find that this factor does not have a qualitative impact on the analysis. Therefore, we will not present this part of the analysis due to space limitation.\(^95\)

Within every partnership there will be one or multiple decision makers. It is suggested that antitrust immunity has become virtually the norm for participants in all major international airline joint ventures (Gillespie and Richard, 2012), so we model that any partnership between an airline and an alliance is able to obtain antitrust immunity and work together to set the price for all the markets in which they have parallel or complementary interactions. In other words, the partnership is a “joint-venture alliance”.\(^96\) However, different from a merger, an airline remains relatively independent

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\(^95\) A technical appendix containing the analysis of the case with economies of traffic density is available upon request from the authors. The following functional form has been used: \( C(\omega, W) = \omega [1 - (1/2)\delta W] \) where \( W \) is the total traffic of an airline/alliance and its allied partner(s) on a link, \( \omega \) is the traffic offered by that particular airline/alliance on that particular link, and \( \delta > 0 \) indicates the degree of density economies. Note that this setting is not exactly the same as the previous literature (i.e., Brueckner and Spiller, 1991; Zhang, 1996; Brueckner, 2001; Flores-Fillol and Moner-Colonques, 2007) because asymmetric traffic distribution is incorporated, but the underlying logic follows suit.

\(^96\) We consider a profit sharing joint venture without any concern of “carve-out” (Brueckner and Proost, 2010). In other words, the partnership is at the highest possible level. This might not apply to some real cases, but analysis with respect to an extreme (but common) cooperation form will generally have implications to more general conclusions. Besides, carve-out is still a controversial remedy and thus far
even after it joins an alliance. Take the partnership between A and H as an example. It is more reasonable to assume that A and H jointly maximize the profits from the code-shared connecting market and the hub-to-hub market like a joint venture, and separately maximize the other parts of their profits.\(^\text{97}\) Therefore, A and H are the operators of their independent markets (12, 13 and 34), while the joint venture AH is the operator of the collaborative markets (23, 24 and 14). Meanwhile, if the two local airlines join the same global alliance (e.g. partnership ABH or ABK), we assume that they are not allowed to set price together in markets where they are the only competitors (markets 12 and 13) due to the fact that antitrust immunity cannot be extended to domestic partners (Gayle, 2008; Cruise and Pettit, 2009). Let \(\Theta\) be a set of ten possible partnerships between local airlines and global alliances, i.e. \(\Theta = \{A, B, H, K, AH, AK, BH, BK, ABH, ABK\}\).\(^\text{98}\) Based on the above-mentioned rules, for every partnership \(\theta \in \Theta\), we can find a set of decision makers \(\Psi(\theta)\), while each decision maker \(\psi \in \Psi(\theta)\) decides the prices for a set of markets \(M(\psi)\). Similarly, itineraries can also be attributed to different decision makers in partnerships. In other words, there is a set of itineraries \(I(\psi)\) that are operated by a particular decision maker \(\psi\) in a particular partnership \(\theta\).

Before we present the objective functions, we’ll need to discuss the revenue sharing mechanism between the local airlines and the global alliances under cooperation, because it is the revenue sharing rule that determines the profits of the airlines and the alliances. Most of the theoretical studies in airline alliances assume that partners split the joint profit equally (Park, 1997; Bilotkach, 2007; Flores-Fillol and Moner-Colonques, 2007). One reason behind this treatment is that within a joint venture, the splitting of profit depends on the ownership structure of the company. If a partnership is formed between from common in reality (Reitzes and Moss, 2008; Bilotkach and Huschelrath, 2011).

\(^{97}\) This arrangement is common in the real world, as the major members of the three global airline alliances, Star Alliance, SkyTeam and oneworld, have all been granted anti-trust immunity for the joint ventures in charge of their international (mainly trans-Atlantic) operations.

\(^{98}\) Note that A, B, H and K are elements in \(\Theta\), which means that a player who stays independent constitutes a virtual “partnership”.
one global alliance and one local airline, in equilibrium the two partners will contribute the same amount of flights for the cooperative market; therefore, it is more reasonable to assume that the profit from these markets is shared evenly between the two partners other than through negotiation. Furthermore, if a partnership is formed between one global alliance and two local airlines, the rule also holds but each airline can only obtain $\frac{1}{4}$ of the total joint venture profit, since the global alliance will provide twice as many flights as each of the local airlines does for the cooperative market.\(^99\)

The objective functions of a company (airline or alliance) and a joint venture are different since the profit of the joint venture will go to the companies eventually based on the revenue sharing mechanism. We use $t$ to denote the company within a partnership $\theta$ and $s$ to denote the joint venture formed by this partnership ($t, s \in \Psi(\theta)$). And the objective functions are:

\[
\pi^\theta_t = \sum_{m \in M(t)} \sum_{i \in I(m,t)} (p_i^m - c)q_i^m + r_t^\theta \pi^\theta_s
\]

\[
\pi^\theta_s = \sum_{m \in M(s)} \sum_{i \in I(m,s)} (p_i^m - c)q_i^m
\]

where $c = 1$ as assumed above, and $r_t^\theta$ is the fraction of joint venture profit retained by company $t$. In particular, for an airline, $r_t^\theta$ will be $\frac{1}{2}$ when the partnership includes one local airline and one global alliance, $\frac{1}{4}$ if the partnership includes two local airlines and one global alliance, and zero otherwise.

\(^{99}\) This principle is called “capacity-based formula” which is commonly adopted by the alliance joint ventures, as suggested in Gillespie and Richard (2012).
5.3 Scenario Comparisons

5.3.1 Scenario definitions

Given the symmetry between the two airlines as well as between the two alliances, there will be four scenarios with respect to different partnerships.

Scenario 1 corresponds to the situation in which both airlines stay out of the alliances. In this case, passengers flying between points 1 and 4 (or 5) can only purchase two interline tickets. It should be noted that the passengers would not buy tickets from three different companies due to the quality differentiation assumption.

Scenario 2 is the situation when only one airline joins one alliance. There are four different possibilities for this scenario: airline A joins alliance H while airline B and alliance K remains unallied; airline B joins alliance H while airline A and alliance K remains unallied; airline A joins alliance K while airline B and alliance H remains unallied; and airline B joins alliance K while airline A and alliance H remains unallied. Given the symmetry between the two airlines as well as between the two alliances, any of the four cases is representative to all the possibilities. So we’ll use the first possibility as an example here and whenever detailed analysis is needed in the following text. When A joins H, they act like one company in dealing with market 14. As pointed out by Park et al. (2001) and Zou et al. (2011), complementary alliances provide connecting passengers with improved transfer services and greater convenience, such as shorter layover time, one-stop check-in, more flexible scheduling, and shared frequent flyer programs, which would lead to an increased satisfaction and willingness-to-pay. Therefore, according to our quality differentiation assumption, only tickets offered by the A-H alliance will survive in market 14 (Park, 1997; Brueckner, 2001). However, there are two different itineraries available from the A-H alliance in this market, with one being the flights offered by A for links 12 and 23 plus the flight offered by H for link 34, and the other being the flight offered by A for link 12 plus the flights offered by H for links 23 and 34. Given that passengers have different preferences towards airline A and alliance H, there still exists horizontal differentiation between these two itineraries even after a partnership.
Scenario 3 is the case when each local airline joins a different alliance. There exists two possibilities for this scenario: airline A joins alliance H while airline B joins alliance K, and airline A joins alliance K while airline B joins alliance H. Again we only need to consider the first as a representative case because of symmetry.

Scenario 4 is the situation in which both airlines join the same alliance. Here we also consider one representative case, in which both airlines A and B join alliance H and leaves alliance K unallied in that country (the other possibility is airline A and B join alliance K and leaves alliance H unallied). Note that according to real business practices, when both local airlines join the same alliance, they should still provide two differentiated itineraries (with the domestic leg operated by A and B respectively) instead of only one.

We notice that not all the combinations of $\alpha$ and $\gamma$ are feasible so we need to consider the feasible range. Feasibility in this case requires three groups of conditions. The first group is the non-negativity conditions for all the resulting traffic volumes, prices and profits. The second order conditions for concavity also need to be satisfied. Lastly, we also need to guarantee the stability of the equilibrium. Given the complexity of the conditions, it

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100 Consider that brand loyalty is only related to the frequent flyer program. Since there are multiple airlines in an alliance thus bringing with them multiple programs with varied and complex rules, alliances typically offer a single alternative loyalty program that is also integrated with the primary loyalty program belonging to the “home” airline. In order to protect and maintain the primacy of individual airline FFPs, most alliances have the rule that a passenger has to take a minimum number of flights before being eligible for an alliance loyalty program. The alliance loyalty program also has its own set of tiers. Many member airlines also have an additional premium status beyond the alliance’s tier system that is not recognized across the alliance. Overall, a flight offered by the “home” airline is still preferred to the flight served by its alliance partner.

101 One example is that before US Airways exited Star Alliance on March 31, 2014, the alliance provided a few connecting flights from Pittsburgh to Shanghai PVG (Pudong Airport) through Chicago, with the leg from Chicago to Shanghai operated by United Airlines and the leg from Pittsburgh to Chicago operated by both United Airlines and US Airways.

102 Stability of the Nash equilibrium in this paper refers to the sufficient condition for local stability given
is not easy to obtain the explicit form of the feasible boundary. However, numerical analysis is able to give a clear pattern of the feasible range, as illustrated in Figure 5.2.

**Figure 5.2 Feasible ranges for $\alpha$ and $\gamma$**

Note: Shaded area—infeasible; Blank area—feasible

From Figure 5.2 we can see that the larger $\gamma$ is, the larger the lower bound of $\alpha$ needs to be to ensure all the feasibility conditions. But generally, as long as $\alpha$ is larger than a certain value, feasibility always holds.

5.3.2 Comparisons of prices and profits

Due to the complexity of the network, the exact expressions for equilibrium prices and profits are complicated and hence suppressed from the main text. We only present the by Zhang and Zhang (1996) in their Proposition 1 and equation (5.8). In particular, let $T$ be the mapping from the matrix of decision variables of all the players to the matrix of best response of these players. We require $T$ to be a contract mapping around the equilibrium. As proved by Zhang and Zhang (1996), if $T'$ denotes the derivative of $T$ with respect to all the decision variables across players, the local stability can be achieved as long as there exists a matrix norm $\|T'\|$ which is less than unity. Thus, one sufficient condition is that the maximum absolute eigenvalue of $T'$ is less than 1, which is the condition applied in this paper.
comparisons of prices and profits between different scenarios here, which are summarized in the following Tables 5.1 and 5.2, respectively.\textsuperscript{103}

Table 5.1 Price comparisons between different scenarios

<table>
<thead>
<tr>
<th>Market Comparison</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>23</th>
<th>24</th>
<th>25</th>
<th>34</th>
<th>35</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 vs. 1</td>
<td>+*</td>
<td>+</td>
<td>−</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>−</td>
<td>+</td>
<td>−</td>
</tr>
<tr>
<td>3 vs. 2</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>−</td>
<td>+</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>4 vs. 2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4 vs. 3</td>
<td>−</td>
<td>−</td>
<td>0</td>
<td>+</td>
<td>+ when $y$ is large</td>
<td>0</td>
<td>−</td>
<td>0</td>
<td>−</td>
</tr>
<tr>
<td>4 vs. 1</td>
<td>+</td>
<td>+</td>
<td>−</td>
<td>+</td>
<td>+</td>
<td>−</td>
<td>+</td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>3 vs. 1</td>
<td>+</td>
<td>+</td>
<td>−</td>
<td>−</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

* This is the sign of $p_{12}^{13} - p_{12}^{13}$ and $p_{12}^{13} - p_{12}^{13}$

There is a sign (+ or -) in every cell in Table 5.1 which indicates the direction of change from one scenario to the other. Here we’ll use the comparison between Scenarios 1 and 2 (with the representative cases given in Section 5.3.1) to illustrate the economic intuition behind the price comparisons.

From Scenario 1 to Scenario 2 (refer to the row of 2 vs. 1 in Table 5.1), the formation of

\textsuperscript{103} A detailed derivation of price comparisons (and profit comparisons in the following text), as well as the two propositions, will be available upon request.
AH partnership excludes B from market 14 only. Although AH joint venture becomes the monopoly in this market, integration also eliminates double marginalization and eventually leads to a lower price. Price in market 23 drops due to lowered horizontal competition. Since there is no change in the structures of the other markets, the main driving force in other markets comes from breaking the multi-market interaction between these markets and market 14. In Scenario 1, four itineraries compete in market 14, two compete in markets 12 and 13, and H is the monopoly in markets 24 and 34. Therefore, market 14 is the most elastic market, followed by market 12 or 13 and then market 24 or 34. Therefore, in Scenario 1, airlines and alliance H have to charge lower prices to accommodate the most elastic market 14 while in Scenario 2, prices in markets 12, 13, 24 and 34 are no longer linked with the demand in market 14 and hence the airlines and alliance H will raise price in these markets as the demands of these markets are less elastic in price. Since the fares of markets 12 and 25 (or 13 and 35) are the sub-fares for market 15, price increase in markets 12 and 13 drives down prices in markets 25 and 35 due to the vertical competition between the local airlines and alliance K in market 15, while the overall price change in market 15 is still positive.

The other scenario comparisons follow very similar reasoning. There is only one cell in Table 5.1 (market 23 when comparing Scenarios 3 and 4) where the comparison of price is not clear-cut. The reasoning goes as follows. Ignoring the interaction between the four players, from Scenario 3 to Scenario 4, alliance K will have an incentive to reduce its price in market 23 because it no longer considers the itinerary operated by airline B and has to face competition from the ABH joint venture which operates three itineraries. However, by taking each other into account, the other three players in the ABH joint venture will have an incentive to increase their prices in market 23 due to enhanced dominance in this market. This increase, in turn, will impose an upward pressure on the price of K since price is strategic complement. When $\gamma$ is large this pressure is strong and makes the price of K in market 23 increase.
Table 5.2 Conditions when the profits of players will increase under scenario comparisons

<table>
<thead>
<tr>
<th>Scenario Comparison</th>
<th>Player 1</th>
<th>Player 2</th>
<th>Player 3</th>
<th>Player 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 vs. 1</td>
<td>Always</td>
<td>When $\gamma$ is large</td>
<td>When $\alpha$ and $\gamma$ are both small</td>
<td>Never</td>
</tr>
<tr>
<td>3 vs. 2</td>
<td>When $\gamma$ is large</td>
<td>Always</td>
<td>Always</td>
<td>When $\alpha$ and $\gamma$ are both small</td>
</tr>
<tr>
<td>4 vs. 2</td>
<td>When either or both of $\alpha$ and $\gamma$ are small</td>
<td>Always</td>
<td>Always</td>
<td>Always</td>
</tr>
<tr>
<td>4 vs. 3</td>
<td>When $\gamma$ is small</td>
<td>When $\gamma$ is small</td>
<td>Always</td>
<td>When either $\alpha$ or $\gamma$ is large</td>
</tr>
<tr>
<td>4 vs. 1</td>
<td>Always</td>
<td>Always</td>
<td>When $\gamma$ is small</td>
<td>When $\gamma$ is large</td>
</tr>
<tr>
<td>3 vs. 1</td>
<td>When $\gamma$ is not very small</td>
<td>When $\gamma$ is not very small</td>
<td>When $\alpha$ and $\gamma$ are both small</td>
<td>When $\alpha$ and $\gamma$ are both small</td>
</tr>
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</table>

In Table 5.2 we can see that profit comparisons are much less clear-cut than price comparisons. To give a better illustration, we use a series of graphs (Figure 5.3) to illustrate the profit comparisons that are not straightforward.
Figure 5.3 Profit comparisons for the less straightforward cases

The horizontal and vertical axes of the graphs in Figure 5.3 capture the values of $\gamma$ and $\alpha$, respectively. The solid curves plot the combinations of $\gamma$ and $\alpha$ that will make the profit differences to be zero (i.e., these are the indifference curves between profits). Some solid curves also come with a corresponding asymptote, which is illustrated as a heavy dashed line. The light dashed line is the “feasibility border” that has been discussed in Figure 5.2.
We will again use the comparison between Scenarios 1 and 2 (with the representative case given in Section 5.3.1) to illustrate these mechanisms, while the other comparisons follow suit. From Scenario 1 to Scenario 2, the profits of all four players from market 23 increase because of eased horizontal competition. Both local airlines end up earning more profits from markets 12 and 23 due to the fact that their prices in these two markets are closer to the duopoly levels. Due to similar reasons, alliance H also earns more in markets 24 and 34. By contrast, alliance K earns less in markets 25 and 35 since its prices are further away from the monopoly prices under Scenario 2. K also loses in market 15, since the total price for this market increases, while the proportion that belongs to K decreases. From market 14, airline A gets more profit while airline B as well as alliance H earn less. This is because in Scenario 2, B is driven out from this market by the formation of the exclusive AH partnership, which hurts both airline B and alliance H, with a particularly strong impact when $\alpha$, the market size, is large. Besides, H is able to extract a large proportion of profit from market 14 in Scenario 1, especially when $\gamma$ is large, i.e., when the two local airlines are fiercely competing for feeding traffic from H. However, the fixed revenue sharing scheme in Scenario 2 puts H at a disadvantage, making its profit decrease. This decrease is particularly significant when $\gamma$ is large.

From the above analysis, we can see that airline A earns more profit from all the markets where it operates, so it will always benefit from shifting from Scenario 1 to Scenario 2. For airline B, when $\gamma$ is large, the loss in market 14 is relatively small and dominated by the gain from other markets, so it will benefit from the scenario shift too. Alliance H is in a similar situation. When $\alpha$ and $\gamma$ are both small, its loss in market 14 will be small and dominated by the gains from other markets where it operates, leaving a net benefit from this scenario change. Alliance K earns less profit in all but one market (market 23), which makes it always worse off when shifting from Scenario 1 to Scenario 2.

One interesting observation is that the “Prisoner’s Dilemma” suggested by both Bilotkach (2005) and Flores-Fillol and Moner-Colonques (2007) is also present in our results. The two papers both argue that even though it is possible for an airline’s profit to decrease after joining an alliance, airlines are still inclined to enter alliances because the worst outcome for an airline happens when it stays independent when its competitor joins an
alliance. This mechanism can also be seen on the first three rows of Table 5.2. A local airline will always be better off to join an alliance no matter how its competitor moves. However, under certain condition both airlines may be worse off when they each join a different alliance (last row in Table 5.2). On the other hand, our findings also differ from those of the previous papers. In particular, we further show that if the two local airlines both join the same alliance, this “Prisoner’s Dilemma” disappears and the airlines are always better off with the partnership (second last row in Table 5.2). This is reasonable because Scenario 3, where each local airline joins a different alliance, is in a similar setting with both Bilotkach (2005) and Flores-Fillol and Moner-Colonques (2007); while Scenario 4, where both local airlines join the same alliance, is unique for our paper. In other words, our results are consistent with the previous literature when the setting is similar and also reveal interesting new findings with innovation of the modeling.

5.4 Game Equilibrium

5.4.1 Game setting

Before we start to analyze the game, we need to specify the game structure first. One feature of this paper is that it specifically considers a four-player game, which is, although still rough, a better approximation of the real world than a two-player game that is usually adopted in the alliance literature. To make our analysis complete, we examine both a simultaneous game and a sequential game. While a sequential game would be a more realistic setting if we consider the timing of formal alliance partnership announcements, a simultaneous game might be appropriate for many cases since the formation of alliance partnerships is usually a long and painful process.\textsuperscript{104} Overlap in timing for two partnership formations is thus highly possible.

To be specific, in the simultaneous game, the strategy set for the two local airlines is \{N,
H, K}, meaning to stay independent, to propose to join alliance H, and to propose to join alliance K, respectively. While the strategy set for the two global alliances is {N, A, B, AB}, meaning to do nothing, to invite airline A, to invite airline B, and to invite both airlines, respectively. A partnership will be formed only when both the local airline and the global alliance intend to do so. For example, if airline A chooses to join alliance H while alliance H chooses to invite airline A, then the partnership between A and H will be formed. On the other hand, if A chooses to join H but H chooses to invite only B, no partnership between A and H will be realized. Given that there are four players, the normal form game is quite large. However, since we impose symmetry between the local airlines and between the global alliances, the equilibrium outcomes can be categorized into the four scenarios summarized above.

In the sequential game, we let one local airline move first. Given the symmetry, it does not really matter which of the two airlines is the first mover. Suppose airline A makes the first move, its strategy set is still {N, H, K}. If airline A chooses to join alliance H or K, the next mover of the extensive game will be the chosen alliance. This alliance will then have to choose in the strategy set {AC, DE}, meaning accept and decline, respectively. If A chooses to stay independent, or after the chosen alliance’s move, airline B will need to move next, facing the same strategy set as airline A. The game ends here if airline B chooses to be independent, or else the alliance chosen by B will need to make another round of decision between accepting B and declining B.

5.4.2 Simultaneous game equilibrium

With the help of the price and the profit comparisons, we are able to derive the equilibria under both the simultaneous game and the sequential game setting. We focus on pure Nash equilibrium for the simultaneous game, so we might see multiple equilibria under certain conditions. The equilibrium outcomes are summarized below as Proposition 5.1.

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105 This assumption fits reality rather well, given that a negotiation usually kicks off when an airline shows the intention of joining an alliance, instead of the other way around.
Proposition 5.1 In a simultaneous game, there may exist multiple Nash equilibria:

(1) when the market size and the product substitutability are both relatively small, all the four scenarios are possible equilibrium outcomes;
(2) when the market size is at a medium level while the product substitutability is relatively small, the only scenario that will not be a possible equilibrium outcome is the case when only one local airline joins one global alliance;
(3) when the market size is at a medium level while the product substitutability is sufficiently large, the two possible equilibrium outcomes are both local airlines staying independent, and both local airlines join the same alliance;
(4) when the market size and the product substitutability are both sufficiently large, it is only possible for both local airlines to stay independent.

Figure 5. 4 Simultaneous equilibrium outcomes

Note:
I. Scenario 1; II. Scenario 1 + Scenario 4; III. Scenario 1 + Scenario 3 + Scenario 4
IV. Scenario 1+ Scenario 2 + Scenario 3 + Scenario 4

We use Figure 5.4 to give a visual representation of Proposition 5.1. Note that the range of $\alpha$ can go beyond 50. We set the upper bound of $\alpha$ in this figure to be 50 just for illustration clarity, because the pattern does not change even if we include a larger range of $\alpha$. Besides, the shaded area at the bottom is the infeasible area indicated in Figure 5.2.

The feasible domain of Figure 5.4 is divided into four areas by three boundary lines, which are the three indifference curves in panels (b), (d) and (h) of Figure 5.3. From Figure 5.4 we can see that area IV is the only area where Scenario 2 is a possible equilibrium outcome. This is because in Scenario 2, both the airline and the alliance in
partnership can unilaterally change the outcome to Scenario 1. This deviation is always unbefeficial for the airline (see Table 5.2, Scenario 2 vs. Scenario 1 for A), and beneficial for the alliance only in the domain above the indifference curve between π_{H2} and π_{H1} (see panel (b) in Figure 5.3), which is out of area IV. Therefore, Scenario 2 is only possible in area IV. Similarly, areas III and IV are the areas where Scenario 3 is a possible equilibrium outcome. Starting from Scenario 3, all the four players are able to change the outcome unilaterally, but only to Scenario 2. This move is always undesirable for the airlines (see Table 5.2, Scenario 3 vs. Scenario 2 for A), and desirable for the alliances in the domain above the indifference curve between π_{K3} and π_{K2} (see panel (d) in Figure 5.3). Therefore, Scenario 3 happens only below this indifference curve (areas III and IV). The same logic applies to Scenario 4 as well, which is a possible equilibrium outcome in areas II, III and IV. In Scenario 4, all the three players (two airlines and one alliance) that are in a partnership can change the outcome. In particular, the two airlines can shift the situation into Scenario 2, while the alliance can shift the situation into Scenario 1 or 2. From the comparison of Scenario 4 vs. Scenario 2 for B and H in Table 5.2 we can conclude that both the airlines and the alliance do not have any incentive to deviate into Scenario 2. However, it is beneficial for the alliance to deviate into Scenario 1 when the parameter combination is in the domain above the indifference curve between π_{H4} and π_{H1} (see panel (h) in Figure 5.3). Therefore, Scenario 4 will be a possible equilibrium outcome in all areas but area I. The reason why Scenario 1 is always an equilibrium outcome in the simultaneous game is because given that three players choose not to work with anyone else, the other player does not have any incentive to deviate since it will not change the result.

To narrow down the simultaneous game solutions, we need to impose an equilibrium selection criterion. However, it will not be discussed in this paper. On the one hand, there exist multiple selection criteria, including risk dominance, payoff dominance and others, which are all possible under different situations. On the other hand, which equilibrium will be eventually selected totally depends on the selection criterion adopted. Therefore, here we refrain from taking this step and consider all the possibilities.
5.4.3 Sequential game equilibrium

If the players play a sequential game instead, we’ll be able to obtain the sub-game perfect equilibrium. The game can be presented in an extensive form game tree in Figure 5.5.

**Figure 5.5 Extensive form of the sequential game**

Note:

1 = (π_A4, π_B4, π_H4, π_K4); 2 = (π_A2, π_B2, π_H2, π_K2); 3 = (π_A2, π_B2, π_H2, π_K2);

4 = (π_A3, π_B3, π_H3, π_K3); 5 = (π_A2, π_B2, π_H2, π_K2); 6 = (π_B2, π_A2, π_H2, π_K2);

7 = (π_A1, π_B1, π_H1, π_K1); 8 = (π_A1, π_B1, π_H1, π_K1); 9 = (π_B2, π_A2, π_K2, π_H2);

10 = (π_A1, π_B1, π_H1, π_K1); 11 = (π_B2, π_A2, π_H2, π_K2); 12 = (π_A1, π_B1, π_H1, π_K1);

13 = (π_A1, π_B1, π_H1, π_K1); 14 = (π_B2, π_A2, π_K2, π_H2); 15 = (π_A1, π_B1, π_H1, π_K1);

16 = (π_A3, π_B3, π_H3, π_K3); 17 = (π_A2, π_B2, π_K2, π_H2); 18 = (π_A2, π_B2, π_K2, π_H2);

19 = (π_A4, π_B4, π_K4, π_H4); 20 = (π_A2, π_B2, π_K2, π_H2); 21 = (π_B2, π_A2, π_H2, π_K2);

22 = (π_A1, π_B1, π_H1, π_K1); 23 = (π_A1, π_B1, π_H1, π_K1); 24 = (π_B2, π_A2, π_K2, π_H2);

25 = (π_A1, π_B1, π_H1, π_K1).
For the convenience of presentation, we use the representative case in Section 5.3.1 to denote the payoff profiles. For example, \( \pi_{A2} \) does not necessarily mean the profit of airline A under Scenario 2. It denotes the profit of the local airline that joins a global alliance under Scenario 2, while this local airline can be either airline A or airline B. In other words, a payoff profile \((\pi_{B2}, \pi_{A2}, \pi_{K2}, \pi_{H2})\) comes with a case in which airline B joins alliance K, while airline A and alliance H are unallied in this network. Scenarios 3 and 4 also follow the same treatment.

**Proposition 5.2** In a sequential game, when the market size and the product substitutability are both sufficiently large, both local airlines will stay independent. Otherwise, both local airlines will join the same alliance in equilibrium.

**Figure 5.6 Sequential equilibrium outcomes**

Note:

i. Scenario 1; ii. Scenario 4

There are four stages in the game. In the first stage of the game, airline A chooses to propose to join either of the two alliances, or to stay independent. If A does not propose, either no partnership will be formed or it will be alone while its domestic rival will form a partnership with one alliance, which are the two worst cases for A. From the profit comparisons in Table 5.2 (Scenario 2 vs. 1, 3 vs. 2 and 4 vs. 2) we can see that the airline will always benefit from joining an alliance, irrespective of what the other airline chooses.
to do. Therefore, at this stage A will always propose to one alliance (either H or K since the outcome will be symmetric). In the following analysis we only consider the case when A chooses H, given that it is symmetric to the case when A chooses K.

We can use backward induction to analyze the other stages of the game. If H accepts A and then B has three choices: proposing to join H, proposing to join K or staying independent. If B proposes to H, at the final stage H will need to choose between forming ABH cartel (Scenario 4) and keeping with AH joint venture (Scenario 2). For H the former is always better than the latter due to increased market power in market 23 and improved itinerary variety in market 14, thus H will always choose to accept B’s proposal, leading to Scenario 4. Since staying as part of a joint venture is always better than having no partnership, staying independent will be a dominated strategy for B (see Scenario 4 vs. 2 in Table 5.2). If B proposes to K, at the last stage K faces a choice between forming separate joint ventures (corresponding to Scenario 3) and leaving AH the only joint venture (corresponding to Scenario 2). The former helps to reduce competition in market 23 and restore monopoly position in markets 25 and 35 via eliminating their interactions with market 15. However, the drawbacks of forming a separate BK joint venture include that the profit from market 15 will decrease due to reduced itinerary variety and that K has to share some of its profit in market 15 with B. Therefore, only when market size and product substitutability are both small, these drawbacks will be small and K will find two separate joint ventures a better idea. Given that Scenario 2 is always dominated by Scenario 4, B will only consider choosing K when K will choose accepting B, which will happen only when both the market size and the product substitutability are small. Interestingly, when substitutability is small, B will prefer forming ABH cartel to creating BK joint venture. This is because forming a competing BK joint venture will eliminate A’s presence in market 15 compared with the case of ABH, though the cartel has larger market power in market 23. When substitutability is weak, the benefit from market power in market 23 will dominate and hence B will prefer Scenario 4. Therefore, no matter whether K prefers Scenario 2 or 3, B will always choose to propose to H, leading to Scenario 4 as the equilibrium outcome. Due to the fact that Scenario 4 is the best outcome for H in this domain, H will always accept A in the second stage because
Scenario 4 will not be reachable otherwise. The analysis for the domain above the indifference curve between $\pi_{H4}$ and $\pi_{H1}$ (panel (h), Figure 5.3) follows similar rationale. In the second stage if H chooses to accept A then Scenario 4 will be reached eventually. It is worse for H than Scenario 1, which is the outcome if H chooses to decline A. Therefore, H will decline A’s proposal, leading to Scenario 1 as the equilibrium outcome.

5.4.4 Discussion

The results are somewhat surprising since Scenario 4, in which both local airlines join the same alliance, appears to be a predominant equilibrium outcome. On the other hand, Scenario 3, in which each airline joins a different alliance, exists with a much lower probability. Though Scenario 4 occurs with higher probability in our framework – both in the simultaneous game and in the sequential game – a few factors might play a role in explaining why a lot of Scenario 3 situations occur in reality. First, the conditions for Scenario 3 outcome to exist, although seemingly restricted, are actually common. Aviation industry is a highly competitive one, so it is hard to believe that a strategic move as important as applying for alliance membership by an airline is not followed and matched by peers within the same country. In this case, a simultaneous game describes the situation more accurately. The behavior of the Chinese airlines offers a good illustration of how crucial the timing of decision-making can be. Air China joined Star Alliance in 2007, the same year when China Southern Airlines joined SkyTeam. Almost four years later, when China Eastern Airlines decided to join an alliance, it picked SkyTeam as well (even though oneworld also invited China Eastern Airlines). This pattern fits perfectly with the prediction of our model. The same story also happened in countries like Australia, UK and Mexico.106 On the other hand, for a country (or a united market like Europe) large enough to support more than one legacy carrier (since LCC is

106 Ansett Australia joined Star Alliance in 1999. In the same year, Qantas joined oneworld as a founding member. Similarly, British Midland International joined Star Alliance in 2000, almost the same time when British Airways started oneworld. Aeromexico joined SkyTeam and Mexicana joined Star Alliance both in 2000.
not yet a part of any of the three major global alliances), it happens more often that each of those carriers has a focus for a certain territorial realm and only competes for some of the densest routes. In other words, the substitutability of their services is actually not very high. Second, some other features have been omitted from our analysis, such as the possibility of repeated games and the principle-agent aspect of this problem.\footnote{107} In reality, we have witnessed a few changes of relationship within and across alliances, such as the assimilation of Wing alliance into SkyTeam and the shift of Continental Airlines from SkyTeam to Star Alliance, suggesting that a repeated game setting that allows for strategy adjustment may well induce different outcomes.\footnote{108} Decision delegation is also another issue to consider, since the delegates (CEOs and other managers of the airlines) may need to take into account many aspects of the problem such as the political and historical contexts.\footnote{109} In particular, it is more possible to raise the concern of the local government if two of the major local airlines declare to join the same alliance. Thus more political barriers and higher costs may follow. In other words, the different alliance formation outcomes might be affected by the approaches and attitudes of antitrust authorities in different countries. The ‘Open-Economy Industrial Organization’ literature has suggested that export oriented countries like China tend to enhance the weight of post-merge international competitive gains, thus favoring lenient domestic merger policy (e.g. Head and Ries, 1997; Yano, 2001; Zhang and Chen, 2002; Clougherty and Zhang, 2005). The main insight is that international competitive gains have a particularly strong weight vis-à-vis domestic consumer losses when an economy is a major exporter in its welfare assessment of a domestic merger. This might offer another explanation for the

\footnote{107}{Besides, from the perspective of marketing, joining different alliances helps the local airlines to better differentiate their products with the image of the alliance and the auxiliary benefits that come with it (such as FFP miles, lounges and other standard services within the alliance).}

\footnote{108}{Some might argue that these cases are induced by mergers (Delta/Northwest and United/Continental), but it also suggests that the sunk cost of joining an alliance is so large that only events like merger and acquisition can shift the decisions once made, explaining why this kind of adjustment is far from common in the real business world.}

\footnote{109}{Anecdotal evidence shows that a good relationship between managements of the local airline and any existing member of an alliance is helpful for the potential partnership.}
observation that the Chinese government allowed two major Chinese airlines to join the same global alliance, which is very likely to be infeasible under the legal environments of some other countries like the US. Overall, the reasons for Scenario 3 to be seemingly more common and Scenario 4 to be seemingly less common in reality may be multi-fold.

Furthermore, our results are largely consistent with the empirical study by Gaggero and Bartolini (2012). They find that competitors’ decision to enter an alliance tends to have a positive impact on alliance participation, which confirms the very rare event of Scenario 2 equilibrium outcomes.\(^{110}\) In addition, they also find that the larger the market size, the lower the possibility that an airline joins any alliance, which corresponds to the increasing probability of Scenario 1 when \(\alpha\) increases.

The parameter of market size \(\alpha\) plays a very interesting role. Note that this parameter can also represent the economy in general. In particular, when the global economy is good, \(\alpha\) should adopt a larger value; the opposite is also true when the economy is generally bad. The analytical results we obtain tell that the worse the economy, the higher the possibility of alliance partnership formation, and the more concentrated an alliance tends to be. This prediction fits the reality very well.\(^{111}\)

Our results are of particular interest because of the predominance of Scenario 4, since this is exactly the scenario that has been largely ignored by previous literature. Recall that previous analytical studies focus mainly on limited scope of partnership, i.e., an airline can only choose to cooperate with a predetermined airline (alliance), even with the existence of multiple potential partners (Zhang and Zhang, 2006; Flores-Fillol and

\(^{110}\) In Gaggero and Bartolini (2012), the impact of competitors’ decision on an airline’s decision is only statistically significant for oneworld, but the signs of the coefficients are positive for all the three alliances.

\(^{111}\) As pointed out by Doganis (2006), “the most active period of alliance-making was triggered by the deteriorating financial performance of international airlines as they were hit first by the crisis in the tiger economies of East Asia from late 1997, then by the economic slow-down in some European states in 1998, followed by the rapid escalation of fuel prices in 1999… As the global economic downturn began to bite in 2000 and the airline crisis deepened, especially after the attacks in New York in September 2001, the alliance frenzy intensified.”
Moner-Colonques, 2007; Bilotkach, 2005), while no empirical work has ever attempted to address the phenomenon of two competing airlines ending up in the same alliance either. This common simplification, according to our results, might not be appropriate in a sense that the incentive of alliance partnership is not fully considered.

Our analysis also shows the importance of competition in the alliance partnership formation. One reason why Scenario 4 dominates the other scenarios is that competition is mitigated not only at the international level but also at the domestic level. In particular, by joining the same alliance, the two local airlines are de facto collaborating. Even when their cooperation cannot get antitrust immunity from the government (as modeled in this paper), the airlines are still able to achieve some competition mitigation with easier tacit collusion. In fact, as suggested by Doganis (2006), as a result of an alliance, two carriers previously competing on a route may decide that only one of the alliance partners should operate the route. With this agreement, they can circumvent the problem without antitrust immunity. Ito and Lee (2007) also support this idea by showing that the overwhelming majority of U.S. code-share itineraries involve a single operating carrier only, a phenomenon that they refer to as virtual code sharing.

5.5 Concluding Remarks

In this paper, we adopt a game theoretic structure to study the partnership formation of local airlines and global alliances under the situation when there are multiple local airlines and more than one alliance. We try to identify all the possible equilibrium outcomes and their corresponding conditions so as to offer some insights for real-world experiences. We find that multiple equilibrium outcomes may exist in a simultaneous game, but the number of possible equilibrium outcomes will decrease when the market size or the product substitutability between companies increase. On the other hand, if a sequential game is played, we show that when either the market size or the substitutability is relatively small, both local airlines will join the same alliance in equilibrium. Otherwise, both local airlines will stay independent.

This paper enriches the literature in airline alliance partnership formation by considering
a more realistic setting. In particular, we take into account a larger range of cooperative schemes, the asymmetry between local airlines and global alliances and make a complete analysis based on a more complicated network. The results are informative. We explore the rationale behind different alliance partnerships and explain why a variety of different situations exist in reality. In particular, we illustrate how some country/region with certain characteristics favors non-allied airlines, while the others tend to induce alliance partnership at various concentration levels.

Although we have tried to make the setting more realistic and complicated, some features are still omitted from our analysis, such as the possibility of repeated games and the principle-agent problem within airlines/alliances. It would be interesting to enrich the model even more in future research and study the impacts of these factors. Since we have analytically obtained the equilibrium outcomes for the partnership formation games between local airlines and global alliances, another direction of future study will be to empirically test these predictions. Besides, it would be interesting and meaningful to study the welfare implications of different equilibrium outcomes discussed in this paper, so that corresponding policy suggestions can follow.
6 Strategic Considerations behind the Network-Regional Airline Tie Ups – A Theoretical and Empirical Study

6.1 Introduction

Regional airlines in the United States (US) have had a varied history in their contractual relationship with network airlines. Initially they provided feed from small centers to hubs on a contractual basis but this changed as network airlines invested in regionals or bought them outright in the 1980s and 1990s. More recently in the last ten years, network airlines have reverted to contracting with regional airlines which now may serve one or more network airlines in a market. Regional airlines are also assuming a more significant role in moving domestic passenger traffic. In 2011 the regional airlines had over 13,000 daily departures and operated a combined fleet of about 2,500 aircrafts. These regional airlines carried over 160 million passengers and 50 percent of the nation’s scheduled domestic flights. A significant proportion of regional airlines have gone unnoticed by the public since their planes display the logos and liveries of network airlines.113

Studies on regional airlines mainly focus on their vertical relationship with the network airlines (Forbes and Lederman, 2007; 2009; 2010; Levine, 2011).114 Regional airlines operate short- and medium-haul scheduled service, connecting smaller communities with larger cities. In the U.S. almost all regional airlines operate under outsource agreements with one or more network airlines. Under these agreements, a regional airline operates flights on behalf of one or more network airlines which ticket these flights.115 In addition

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112 A version of this chapter has been accepted by and will be forthcoming in *Transportation Research Part B: Methodological*.

113 Interestingly, this segment of the industry is also neglected by the researchers to a surprising extent, especially when compared with the numerous studies on large network airlines and low cost carriers.

114 Another relevant stream of literature focuses on the impacts of introducing regional jets into the aviation industry (Dresner et al, 2002; Brueckner and Pai, 2009; Fageda and Flores-Fillo, 2012a,b). The regional jet technology is closely related to the contractual relationship between network airlines and regional airlines, although this relationship is not explicitly taken into consideration in these papers.

115 SkyWest provides feeder services for United Airlines, Alaska Airlines, Delta Air Lines and US Airways,
to using the network airline’s code, the regional airline’s flights also share the network airline’s brand. In particular, the regional airline’s planes are painted in the network airline’s livery; the regional airline’s flight attendants wear the uniforms of the network airline; passengers traveling on the regional airline earn the network airline’s frequent flyer points; and the regional airline uses the logos, trademarks and even the name of the network airline (for example, regional airline Comair operates for Delta under the name Delta Connection). To facilitate passenger connections between the regional airline and the network airline, the schedules of the two are coordinated, and often the regional airline’s schedule is dictated by the network airline. Check-in and baggage handling are also coordinated so that passengers need only to check in their luggage once, at the start of their trip.

Few papers have been dedicated to this topic, especially in comparison with the abundance of literature in the contractual relationship between network airlines, namely, airline alliances (e.g., Park et al., 2001; Bilotkach, 2007). In the existing literature, cost differences and break-even load factors are suggested as the principal reasons why network airlines would subcontract service to independent regional airlines. Even though regional airlines operate aircraft that have somewhat higher CASM (cost per available seat mile), they have smaller break-even load factors, limited capacity in the market and lower factor prices for flight and cabin crew.\footnote{It is well accepted that regional airlines have a cost advantage on the types of routes they serve (Forbes and Lederman, 2007; 2009; 2010). Network airlines tend to use regional airlines to serve short (up to 1-1.5 hours stage length), low-density routes that are most efficiently served by a small number of daily flights on small aircraft as they feed passengers into the legacy carriers network. It has been argued that there can be incentives for a network airline to vertically integrate with one or more regional airlines and maintain them as fully owned subsidiaries. Forbes while Chautauqua provides feeder services for United Airlines, American Airlines, Delta Air Lines, Frontier Airlines and US Airways.\footnote{The regionalized airlines tend to have non-unionized work forces with flexible work rules.}}
and Lederman (2009) contend that vertical integration is motivated by two types of operational decisions - ex-ante scheduling decisions, and real-time adjustments to schedule disruptions. Contracts between network airlines and regional airlines generally cover ex-ante scheduling decisions but not real-time adjustments to schedule disruptions. Thus, there is an incentive problem between network airlines and the regional airlines that results from the incompleteness of the contracts with respect to real-time schedule adjustments. Ownership of a regional airline mitigates this incentive problem by giving the network airline residual rights of control over how the regional airline’s physical assets and labor force are used. Forbes and Lederman (2009) predict that a network airline’s optimal choice of organizational form will reflect the tradeoff between its incentive to exercise control over its regional airline and its incentive to maximize the labor cost savings that its regional airline provides. Levine (2011) points out that after deregulation, airline networks are organized with a variety of firm structures, and individual networks have changed as particular conditions have changed over time.

These analyses stress the relationship within a vertical structure and ignore the interactions between airline groups and the possible strategic function of setting up contracts with independent regional airlines. This paper shows, both theoretically and empirically, that while cost difference plays an important role in defining the relationship between network and regional airlines, negotiating subcontracts with regional airlines can also help a network airline achieve strategic goals when they are competing with other network airlines. The intuition is as follows: since competition in the airline industry is characterized as Cournot competition (Brander and Zhang, 1990), by subcontracting with multiple independent regional airlines, a network airline can credibly commit to (potential) competitors that it can act as aggressively as it wants. We show that if the network airline does not serve a regional market directly, and allows the regional airlines, with which it has subcontracts, to make independent decisions, the network airline can establish a strategic advantage by coercing its competitors to yield market share, or may even preempt the market, given that these network competitors cannot adopt the same strategy. This is called “strategic divisionalization” (Schwartz and Thompson, 1986). However, since this strategy can be implemented by other network airlines, the
competitors might become stuck in a state of intense competition, which eventually hurts everyone in the market (Corchon, 1991). We show that if the network airline can also serve the regional markets directly, and provide a higher priority to its own fleet than the regional airlines with which it subcontracts, the network airlines will be able to send a signal of softer competition. In summary, subcontracting with regional airlines offers the network airlines a flexible tool to customize their competitive strategy for different regional markets.

This conjecture is supported by the diversified relationships, between network and regional airlines. Table 6.1 illustrates that a network airline, in this case US Airways, uses regional airlines in different ways for different markets.\footnote{These data were collected for flights on January 7, 2013.} In particular, for some regional markets, such as Jacksonville – Charlotte, US Airways operates its own fleet, while for other markets such as Flagstaff – Phoenix and Tucson – Phoenix, US Airways subcontracts with one or more regional airlines. Additionally, a mix of US Airways own fleet (and fully owned subsidiaries), and regional airlines can be found in a market like Washington, D.C. – Philadelphia.\footnote{This is far from a special case. Please refer to Table 6.2 in Section 6.3 for the percentages of different contractual relationships between network and regional airlines in the US.} The most interesting observation here is that if we do not consider strategic motives, it would be quite puzzling as to why US Airways uses multiple independent regional airlines in one local market, and not in others, for reasons that apparently go beyond a basis of cost differences and frequency enhancement.
Table 6.1 Some markets served by US Airways on Jan. 7th, 2013*

<table>
<thead>
<tr>
<th>Market</th>
<th>Network airlines</th>
<th>Regional Airlines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Brand Name</td>
<td>Daily Frequency</td>
</tr>
<tr>
<td>Flagstaff → Phoenix</td>
<td>US Airways</td>
<td>0</td>
</tr>
<tr>
<td>Jacksonville → Charlotte</td>
<td>US Airways</td>
<td>6</td>
</tr>
<tr>
<td>Tucson → Phoenix</td>
<td>US Airways</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Washington, D.C. → Philadelphia</td>
<td>US Airways</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

* Note that we only present flight frequencies here, but the readers must bear in mind the fact that regional airlines normally use aircrafts that are smaller (regional jets or turboprops) than those used by network airlines.

**Piedmont Airlines is a fully owned subsidiary of US Airways.

The key finding of this paper is that, if there is no cost difference between two or more network airlines or between network airlines and regional airlines, none of the network airlines have an incentive to contract with any regional airlines, as neither cost saving nor strategic advantage can be achieved. However, when there is a cost difference between network airlines in a specific market, the more cost efficient network airlines will operate in that specific market using their own fleet to accommodate competition if the market is large enough. In smaller markets they will contract with a sufficient number of regional airlines, as well as operate their own flights in that market to compete and drive-out/preempt the less efficient competitors. Also when there is a cost difference between
network and regional airlines, a network airline will outsource all of its traffic in the market to as many regional airlines as possible when the cost difference is significant. If the cost difference is not significant, the network airline will not contract with any regional airline and will serve the market only with its own fleet.

The contribution of this paper is two-fold. Firstly, it examines the strategic relationship between network airlines and regional airlines and provides a framework to explain the various contractual relationships between network and regional airlines. Secondly, it enriches the “strategic divisionalization” literature by proposing a mechanism that allows firms to adjust their competitive strategies to achieve profit maximization under different conditions. We illustrate how this mechanism works in the airline industry.

The remainder of this paper is organized as follows. In Section 6.2, the theoretical model is developed along with propositions that are subsequently tested. Section 6.3, presents the econometric models used to test the theoretical predictions, as well as illustrate the empirical results. Section 6.4 provides a summary the results and discussion of the implications.

6.2 Theoretical Analysis

6.2.1 Model setting

The model is structured as a three-stage game. In the first stage, the network airlines decide how many regional airlines to subcontract with, if any. In the second stage, the network airlines determine what portion of the market to serve with their own fleets. In the last stage, each of the regional airlines determines how many passengers to serve, independently, given their knowledge of the traffic provided and served by the network airlines. We allow network airlines to make quantity decisions, prior to regional airlines,

---

119 This setting is related to the “endogenous merger” literature on endogenous choices of merger and alliance (e.g., Kamien and Zang, 1990; Bloch, 1995). Given the assumption that the number of regional airlines is sufficiently high, the first stage of the game can be viewed as “endogenous splitting”.

because even with a contract the two may still face conflicting incentives.\textsuperscript{120} It is natural to assume that network airlines will give priority to their own fleet during scheduling. In fact, there exist some institutional arrangements to secure such priority. For example, scope clauses in labor union contracts between network airlines and its labor unions create a constraint on the amount of routes that the network airline can outsource to the regional airline.\textsuperscript{121} In order to simplify the modeling we assume that the network airlines are able to design a contract with which they receive all of the rents.\textsuperscript{122}

We note that the regional airlines that operate under the name of a network airline do not always make independent decisions. In fact, in countries like the U.S., the network airline have specified the number of flights that they want from the regional airlines in the contract for most of the cases, especially for feed traffic that connects with a network airline hub. In return, the network airline generally pays the regional airline a fixed-fee for each departure, fixed fee for each passenger, with additional incentives based on completion of flights, on-time performance and baggage handling performance. In addition, the network and the regional airlines often enter into an arrangement pursuant to which the network airline bears the risk of changes in the price of fuel and other such costs. This is called “fixed-fee arrangements”. However, through subcontracting with

\textsuperscript{120} As argued by Forbes and Lederman (2009), network airlines and regional airlines will generally face conflicting incentives because while network airlines seek to optimize the overall profitability of their network, regional airlines face financial incentives that are based only on the subset of routes that they serve.

\textsuperscript{121} Typically, scope clauses take on one of two forms: 1) there is a cap on the total number of outsourcing by the network airlines to a regional airline partner or 2) the network airline must increase the amount of flights used by its own fleet by a pre-determined ratio for every increase in outsourced routes to regional airlines.

\textsuperscript{122} This is especially the case in recent years. As the business environment of the air industry is getting more and more harsh, network airlines become increasingly cost-conscious and tend to utilize their bargaining power to undercut regional airlines. Besides, many regional airline groups, such as Pinnacle in 2012, have gone bankrupt, while the surviving rest are also losing ground in the negotiation with network airlines due to their bad financial performances. It is also assumed that the structure of the contract between the network airline and each regional airline is such that every management team has full incentive to maximize the profit. In Appendix B.1 it will be argued how different types of contracts can result in fully incentivizing the management teams to maximize the profit and leave the rents to regional airlines.
(multiple) regional airlines, a network airline preserves the capability of granting the regional airlines the right to make independent decisions by short contractual periods and per-passenger revenue-sharing arrangements.\textsuperscript{123} Under a revenue-sharing arrangement, the network airline and regional airline negotiate a proration formula, pursuant to which the regional airline receives a percentage of the ticket revenues for those passengers traveling for one portion of their trip on the regional airline and the other portion of their trip on the network airline. All costs associated with the regional airline flight are borne by the regional airline. Although pure revenue-sharing arrangements are less common than fixed-fee arrangements in the network-regional relationship, it works as a commitment with which the strategic effects discussed below can be achieved. As suggested by standard economic theory, a commitment, as long as it is credible, does not need to be implemented in order to achieve strategic goals.\textsuperscript{124} In effect, by keeping the option easily implementable within arm’s reach, the network airline can accomplish the same strategic purposes even in the cases when independent decision-making is not explicitly granted to the regional airlines.

The mathematical models used in the paper are attempted to be close to that of papers such as Schwartz and Thompson (1986), Corchon (1991), and Baye et al. (1996). Some simplifications have been made for the tractability of the model. However, it should be noted that two important factors of the network-regional airline relationship are abstracted away, leaving some of the conclusions subject to scrutiny. First, the distance of the particular market is not taken into consideration; second, the strategic scenario may be considerably different whether regional airlines are used to feed hubs or provide

\textsuperscript{123} The contractual periods between a network airline and a regional airline are usually short. For example, the contract between United and SkyWest Airlines expires and needs to be renegotiated almost every two years. In particular, the United Express Agreement between these two companies is scheduled to expire incrementally on December 31, 2011, 2013, 2015, 2018 and 2020. There are cases when revenue-sharing arrangements are adopted in a network-regional contract. For example, in 2008, 20 of the 44 Brasilia turboprops that SkyWest Airlines operated as United Express were contracted under a revenue-sharing arrangement.

\textsuperscript{124} For example, an incumbent can build excess capacity, without fully utilizing it, in order to preempt potential entry, as suggested by Dixit (1980).
services in point-to-point routes.

6.2.2 Homogenous cost structure among airlines

Using backward induction we establish the Nash-Equilibrium results of the competition among $n$ homogenous network airlines. To begin we assume that a network airline has the same cost structure as the regional airlines it subcontracts with.\footnote{It is generally accepted that regional airlines have lower per passenger operating cost than network airlines. However, a similar cost structure is still possible under some circumstances. For example, regional airlines are usually banned by the “scope clauses” to operate larger aircrafts, while larger aircrafts incur less per passenger operating cost as long as the load factor is maintained above a certain level (Brueckner and Pai, 2009). In other words, the cost disadvantage of network airlines can sometimes be compensated by the more efficient aircrafts that they operate.} This assumption is based on the fact that when a network airline works closely with one or more regional airlines, there will likely be cost synergies, given that a good many of cost sources such as factor inputs, airport facilities and route densities can be shared among the partners. For example, a network airline may gain a cost advantage if it has a significant market share at an airport since it can use ground facilities and staff more efficiently and also obtain stronger negotiation power with the airport. This cost advantage can be largely passed on to the regional airlines collaborating with the network airline. The alternative, cost heterogeneity happens most often between “airline groups” rather than between network airlines only; cost heterogeneity between network airlines and regional airlines is considered in Section 6.2.4.

Consider there are $n$ homogenous network airlines competing in a market with an inverse demand function defined as:

$$P = A - Q_T$$

(6.1)

$P$ represents the equilibrium price and $Q_T$ represents the total passengers being served. We represent the total passengers served by the $i^{th}$ network airline by $Q_i$, the total number of passengers being served by the $j^{th}$ regional airline that contracts with the $i^{th}$ network
airline by \( q_{i,j} \), and the total number of regional airlines that contract with the \( i^{th} \) network airline by \( \delta_i \). Therefore, \( Q_T \) can be expressed as:

\[
Q_T = \sum_{i=1}^{n} Q_i + \sum_{i=1}^{n} \sum_{j=1}^{n} q_{i,j} = \sum_{i=1}^{n} (Q_i + \sum_{j=1}^{n} q_{i,j}) \tag{6.2}
\]

Define the marginal cost of production as \( C \). By introducing \( \theta = A - C \), the profit function of each of the regional airlines can be written as:

\[
\pi_{i,j} = (\theta - Q_T) q_{i,j} \tag{6.3}
\]

In the last stage of the game, all regional airlines maximize their own profit by choosing a profit maximization \( q^* \). The first order condition of the \( j^{th} \) regional airline is:

\[
\frac{\partial \pi_{i,j}}{\partial q_{i,j}} = \theta - Q_T - q_{i,j} \tag{6.4}
\]

In total there are \( \sum_{i=1}^{n} \delta_i \) equations of form (6.4). By solving this system of equations the symmetric Nash-equilibrium for the output of each regional airline will be:

\[
q^* = \frac{\theta - \sum_{i=1}^{n} Q_i}{1 + \sum_{i=1}^{n} \delta_i} \tag{6.5}
\]

We can now update the total quantities produced by all network and regional airlines by inserting \( q^* \) into equation (6.2) and derive:

\[
Q_T = \frac{\sum_{i=1}^{n} Q_i + \theta \sum_{i=1}^{n} \delta_i}{1 + \sum_{i=1}^{n} \delta_i} \tag{6.6}
\]

We next turn to Stage 2 and concentrate on the quantity decision of the network airlines. Considering equation (6.6) the profit function of the \( i^{th} \) network airline can be written as:

\[
\Pi_i = \left( \theta - \frac{\sum_{j=1}^{n} Q_j + \theta \sum_{i=1}^{n} \delta_i}{1 + \sum_{i=1}^{n} \delta_i} \right) Q_i \tag{6.7}
\]
The first order condition of the profit function of each network airline with respect to its output can be expressed as:

$$\frac{\partial \Pi_i}{\partial Q_i} = \frac{\theta - \sum_{j=1}^{n} Q_j - Q_i}{1 + \sum_{j=1}^{n} \delta_j}$$ (6.8)

The symmetric Nash-equilibrium is given by:

$$Q^* = \frac{\theta}{n + 1}$$ (6.9)

We can update the quantity produced by each regional airline and the total quantity produced by all airlines as a function of $\delta_i$s.

$$q^* = \frac{\theta}{(1 + n)(1 + \sum_{i=1}^{n} \delta_i)}$$ (6.10)

$$Q^*_T = \frac{\theta (n + (1 + n) \sum_{i=1}^{n} \delta_i))}{(1 + n)(1 + \sum_{i=1}^{n} \delta_i)}$$ (6.11)

Now, we consider the first stage where each network airline decides on the number of regional airlines to negotiate contracts with. It is natural to assume that the network airlines will maximize the profit of the whole group, which includes the profit that the network airline makes on its own, and the total profit earned by all of its regional airlines. Therefore, the network airline seeks to choose the optimal $\delta_i$ to maximize

$$\bar{\Pi}_i = (\delta_i q^* + Q^*)(\theta - Q^*_T) = \frac{\theta^2 (1 + \sum_{j=1}^{n} \delta_j + \delta_i)}{(1 + n)^2 (1 + \sum_{j=1}^{n} \delta_j)^2}$$ (6.12)

Proposition 6.1 If the cost efficiency of the regional airlines is the same as the network airlines, the result of the quantity competition among $n$ homogenous network airlines is that they each contract with 0 regional airlines and serves $Q^* = \frac{\theta}{n+1}$ passengers on their own.

Proof: Consider the partial derivative of the profit function (6.12) with respect to $\delta_i$.  

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\[
\frac{\partial \bar{\Pi}_i}{\partial \delta_i} = \frac{-2\theta^2 \delta_i}{(1 + n)^2(1 + \sum_{j=1}^n \delta_j)^3} \leq 0
\]

As the first order derivative is never positive, the best strategy that each network airline should adopt is to choose \( \delta_i^* = 0 \), therefore \( Q^* = \frac{\theta}{n+1} \). \(^{126}\)

Q.E.D.

Proposition 6.1 says that homogenous network airlines have no incentive to contract with regional airlines that do not show superior cost efficiency. On the one hand, as stated earlier, regional airline’s relative cost efficiency in the smaller regional market is one of the prime reasons that network airlines outsource their traffic. The incentive to contract with the regional airlines would no doubt be lower without this driving force. On the other hand, from a strategic perspective, rival network airlines will not be intimidated by the decision of one network airline setting up contracts with regional airlines because they know it is a self inflicted losing strategy. \(^{127}\)

In contrast to the results from some studies, such as Baye et al. (1996), that predict the equivalent results of full competition for some extreme cases, Proposition 6.1 indicates that intense competition will not happen when the homogenous competitors compete in a multi-stage manner.

In effect, such a game structure is used as a commitment among homogenous network airlines.

\(^{126}\) If the network airlines also consider the profit of the regional airlines at the second stage of the game, Proposition 6.1 would still hold under this assumption:

\[
Q_i^* = \frac{\theta(1 + \left( \sum_{j=1}^n \delta_j \right) - \delta_i)}{(1 + n)((n - 1)\delta_i)}
\]

\[
\frac{\partial \bar{\Pi}_i}{\partial \delta_i} = \frac{-2\theta^2(n - 1)(1 + \left( \sum_{j=1}^n \delta_j \right) - \delta_i)}{(1 + n + (n - 1)\sum_{j=1}^n \delta_j)^3} \leq 0
\]

\(^{127}\) Throughout the paper we intentionally disregarded the fixed costs associated with contracting with regional airlines since if the models show sustainable equilibriums in the case of zero fixed cost of contracting with regional airlines, the results will be true for the cases where they incur positive fixed costs on contracting with regional airlines.
airlines not to compete more intensively than Cournot, even when including regional airlines in the game. They will act softly when they encounter rivals identical to themselves. Proposition 6.1 provides a potential explanation as to why we do not observe any regional airlines in some of the markets.

6.2.3 Heterogeneous cost structures among network airlines

In this section we consider competition among network airlines with different variable costs. Again, we assume that a network airline has the same cost structure with the regional airlines that it subcontracts with so this cost heterogeneity is among “airline groups”.

We assume that network airline $i$'s marginal cost of operating in a specific city pair is $C_i$. By considering the linear inverse demand function, the profit function of the $j^{th}$ regional airline that contracts with the $i^{th}$ network airline can be written as:

$$\pi_{i,j} = (P - C_i)q_{i,j}$$ (6.13)

Similar to equation (6.4), the changes in each regional airline's profit with respect to its output level can written as:

$$\frac{\partial \pi_{i,j}}{\partial q_{i,j}} = A - C_i - Q_T - q_{i,j}$$ (6.14)

Therefore, the Nash-equilibrium for each regional airline of the $i^{th}$ network airline is:

$$q_{i,j}^* = \frac{A - \sum_{k=1}^{n} C_k + \sum_{k=1}^{n} C_k \delta_k - (1 + \sum_{k=1}^{n} \delta_k)C_i}{1 + \sum_{k=1}^{n} \delta_k}$$ (6.15)

and, the total number of passengers served by all regional airlines is:

$$\sum_{i=1}^{n} \sum_{j=1}^{\delta_i} q_{i,j}^* = \frac{(A - \sum_{k=1}^{n} C_k)(\sum_{k=1}^{n} \delta_k) - \sum_{k=1}^{n} C_k \delta_k}{1 + \sum_{k=1}^{n} \delta_k}$$ (6.16)
We solve the second stage game to determine the number of passengers served by the network airline. The profit function of the $i^{th}$ network airline can be written as:

$$\Pi_i = (P - C_i) Q_i$$  \hfill (6.17)

The first order condition of the network airline’s profit, with respect to their output level, can be expressed as:

$$\frac{\partial \Pi_i}{\partial Q_i} = A - C_i - Q_T - Q_i$$  \hfill (6.18)

By substituting (6.16) in (6.18) and solving the first order conditions, the Nash equilibrium for outputs of each network airline on its own will become:

$$Q_i^* = \frac{A + \left( \sum_{j=1}^{n} C_j - (n + 1)C_i \right) \left( 1 + \sum_{j=1}^{n} \delta_j \right) + \sum_{j=1}^{n} C_j \delta_j}{n + 1}$$  \hfill (6.19)

Therefore, the output of each regional airline can be expressed as:

$$q_{i,j}^* = \frac{Q_i^*}{1 + \sum_{j=1}^{n} \delta_j}$$  \hfill (6.20)

From (6.20) we can see that $Q_i^* \geq q_{i,j}^*$, which means that it is not possible to have $Q_i^* = 0$ while $q_{i,j}^* > 0$.

The margin of each network or regional airline, $P - C_i$ can be expressed as:

$$P - C_i = A - Q_T - C_i = q_{i,j}^* = \frac{Q_i^*}{1 + \sum_{j=1}^{n} \delta_j}$$  \hfill (6.21)

In stage 1, each network airline decides on the number of regional airlines to contract with. They consider the total profit available from their own network airline operators and $\delta_i$ the regional airlines. The total profit they can earn can be written as:
\[ \Pi_i = (P - C_i)(Q_i^* + \delta_i q_{i,j}^*) \]  
(6.22)

By substituting (6.19), (6.20), and (6.21) into (6.22) the airlines total profit can be re-expressed as:

\[ \Pi_i = \frac{(1 + \delta_i + \sum_{j=1}^{n} \delta_j)Q_i^{*2}}{(1 + \sum_{j=1}^{n} \delta_j)^2} \]  
(6.23)

**Proposition 6.2** Among heterogeneous network airlines that compete with each other, only the more cost efficient companies - the companies whose marginal cost is less than the average marginal cost of all of the companies - may set up contracts with regional airlines.

Proof: The results will become apparent if we take the first order derivatives of (6.23) with respect to the number of regional airlines.

\[ \frac{\partial \Pi_i}{\partial \delta_i} = \frac{-2\delta_i Q_i^{*2}}{(1 + \sum_{j=1}^{n} \delta_j)^3} + \frac{2Q_i^*(\sum_{j=1}^{n} C_j - nC_i)(1 + \delta_i + \sum_{j=1}^{n} \delta_j)}{(n + 1)(1 + \sum_{j=1}^{n} \delta_j)^2} \]

\[ \frac{-2\delta_i Q_i^{*2}}{(1 + \sum_{j=1}^{n} \delta_j)^3} \leq 0 \] and for \( C_i \geq \frac{\sum_{j=1}^{n} C_j}{n} = \bar{C} \) results in \( \sum_{j=1}^{n} C_j - nC_i \leq 0 \), therefore, \( \frac{\partial \Pi_i}{\partial \delta_i} \leq 0 \) for \( C_i \geq \bar{C} \). Hence, those airlines which have marginal costs higher than the average marginal cost of all of the existing airlines, have no incentive to negotiate a contract with any regional airlines; only the more cost efficient airlines may have an incentive to contract with regional airlines.

Q.E.D.

The results in Proposition 6.2 are intuitive. More cost efficient network airlines will not be intimidated by the threat of competition from less efficient network airlines that set up contracts with regional airlines. However, the less cost efficient network airlines have legitimate reasons to view cost efficient network airlines’ contract relationships with regional airlines as a serious threat.
We show the circumstances under which the efficient network airlines will set up contracts with regional airlines, and under what conditions the inefficient network airlines will no longer serve the market, if efficient network airlines contract with regional airlines.

In the following subsections we will first consider competition between 1 efficient and \( n-1 \) inefficient network airlines, and then we consider the general case of \( m \) efficient and \( n \) inefficient network airlines.

### 6.2.3.1 One efficient and \( n-1 \) inefficient airlines

Assume one efficient and \( n-1 \) inefficient network airlines and without loss of generality normalize the marginal cost of the efficient network airline to zero. \( C \) is the marginal cost of less efficient network airline.

Based on Proposition 6.2, we know that the inefficient network airlines will not contract with regional airlines as \( C \) is more than the average cost of all network airlines \( \bar{C} = \frac{(n-1)C}{n} \leq C \). Therefore, it is straightforward to show that the Nash-equilibrium output for the regional airlines that contract with the efficient network airline is:

\[
q_i^* = \frac{A - \sum_{j=1}^{n} Q_j}{1 + \delta_i} \tag{6.24}
\]

The Nash-equilibrium result for the output of the more efficient network airline on its own is:

\[
Q_i^* = \frac{A + (n - 1)(1 + \delta_i)C}{n + 1} \tag{6.25}
\]

and the Nash-equilibrium result for the output of the less efficient network airlines is:

\[
Q_j^* = \frac{A - 2(1 + \delta_i)C}{n + 1} \tag{6.26}
\]

Therefore, for \( \delta_i \geq \frac{A}{2C} - 1 \) the inefficient network airlines will become unprofitable. By
substituting (6.25) and (6.26) into (6.24) we have:

\[ q_i^* = \frac{A + (1 + \delta_i)(n - 1)C}{(n + 1)(1 + \delta_i)} \]

(6.27)

Proposition 6.3 If there is one efficient and \( n-1 \) inefficient network airlines, either the cost efficient network airline will never contract with regional airlines, or the cost efficient network airline will negotiate a contract with \( \frac{A}{2c} - 1 \) regional airlines and drive inefficient network competitors out of the market. The efficient network airline's decision depends on the following conditions:

\[ \delta_i^* = \begin{cases} 
0 & \text{if } \frac{A}{c} \geq 1 + n^2 \\
\frac{A}{2c} - 1 & \text{otherwise} 
\end{cases} \]

Proof: By looking at \( \frac{\partial \bar{\Pi}_i}{\partial \delta_i} \) it is easy to see \( \bar{\Pi}_i \) is an increasing function of \( \delta_i \) from 0 to

\[ \delta_i = \frac{A - \sqrt{A(A - 4c(n-1))}}{2c(n-1)} - 1. \]

It is a decreasing function of \( \delta_i \) for \( \delta_i = \frac{A - \sqrt{A(A - 4c(n-1))}}{2c(n-1)} - 1 \) to \( \delta_i = \frac{A - \sqrt{A(A - 4c(n-1))}}{2c(n-1)} + 1 \) and an increasing function of \( \delta_i \) for \( \delta_i = \frac{A - \sqrt{A(A - 4c(n-1))}}{2c(n-1)} + 1 \) to \( \delta_i = \frac{A}{2c} - 1. \)

Therefore, the optimal number of regional airlines, \( \delta_i \), is either \( \delta_i^{**} = \frac{A}{2c} - 1 \) or \( \delta_i^* = \frac{A - \sqrt{A(A - 4c(n-1))}}{2c(n-1)} - 1. \) It is straightforward to show \( 0 \leq \delta_i^* \leq 1. \)

By imposing integer conditions on the total number of regional airlines, the result of \( \bar{\Pi}_i(\delta_i=0), \bar{\Pi}_i(\delta_i = 1), \) and \( \bar{\Pi}_i(\delta_i = \frac{A}{2c} - 1) \) can be compared. It can be verified that the optimal level of regional airlines that an efficient network airline will contract with is:

\[ \delta_i^* = \begin{cases} 
0 & \text{if } \frac{A}{c} \geq 1 + n^2 \\
\frac{A}{2c} - 1 & \text{otherwise} 
\end{cases} \]
Q.E.D.

Figure 6.1 shows how the decision of the efficient airline is contingent on the ratio of the cost of the inefficient airlines to the market size, $C/A$, and $n$, total number of airlines in the market.

**Figure 6.1 Decision of the most efficient airline for different $C/A$, and $n$**

Note: Region A corresponds to conditions where the efficient airline will not contract with any regional airlines. In region B it will contract with enough regional airlines to make the entrance of competitors unprofitable.

There are two distinct areas in Figure 6.1. In Region B, if the market size is small or the efficient network airline is considerably more efficient that the other network airlines, the efficient network airline will negotiate contracts with a sufficient number of regional airlines to pre-empt the competition.

Region A of Figure 6.1 shows the outcome when the market is large and the comparative cost advantage is small. In Region A, the incentive for the efficient network airline to contract with regional airlines is weak. This is because, in such an environment, both less efficient and more efficient companies can reap reasonable profits when engaged in
Cournot competition. Besides, when the market is large, existing carriers can all achieve density economies, so there is no need to compete aggressively.

### 6.2.3.2 $m$ efficient and $n$ inefficient airlines

Now consider the case of $m$ efficient and $n$ inefficient network airlines that can potentially serve a city pair. We normalize the cost of the efficient network airlines to 0 and consider the marginal cost of less cost-efficient network airlines to be $C$. Again, based on the results of Proposition 6.2, we can expect that the less-efficient network airlines will not contract with any regional airlines. Therefore, we only consider the number of regional airlines in a contract with the efficient network airlines, $\delta_l$. It is relatively straightforward to compute the Nash-Equilibrium for the total number of passengers served by the regional airlines, $q^*_l$ and by the efficient network airlines on their own, $Q^*_l$, and passengers served by the inefficient network airlines, $Q^*_j$, as (6.28), (6.29), and (6.30):

$$q^*_l = \frac{A + n(1 + \sum_{j=1}^{m} \delta_j)C}{(1 + \sum_{j=1}^{m} \delta_j)(1 + n + m)} \quad (6.28)$$

$$Q^*_l = \frac{A + n(1 + \sum_{j=1}^{m} \delta_j)C}{1 + n + m} \quad (6.29)$$

$$Q^*_j = \frac{A - (m + 1)(1 + \sum_{j=1}^{m} \delta_j)C}{1 + n + m} \quad (6.30)$$

Therefore, for $\delta_l \geq \frac{A - C(m+1)}{Cm(1+m)}$ the inefficient airlines cannot operate profitably in that city-pair.

**Proposition 6.4** If there are $m$ efficient and $n$ inefficient network airlines, either the efficient network airlines will never contract with any regional airlines, or they will contract with $\frac{A - C(m+1)}{Cm(1+m)}$ regional airlines and preempt the competition from inefficient competitors. The efficient network airline’s decision depends on the following conditions:
\[ \delta^*_i = \begin{cases} 
0 & \text{if } A \geq C + \frac{(1+n)^2}{m} \\
\frac{A-C(m+1)}{C(m+1)} & \text{otherwise} 
\end{cases} \]

Proof: By considering the change in \( \Pi_i \) with respect to \( \delta_i \) and imposing symmetry on the \( \delta_i \)'s we have:

\[ \frac{\partial \Pi_i}{\partial \delta_i} = \frac{2(A + Cn(1 + m\delta_i))(-A\delta_i + Cn(1 + m\delta_i))^2}{(1 + n + m)(1 + m\delta_i)^2} \]

Thus \( \Pi_i \) is increasing over \( \delta_i \) from 0 to \( \frac{A-Cmn-\sqrt{A(A-4Cmn)}}{2Cmn} \), decreasing in \( \delta_i = \frac{A-Cmn-\sqrt{A(A-4Cmn)}}{2Cmn} \) to \( \frac{A+Cmn-\sqrt{A(A-4Cmn)}}{2Cmn} \), and increasing in \( \frac{A+Cmn-\sqrt{A(A-4Cmn)}}{2Cmn} \), to \( \frac{A-C(m+1)}{Cm(1+m)^2} \).

It is again easy to check that \( \frac{A-Cmn-\sqrt{A(A-4Cmn)}}{2Cmn} \leq 0.5 \); \( \forall m \geq 2 \). Therefore the symmetric Nash equilibrium is:

\[ \delta^*_i = \begin{cases} 
0 & \text{if } A \geq C + \frac{(1+n)^2}{m} \\
\frac{A-C(m+1)}{C(m+1)} & \text{otherwise} 
\end{cases} \]

Q.E.D.

Proposition 6.4 indicates that although the efficient network airlines have an incentive to keep the inefficient network airlines out of the market, they have no incentive to engage in intense competition with other network airlines that are as efficient. Market size matters too. In small markets the efficient network airlines have a greater incentive to contract with regional airlines and drive inefficient network airlines from the market. However, the efficient network airlines have no incentive to contract with a regional

\[ \text{If } \frac{A-C(m+1)}{Cm(1+m)} \geq \frac{A+Cmn-\sqrt{A(A-4Cmn)}}{2Cmn} \]
airline if the market size is sufficiently large. They prefer to coexist with less efficient airlines and share the profits. It should be noted that these extreme situations (either no or a market pre-emptive number of regional airlines are contracted) exist when the fixed cost of network-regional partnership formation is not taken into account. If this assumption is relaxed, we might well end up with a number in between.

6.2.4 Heterogeneous cost structures between network airlines and regional airlines

So far, only the cost difference between network airlines (“airline groups”) has been considered. However, recognizing that there are markets in which regional airlines are more cost efficient, such as thin or short-haul routes, the cost difference between network airlines and regional airlines should also be considered.\(^{129}\)

To model this scenario we assume that cost efficiency is identical among network airlines and among regional airlines, but different across the two groups. We then normalize the marginal cost of regional airlines to zero and consider \(C_o\) as the marginal cost of network airlines in providing services to passengers. Following the same steps taken in previous sub-sections we can easily verify that:

\[
q_i = \frac{A - (Q_i + Q_j)}{1 + \delta_i + \delta_j} \quad (6.31)
\]

\[
Q_i = \frac{A - C_o(1 + \delta_i + \delta_j)}{3} \quad (6.32)
\]

\(^{129}\) Papers like Brueckner (2009) and Fageda and Flores-Fillol (2012a) assume a higher cost per passenger for regional airlines than for network airlines based on the fact that smaller aircrafts used by the regional airlines are less cost efficient on a per-seat basis. However, this assumption only holds when both the network airlines and the regional airlines maintain a similar level of load factors, which is valid only for larger markets. For markets where the network-regional partnerships exist, it is usually not economical to use larger aircrafts because they cannot be filled. In other words, for markets of out interest, the regional airlines have a cost advantage over the network airlines (Forbes and Lederman, 2009; 2010).
Simulated results show that in a duopoly setting described above the symmetric Nash-Equilibrium is\(^{130}\)

\[
\delta_i^* = \begin{cases} 
0 & \text{if } \frac{A}{C_0} \geq 10 \\
\infty & \text{otherwise} 
\end{cases} 
\]

(6.33)

\[
Q_l^* = \begin{cases} 
\frac{A-C_0}{3} & \text{if } \frac{A}{C_0} \geq 10 \\
0 & \text{otherwise} 
\end{cases} 
\]

Even this simple case is mathematically intractable at the first stage. The simulated results are presented in Figure 6.2.

Figure 6.2 Results of simulation in the case of cost heterogeneity between network and regional airlines

\[^{130}\text{It must be noted that infinity is a pure mathematical hypothetical result. In reality the number of regional airlines that the network airlines can contract with are limited, so it is natural to assume that this number is bounded by total number of available airlines. It is more reasonable to interpret infinity as “as much as possible/feasible”. Moreover, if we take into account the fixed payments to the regional airlines, or a positive marginal cost, infinity will no longer be equilibrium either.}\]
The simulated results suggest that unless there is significant cost advantage for regional airlines compared with network airlines, the homogeneous network airlines will not contract with any regional airline. However, once the relative cost advantage of regional airlines is significant then the network airlines will compete intensely through contracting with as many regional airlines as possible. The result at first glance appears unreasonable since the network airlines end up contracting with an infinite number of regional airlines in equilibrium. However, we do not consider the transactions cost of outsourcing traffic (negotiation, contract designing, etc.) and the limited number of potential regional airlines a network airline can contract with. Taking these factors into consideration may give a much smaller number as the equilibrium.

6.2.5 Hypothesis from the theoretical models

To anticipate the econometric modeling in Section 6.3, the theoretical predictions that will be tested are summarized below.\textsuperscript{131}

Proposition 6.1 states that in the absence of cost differences between network airlines, as well as between network and regional airlines, network airlines have no incentive to contract with any regional airline.

Proposition 6.2 states that only cost efficient network airlines have the possibility to contract with regional airlines.

Propositions 6.3 and 6.4 suggest market size and the magnitude of cost differences between network airlines (airline groups) are the primary determinants of whether cost efficient network airlines will contract with any regional airline and how many to contract with. Specifically, all else being constant, a larger market leads to fewer network airlines contracting with regionals. However, the larger the cost differences between

\textsuperscript{131} It is important to note that throughout sections 6.2.2 to 6.2.4 we changed one variable at a time. By this mechanism we are able to perform comparative statics of our models and later check the mathematical results with our empirical tests.
network airlines, the higher the propensity of the cost efficient network airlines to contract with regional airlines.

The model also predicts the strategic interactions between the decision variables of the network airlines. To be specific, we expect the network airline’s decision on whether to operate in a market with their own fleet is negatively correlated with the decisions of other network airlines on whether or not to operate in this market; while the number of regional airlines that a network airline contracts with is also negatively correlated with the number of regional airlines that other network airlines contract with.\textsuperscript{132}

In Section 6.2.4, we further showed by simulation that the more cost efficient the regional airlines are compared with the network airlines, the higher the tendency of these network airlines to negotiate contracts with regional airlines.

\textbf{6.3 Empirical Tests}

\textbf{6.3.1 Data}

Econometric models are developed to test the predictions stated above. The focus is on the network airline’s basic decision of how many regional airlines to contract with and whether or not to operate in the market with their own fleet. Therefore, rather than the three-stage game analyzed in the theoretical model, we adopt a two-stage game setting for the structural econometric models. Only the first and the second stages of the theoretical model are included with attention shifting in the second stage to whether or not the network airlines operate in the market on their own (a binary decision).

The primary data source is the Airline Origin and Destination Survey (DB1B). DB1B is a 10 percent random sample of tickets sold by U.S. airlines for domestic travel in a

\textsuperscript{132} Readers are referred to Appendix B.2 for predictions about first order strategic effects of decision variables at the first and second stage of the game.
quarterly period. Each record contains an array of information including the ticketing carrier, the operating carrier, the origin and destination airports and the coupon distance. And we supplement the DB1B dataset with U.S. census data for demographic information (such as GDP and population). The details of data construction are given in Appendix C.4.

The summary statistics are presented in Table 6.2.

Table 6. 2 Summary statistics of data sample

<table>
<thead>
<tr>
<th>Number of OD markets</th>
<th>1460</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum number of regional airlines a network airline contracts with in a market</td>
<td>5</td>
</tr>
<tr>
<td>Number of OD markets with a hub airport involved</td>
<td>304</td>
</tr>
<tr>
<td>Number of leisure markets</td>
<td>329</td>
</tr>
<tr>
<td>Number of OD markets with a slot-controlled airport involved</td>
<td>324</td>
</tr>
</tbody>
</table>

From the dataset that we construct, we summarize the main regional partners of each network airline. This information is consistent with the 2010 Annual Report of Regional Airline Association (RAA) and presented in Table 6.3. It should be noted that some of the regional airlines are fully owned subsidiaries of a particular major carrier. However, as argued by Forbs and Lederman (2009), their operations are not integrated into the major’s operation.

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133 The DB1B database is part of TranStats, the Bureau of Transportation Statistics’ (BTS) online collection of databases, and contains coupon-specific information. A coupon indicates the itinerary of a passenger and essentially identifies a segment of travel. Even though the DB1B is only a 10 percent random sample, each quarterly period of the DB1B database contains a very large amount of data.

134 This table is similar to Table 1 in Forbes and Lederman (2009). However, Forbes and Lederman (2009) obtain the information directly from RAA, while we use RAA information for verification only.
Table 6.3 Network and regional partnership in 1st quarter of 2010

<table>
<thead>
<tr>
<th>Network Airline</th>
<th>Regional Partner</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Airlines</td>
<td><strong>American Eagle</strong></td>
</tr>
<tr>
<td></td>
<td>Executive Airlines</td>
</tr>
<tr>
<td>Delta Air Lines</td>
<td>Pinnacle Airlines</td>
</tr>
<tr>
<td></td>
<td>Compass Airlines</td>
</tr>
<tr>
<td></td>
<td>ExpressJet Airlines</td>
</tr>
<tr>
<td></td>
<td><strong>Comair</strong></td>
</tr>
<tr>
<td></td>
<td>SkyWest Airlines</td>
</tr>
<tr>
<td></td>
<td>Mesaba Airlines</td>
</tr>
<tr>
<td></td>
<td>Chautauqua Airlines</td>
</tr>
<tr>
<td></td>
<td>Shuttle America</td>
</tr>
<tr>
<td>United Airlines</td>
<td>PSA Airlines</td>
</tr>
<tr>
<td></td>
<td>Colgan Air</td>
</tr>
<tr>
<td></td>
<td>Trans States Airlines</td>
</tr>
<tr>
<td></td>
<td>ExpressJet Airlines</td>
</tr>
<tr>
<td></td>
<td>GoJet Airlines</td>
</tr>
<tr>
<td></td>
<td>SkyWest Airlines</td>
</tr>
<tr>
<td></td>
<td>ExpressJet Airlines Inc.</td>
</tr>
<tr>
<td></td>
<td>Shuttle America</td>
</tr>
<tr>
<td></td>
<td>Mesa Airlines</td>
</tr>
<tr>
<td>US Airways</td>
<td><strong>PSA Airlines</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Piedmont Airlines</strong></td>
</tr>
<tr>
<td></td>
<td>Colgan Air</td>
</tr>
<tr>
<td></td>
<td>SkyWest Airlines</td>
</tr>
<tr>
<td></td>
<td>Mesa Airlines</td>
</tr>
<tr>
<td></td>
<td>Republic Airlines</td>
</tr>
<tr>
<td></td>
<td>Air Wisconsin Airlines</td>
</tr>
<tr>
<td>Continental Airlines</td>
<td>Colgan Air</td>
</tr>
<tr>
<td></td>
<td>Commutair</td>
</tr>
<tr>
<td></td>
<td>Chautauqua Airlines</td>
</tr>
<tr>
<td></td>
<td>ExpressJet Airlines</td>
</tr>
</tbody>
</table>

Note: Regional airlines in bold are fully owned by the corresponding major airline.
The proportions of different contractual relationships between network and regional airlines in the dataset are given in Table 6.4. We can see that none of these relationships has a value lower than 10 percent, which suggests that the diversity of network-regional relationships is caused by systematic forces rather than some random factors.

### Table 6.4 Percentages of different contractual relationships between network and regional airlines

<table>
<thead>
<tr>
<th>Contractual Relationship</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network operation only</td>
<td>29.71%</td>
</tr>
<tr>
<td>No network operation, one regional airline</td>
<td>24.46%</td>
</tr>
<tr>
<td>No network operation, multiple regional airlines</td>
<td>10.96%</td>
</tr>
<tr>
<td>Network operation and one regional airline</td>
<td>19.52%</td>
</tr>
<tr>
<td>Network operation and multiple regional airlines</td>
<td>15.34%</td>
</tr>
</tbody>
</table>

### 6.3.2 Variables

The variables included in the empirical models are:

- $N_{im}$: The number of regional airlines that network airline $i$ contracts with for market $m$.

- $p_{im}$: A binary variable showing whether network airline $i$ operates its own flights in market $m$. It takes the value 1 if the network airline operates its own flights, and 0 otherwise.

- $MS_{origin_{im}}$: The market share of network airline $i$ in the “origin” airport of market $m$.

- $MS_{dest_{im}}$: The market share of network airline $i$ in the “destination” airport of market $m$.

- $No_{other_{m}}$: The number of smaller network airlines, Low Cost Carriers and independently operating regional airlines in market $m$.

- $log\_Distance_{m}$: Logarithm of the non-stop distance of market $m$. 

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\( \log_{\text{TotPass}}_m \): Logarithm of the total number of passengers in market \( m \) and used to proxy market size.\(^{135}\)

**Hub:** A dummy variable indicating that either the origin or the destination airport is a hub for the network airline.\(^{136}\)

**Slot:** A dummy variable indicating that either the origin or the destination airport is a Slot controlled airport.

**Leisure:** A dummy variable indicating that either the origin or the destination airport is a major tourist destination.

The theoretical model concentrates on three parameters: \( A \) (market size), \( C \) (cost difference between network airlines), and \( C_0 \) (cost difference between network and regional airlines with which they contract). \( \log_{\text{TotPass}}_m \) is used to proxy market size. It should be noted that this variable is the ‘realized’ or ‘equilibrium’ market size, which is not exactly the same as what \( A \) means, although they are highly correlated. The two market-share variables -- \( MS_{\text{origin}}_{im} \) and \( MS_{\text{dest}}_{im} \) -- are used to proxy the cost difference between network airlines. \( \log_{\text{Distance}}_m \) is a control variable.

### 6.3.3 Econometric models

As discussed in Section 6.2, for the network airlines, the number of regional airlines to

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\(^{135}\) Probably the more accurate definition of \( \log_{\text{TotPass}}_m \) is 10\% of the total number of passengers in market \( m \). We intentionally use logarithm functional forms because multiplying the total number of passengers by 10 will only add a constant term to our econometric models. \( \log(10^aX) = \log(10) + \log(X) \)

\(^{136}\) This variable, together with \( MS_{\text{origin}} \) and \( MS_{\text{dest}} \), is a proxy for network airline cost efficiency. Empirical literature suggests that hubs allow an airline to achieve lower costs through economies of density (e.g., Hansen, 1990). Schnell and Hueschelrath (2004) point out hubs have lower costs from three sources, economies of density, economies of scope, economies of aircraft size and homogeneity of fleet. Hendricks et al. (1995) are the first to show endogenous formation of hub-and-spoke network structure in the presence of transport density economies. The relationship between airline market share and operating costs (where higher market share leads to lower operating costs) are described in detail in Belobaba et al. (2009).
contract with in a market is a longer run decision, while whether or not to operate in this market is more of a short-run decision. Therefore, in the first step, the airlines have to decide on the number of regional airlines to contract with, anticipating how many regional airlines other airlines may contract with, and their own and other airline’s decision on whether or not to operate on that route.

In effect, airline $i$’s decision on the number of regional airlines to contract with for route $m$, $N_{i,m}$, depends on the total number of regional airlines that all airlines contract with, $\sum_{j \neq i} N_{j,m}$, whether or not the network airline $i$ operates the route on its own $p_{im}$ (a binary variable), the total number of other network airlines which serve that route, $\sum_{j \neq i} p_{j,m}$, and finally the vector of market specific and airline specific variables,

$$\bar{X}_i = (MS\_origin_{im}, MS\_dest_{im})$$

and

$$\bar{X}_m = (No\_other_m, \log\_Distance_m, GDPpc\_Origin_m, GDPpc\_Dest_m, Delay\_Origin_m, Delay\_Dest_m, \log\_TotPass_m)$$

We can rewrite this relationship:

$$N_{i,m} = f \left( \sum_{j \neq i} N_{j,m}, p_{im}, \sum_{j \neq i} p_{j,m}, \bar{X}_i, \bar{X}_m, \varepsilon \right) \quad (6.34)$$

$N_{i,m}$ and $N_{j,m}$ are chosen simultaneously and the choice of $p_{i,m}$ and $p_{j,m}$ are dependent on the choice of $N_{i,m}$ and $N_{j,m}$.

To address the endogeneity problem in (6.34), arising from the second order effect of variables $p_{im}$ and $\sum_{j \neq i} p_{j,m}$, we change our focus in Stage 2 of the game. In Stage 2, the network airlines decide whether or not to enter the market, given choices made in the first stage; that is, choices on $N_{i,m}$ and $N_{j,m}$. This means, $N_{i,m}$ and $N_{j,m}$ are treated exogenously in the second step. We can write:
\[
\sigma(p_{lm} = 1) = g \left( N_{i,m}, \sum_{j \neq i} N_{j,m}, \sum_{j \neq i} \sigma(p_{j,m} = 1), \tilde{X}_i, \tilde{X}_m, \varepsilon \right)
\] (6.35)

Again, there is an endogeneity issue in (6.35); in the second stage \( p_{l,m} \) and \( p_{j,m} \) s are chosen simultaneously. We follow the two-step estimation approach developed and utilized by Moro (2003) and Bajari et al. (2007, 2010a, b and c).\(^{137}\) It is possible to obtain consistent estimates of the parameters in (6.35) in this two-stage setting. At the first stage we instrument up to the \( k^{th} \)-order polynomial in every network airline specific and market specific variable values and estimate \( \sigma(p_{j,m}) \) for every network airline. We then replace estimated values of \( (p_{j,m}), \sigma(p_{j,m}) \) in (6.35) and next estimate the parameters of interest. We estimate these parameters as:

\[
\sigma(p_{lm} = 1) = g \left( N_{i,m}, \sum_{j \neq i} N_{j,m}, \sum_{j \neq i} \hat{\sigma}_j(p_{j,m} = 1), \tilde{X}_i, \tilde{X}_m, \varepsilon \right)
\] (6.36)

As an example, consider a logistic functional form for \( g \). The market specific and network airline specific variables are the market shares of each network airline at both the origin and the destination airports, the distance between the origin and the destination, the number of other airlines (besides the five network airlines and the regional airlines operating under the network airline’s name) competing in the market, the hub, slot, and leisure dummy variables, and the total number of passengers in this market.

In the first stage we define \( \tilde{Z}_K(\tilde{X}_i, \tilde{X}_j, \tilde{X}_m) \) as the \( k^{th} \)-order polynomial\(^{138}\) in \( \tilde{X}_i, \tilde{X}_j, \tilde{X}_m \). Next we estimate the parameters \( \theta_i \) for every airline \( i \) in (6.37) as:

\[
\sigma_{im}(p_{lm} = 1|\tilde{X}_i, \tilde{X}_j, \tilde{X}_m, \theta_i) = \frac{\exp(\tilde{Z}_K(\tilde{X}_i, \tilde{X}_j, \tilde{X}_m)'\theta_i)}{1 + \exp(\tilde{Z}_K(\tilde{X}_i, \tilde{X}_j, \tilde{X}_m)'\theta_i)}
\] (6.37)

\(^{137}\) Bajari et al. (2010a) have done a very nice survey of this method.

\(^{138}\) \( k=3 \) in our model.
These estimated parameters are next used to estimate $\hat{\sigma}_{jm}$. We use the estimated values of $\hat{\sigma}_{jm}$ in the right hand side of the equation (6.36) and find the parameters of interest in (6.36). For instance we estimate $\alpha, \beta, \gamma, \delta_1, \delta_2$ in the following logit model:

$$
\sigma_{lm}(p_{lm} = 1 | \tilde{X}_i, \tilde{X}_m; \alpha, \beta, \gamma, \delta_1, \delta_2) = \frac{\exp(\alpha N_{i,m} + \beta \sum_{j \neq i} N_{j,m} + \gamma \sum_{j \neq i} \hat{\theta}_j (p_{j,m} = 1) + \delta_1' \tilde{X}_i + \delta_2' \tilde{X}_m)}{1 + \exp(\alpha N_{i,m} + \beta \sum_{j \neq i} N_{j,m} + \gamma \sum_{j \neq i} \hat{\theta}_j (p_{j,m} = 1) + \delta_1' \tilde{X}_i + \delta_2' \tilde{X}_m)} \quad (6.38)
$$

Having obtained unbiased estimates of the parameters we are interested in in the second stage, we return to the first stage of the game. In order to find the unbiased estimates of parameters in (6.34) we will need to follow the exact procedure used to deal with the endogeneity problem in (6.35).

We first regress $N_{i,m}$ on $\tilde{Z}_K(\tilde{X}_i, \tilde{X}_j, \tilde{X}_m)$ and replace $N_{j,m}$ in equation (6.34). We also use the estimated values of $\hat{\sigma}_{im}(p_{im} = 1)$ and $\hat{\sigma}_{jm}(p_{jm} = 1)$. We can now estimate the unbiased parameters in equation (6.39)

$$
N_{i,m} = f \left( \sum_{j \neq i} \tilde{N}_{j,m}, \hat{\sigma}_{im}(p_{im} = 1), \sum_{j \neq i} \hat{\sigma}_{jm}(p_{jm} = 1), \tilde{X}_m, \varepsilon \right) \quad (6.39)
$$

There are several candidates for the functional forms $f(.)$ in (6.34) and (6.39). Since $N_{i,m}$ is a non-negative integer number the Poisson and Negative Binomial functional forms could be used. In addition Tobit or Truncated Regression models can be used to impose non-negativity as well as Probit and Logit models replacing $N_{i,m}$ by $1(N_{i,m} > 0)$. As a result we consider 6 functional forms for $f(.)$.\(^{139}\)

For $g(.)$ in (6.35) to (6.37) two functional forms, Logit and Probit are used. Since the first stage results must be evaluated based on the second stage results, there will be different

\(^{139}\) The use of multiple functional forms can also validate the robustness of our empirical results. If we obtain similar results with different functional forms it means that our model is not sensitive to any particular specification.
combinations of econometrical results. For example, using Logit at the second stage and Tobit for the first stage, will yield different results from the case where Probit is used for the second stage and Tobit for the first stage. Due to the sensitivity of the models to functional forms, ten different combinations of functional forms are investigated. Eight of the combinations where mixing Logit and Probit for the second stage with Poisson, Negative Binomial, Tobit, and Truncated regression models for the first stage. The last two combinations were Logit for the first and second stage and Probit for the first and second stage.

6.3.4 Econometric results

Table 6.5 summarizes the results for second stage game while Table 6.6 summarizes the results of the first stage.

We begin with the analysis of the first order strategic effects of network airline’s decisions on each other. In the first row of both Table 6.5 and Table 6.6, fixing every other variable, for a network airline the number of regional airlines to contract with and whether or not to operate in a given market on its own is negatively correlated with the decision of other airlines, irrespective of the functional forms. This shows the strategic effects can be captured via our econometric models.140

We observe, from the second and third rows of Table 6.6, that the decision regarding the number of regional airlines to contract with is negatively correlated with the airline's expectation on the decision of other airlines to use their network airline on that route.141 In addition, contracting with regional airlines is positively correlated with an airline's expectation of having its network airline operating on the city-pair. The empirical result is also consistent with the predictions of the theoretical model.

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140 Readers are referred to Appendix B.2 for further details.

141 Depending on the model specification we either get non-significant or significant negative results.
Table 6.5 Second stage game estimation results

<table>
<thead>
<tr>
<th></th>
<th>Discrete</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Logit</td>
<td>Probit</td>
<td>Logit</td>
<td>Probit</td>
</tr>
<tr>
<td>$\sum_{j \neq i} \hat{p}_j$</td>
<td>-0.82***</td>
<td>-0.75***</td>
<td>-1.57***</td>
<td>-0.75***</td>
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<tr>
<td>log_Distance</td>
<td>0.47***</td>
<td>0.48***</td>
<td>0.89***</td>
<td>0.46***</td>
</tr>
<tr>
<td>log_TotPass</td>
<td>0.28***</td>
<td>0.26***</td>
<td>0.58***</td>
<td>0.27***</td>
</tr>
<tr>
<td>MS_origin</td>
<td>1.43***</td>
<td>1.49***</td>
<td>2.77***</td>
<td>1.47***</td>
</tr>
<tr>
<td>MS_dest</td>
<td>1.25***</td>
<td>1.32***</td>
<td>2.31***</td>
<td>1.26***</td>
</tr>
<tr>
<td>$N_i$</td>
<td>0.66***</td>
<td>0.31***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sum_{j \neq i} N_j$</td>
<td>-0.10</td>
<td>-0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No_other</td>
<td>0.50***</td>
<td>0.30***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$1(N_i &gt; 0)$</td>
<td></td>
<td></td>
<td>1.31***</td>
<td>0.65***</td>
</tr>
<tr>
<td>$\sum_{j \neq i} 1(N_j &gt; 0)$</td>
<td></td>
<td></td>
<td>-0.13</td>
<td>-0.10</td>
</tr>
<tr>
<td>$1(No_other &gt; 0)$</td>
<td></td>
<td></td>
<td>0.83***</td>
<td>0.50***</td>
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<tr>
<td>Hub</td>
<td>1.18***</td>
<td>1.28***</td>
<td>2.22***</td>
<td>1.19***</td>
</tr>
<tr>
<td>Slot</td>
<td>0.10</td>
<td>0.06</td>
<td>0.16</td>
<td>0.10</td>
</tr>
<tr>
<td>Leisure</td>
<td>0.16**</td>
<td>0.21***</td>
<td>0.31**</td>
<td>0.16**</td>
</tr>
<tr>
<td>Log pseudolikelihood</td>
<td>-1139.86</td>
<td>-1146.45</td>
<td>-1121.64</td>
<td>-1144.24</td>
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<tr>
<td>Pseudo R2</td>
<td>0.6081</td>
<td>0.6058</td>
<td>0.6144</td>
<td>0.6066</td>
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</table>
Table 6.6 First stage game estimation results

<table>
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<th></th>
<th>Probit</th>
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<th>Binary</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Logit</td>
<td></td>
<td>Probit</td>
<td></td>
<td>Logit</td>
<td></td>
<td>Probit</td>
</tr>
<tr>
<td></td>
<td>Negative Binomial</td>
<td>Poisson</td>
<td>Tobit</td>
<td>Truncated</td>
<td>Negative Binomial</td>
<td>Poisson</td>
<td>Tobit</td>
</tr>
<tr>
<td>( \sum_{j \neq i} R_{ij} )</td>
<td>-0.36***</td>
<td>-0.36***</td>
<td>-0.038***</td>
<td>-0.03***</td>
<td>-0.30***</td>
<td>-0.31***</td>
<td>-0.02**</td>
</tr>
<tr>
<td>( \hat{p}_i )</td>
<td>1.70***</td>
<td>1.69***</td>
<td>0.95***</td>
<td>0.98***</td>
<td>2.18***</td>
<td>2.20***</td>
<td>1.21***</td>
</tr>
<tr>
<td>( \sum_{j \neq i} \hat{p}_j )</td>
<td>-0.11</td>
<td>-0.26**</td>
<td>0.04</td>
<td>-0.04</td>
<td>-0.47***</td>
<td>-0.47***</td>
<td>0.00</td>
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<tr>
<td>log_Distance</td>
<td>-0.59***</td>
<td>-0.44***</td>
<td>-0.15***</td>
<td>-0.17***</td>
<td>-0.43***</td>
<td>-0.43***</td>
<td>-0.15***</td>
</tr>
<tr>
<td>log_TotPass</td>
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<td>-0.07***</td>
<td>-0.02***</td>
<td>-0.02***</td>
<td>-0.08***</td>
<td>-0.08***</td>
<td>-0.02***</td>
</tr>
<tr>
<td>MS_origin</td>
<td>2.49***</td>
<td>1.87***</td>
<td>1.01***</td>
<td>1.05***</td>
<td>1.65***</td>
<td>1.63***</td>
<td>0.90***</td>
</tr>
<tr>
<td>MS_dest</td>
<td>2.00***</td>
<td>0.62***</td>
<td>0.34***</td>
<td>0.37***</td>
<td>0.50***</td>
<td>0.48***</td>
<td>0.27***</td>
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<tr>
<td>No_other</td>
<td>-0.09</td>
<td>0.05</td>
<td>-0.02</td>
<td>-0.02</td>
<td>0.04</td>
<td>0.3</td>
<td>-0.03**</td>
</tr>
<tr>
<td>1(No_other &gt; 0)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>0.16</td>
</tr>
<tr>
<td>Hub</td>
<td>0.57***</td>
<td>0.39***</td>
<td>-0.01</td>
<td>-0.00</td>
<td>0.22***</td>
<td>0.20**</td>
<td>-0.09**</td>
</tr>
<tr>
<td>Slot</td>
<td>0.27***</td>
<td>0.58***</td>
<td>0.04**</td>
<td>0.04***</td>
<td>0.61***</td>
<td>0.61***</td>
<td>0.05***</td>
</tr>
<tr>
<td>Leisure</td>
<td>-0.27***</td>
<td>-0.39***</td>
<td>-0.12***</td>
<td>-0.13***</td>
<td>-0.38***</td>
<td>-0.38***</td>
<td>-0.11***</td>
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<tr>
<td>Log likelihood</td>
<td>-1272.90</td>
<td>-3088.19</td>
<td>-5086.10</td>
<td>-5134.69</td>
<td>-3051.95</td>
<td>-3051.01</td>
<td>-5219.77</td>
</tr>
<tr>
<td>Pseudo R2</td>
<td>0.6402</td>
<td>0.4330</td>
<td>0.3324</td>
<td>0.3841</td>
<td>0.4398</td>
<td>0.3407</td>
<td></td>
</tr>
</tbody>
</table>
Looking at the variable for route distance, if all else is constant, distance is positively correlated with the choice of network airlines, but negatively correlated with the number of regional airlines. This is due to the reason that the relative efficiency of regional airlines in comparison with network airlines decreases as the distance increases.

The theoretical models suggest that a network airline will strategically contract with more regional airlines when it enjoys more cost efficiency compared with the other network airlines. The positive coefficient for market share at origin and destination airports in Table 6.6 and the coefficient of hub\textsuperscript{142}, suggest that the greater the cost efficiency the greater the propensity for network airlines to contract with regional airlines; possibly to increase competition to the extent that less competitive airlines could exit the market.\textsuperscript{143}

Finally the structural models predict that the larger the market size the less the inclination to negotiate contracts with regionals. This is because even if you contract with many regionals, the market is big enough to support the entry of other airlines. We considered the total number of passengers as a proxy for market size. This variable in Table 6.6 has negative signs and the variable in Table 6.5 is positive. It appears that, based on these results, in larger markets, network airlines have a tendency to operate alone and are less inclined to contract with regional airlines. This may be due to the fact that network airlines usually operate larger aircrafts while regional airlines are restricted to smaller aircrafts. In thinner markets, the cost advantage of the regional airlines is more significant.

Beside the strategic variables that are correlated with our predictions, we have also two other variables to control for slot-controlled airports (slot) and tourist destinations (leisure). In Forbes and Lederman (2010), the airlines have a higher tendency to use self-owned regional airlines in markets where a slot-controlled airport is involved. They argue

\textsuperscript{142} Out of 10 different specifications, the hub coefficient shows the expected sign in 6 of the 10 instances. In 2 of the instances the coefficient is not significant and in 2 of the cases the coefficients show a counter-intuitive sign with relatively small magnitude.

\textsuperscript{143} It is recognized that besides cost difference, market share may be also capturing a market power effect. However, this factor is not in line with our theoretical prediction so will not be discussed in this paper.
that this is because slot-controlled airports incur more risk and using in-house regional airlines can reduce this risk. Our results further show that under slot control, network airlines have an incentive to contract with more independent regional airlines. This result, although seemingly contradictory with Forbes and Lederman (2010), is actually in line with the same logic. This is because in the case when independent regional airlines are used, the airline-specific risk and disruption will be evened out when more regional airlines are involved. In other words, the number of regional airlines to contract with is another strategic move of the network airlines to manage the risk in the slot-controlled airports.

When controlling for leisure destinations we found that the network airlines tend to contract with less regional airlines. That may come from the fact that in such markets the price elasticity is very high and the market itself drives out less efficient airlines. In other words, the more efficient network airlines do not need strategic tools such as the contract with regional airlines to get rid of the inefficient players.

6.4 Discussions and Conclusion

The relationship between network and regional airlines is diversified across markets. We observe that a network airline may operate a route using its own fleet, or outsource this route to one or more regional airlines, or do both (offering some flights with its own fleet and outsourcing other flights to regional airlines). The existing literature has not investigated this diversity. In this paper we present a game structure in which each network airline first determines the number of regional airlines to contract with in a given market. The network airlines then decide whether and how much to operate in the market with their own fleets. Finally, the regional airlines under contractual relationship with the network airlines determine the flights (or seats) they will offer in the market. The theoretical model predicts a variety of network airline - regional airline relationships, which is consistent with what we observe in airline markets. The forces driving this diversity include the market size and the cost differences between network airlines and between network and regional airlines. Using U.S. data, we empirically test these predictions and find support for what the theoretical model predicted.
Some factors are omitted in the analysis. For example, the cost of outsourcing traffic to regional airlines is neglected. However, we are not arguing that the mechanism we present is the only explanation as to why we see a diversity of relationships in airline markets. It is also possible that by contracting with multiple regional airlines or operating the route on its own, a network airline can gain more bargaining power over the regional airline and is thus able to extract more rents. We are aware of the complexity of this problem, especially in the context of a network industry.

The contribution of this paper is two-fold. First, it enriches the literature on “strategic divisionalization”. We illustrate a game structure through which companies (such as network airlines) can customize their competitive network reach strategies according to the specific situations they are facing. Secondly, it provides insights into the network airline’s relationship with regional airlines. Network airlines recognize that the regional airlines can be used to compete ‘on their behalf’ in less profitable markets and in circumstances where there are cost advantages. Network airlines can also realize some strategic effects in their competition with other network airlines. Interestingly, the relationships that are observed between network airlines and regional airlines are now being observed between international carriers and domestic low cost carriers. Jet Blue’s relationship with Lufthansa is a good example, given that Lufthansa is in the Star Alliance, which includes United-Continental and can obtain feed from these partners.

Policy makers and anti-trust authorities can also draw some lessons from this study since it provides some insights as to when the seemingly identical mechanism is pro-competitive and when it may be anti-competitive.
7 Conclusions

This dissertation consists of two topics in air and rail transport. For the first topic, the interactions between airlines and the high-speed rail, this dissertation contributes to the related literature by providing rigorous theoretical analysis to a few important problems that are either unidentified or only qualitatively discussed before. First, we find that airline-HSR cooperation improves welfare whenever the substitutability between air flights and HSR service is low. When the substitutability is high, then hub capacity plays an important role in assessing the welfare impact of airline-HSR cooperation. Such cooperation improves (reduces) welfare if the hub airport is (is not) seriously capacity-constrained. Second, we show that the introduction of HSR may have a net negative effect on the environment even when HSR is more environmentally friendly than the air transport, because additional demand may be generated by HSR. Furthermore, when the airline and HSR decide on frequencies, the airline tends to reduce the aircraft size in order to offer high frequency. In these circumstances, the introduction of HSR would be detrimental to the environment even on a per-passenger base if the market size is large enough. Moreover, when HSR decides on speed, it has incentive to keep it at the maximum level in order to reduce travel time. When the environmental impacts of HSR increase rapidly with train speed, the overall level of emissions after the introduction of the HSR will be higher than in the case of no modal competition. Third, we demonstrate that the entry of HSR into an airline’s trunk markets or the increase of HSR competitiveness will have an impact on the airline’s long-term decisions such as network structure and market coverage. In particular, if the network structure of the airline is exogenously given, an increase of HSR competitiveness will more likely push the airline to cover more regional (or foreign) markets when the trunk market is larger, or when the network of the airline is closer to hub-and-spoke. And this effect is more prominent when the diminishing rate of the airline’s traffic density benefits (including higher frequency effect on the demand side and economies of traffic density on the cost side) is higher. Meanwhile, if the market coverage of the airline is exogenously given, an increase of the HSR competitiveness will more likely move the airline towards hub-and-spoke network when the trunk market is larger, or when the airline covers more regional (or foreign) markets. And this effect is more prominent when diminishing rate of the airline’s traffic density benefits is higher.
The second topic of this dissertation is on the intra-modal cooperation in the aviation industry. We investigate the relationships between major airlines (airline alliance) as well as between major airlines and regional airlines. We first study the partnership formation for two competing local airlines and two global alliances by allowing each airline to join any of the two alliances and each alliance to take either or both airlines. We find that multiple equilibrium outcomes may exist if these four players are involved in a simultaneous game. On the other hand, if a sequential game is played, we show that when either the market size or the product substitutability is relatively small, local airlines will join the same alliance in equilibrium. Otherwise, local airlines will stay independent. Then we try to illustrate how network airlines can use the contractual relationship with regional airlines as an efficient tool to simultaneously drive out inefficient network airlines and also accommodate other cost efficient network airlines in any specific market. We find that market size, cost differences between network airlines, as well as cost differences between network and regional airlines, are the chief determinants of the network airlines’ decisions on whether or not to serve a market with their own fleet, as well as how many regional airlines to contract with.

Other than the ones discussed in this dissertation, there are still many interesting topics related to the air-rail relationship. For example, the level in the air-HSR cooperation is largely ignored in Chapter 2. However, in reality we can see a variety of air-HSR codeshare agreements. A very rough classification by Wikipedia points out at least four: dedicated services, entire network access, Night&Fly\textsuperscript{144}, and re-protection agreements\textsuperscript{145}. What are the driving forces for this difference to arise? What is the socially optimal intermodal cooperation level? Is the cooperation level related to the role of the decision maker (airlines, airline alliances, etc.)?

\textsuperscript{144} Overnight train service with sleeping cars is offered by an airline from the airline’s hub airport. For example, Swiss Airlines and City Night Line have a Night&Flight product from Zurich Airport to cities like Berlin and Amsterdam.

\textsuperscript{145} Also known as “Good for Trains”, this is an emergency backup service for airline cancellations, providing train tickets in lieu of flights to get passengers to their destination. For example, during the Eyjafjallajökull eruption in 2010, extra trains were provided to support the airlines’ stranded passengers in Europe. Airlines with such agreements include Air Canada and Lufthansa.
the airport, or the HSR operator)? These questions are crucial in terms of having a better understanding of this intermodal partnership and prescribing important policy suggestions to the regulators.

In this dissertation, the study of HSR focuses on its interactions with the air sector. However, other aspects of HSR are also of great importance and deserve more attentions. In almost every major country in the world, there has been a heated debate on whether particular HSR projects should be developed. In the United States, HSR was supposed to be President Obama’s signature transportation project, but despite the administration spending nearly $11 billion since 2009, the projects have gone mostly nowhere and the United States still lags far behind Europe and China in HSR development. Numerous studies and reports have argued for or against HSR development. Other than the potential opportunity of intermodal cooperation with the air transport, as well as the environmental impacts, the development of HSR will also significantly affect some crucial areas of the economy, which deserves a more careful investigation. First, HSR will play an important role in urban development. The development of HSR projects will surely have a significant impact on the power balance between megacities and medium-to-small cities that are linked or not linked by the HSR (e.g., Garmendía et al., 2012; Vickerman, 2014). But whether regional disparities will become larger or smaller with the operation of HSR is still far from clear. On the other hand, although not as flexible as the airlines, HSR development can also adopt different structures, such as corridor, network or hybrid (Perl and Goetz, 2014). It is left largely unexplored under what conditions which structure will appear and the impacts of different structures on urban development and social welfare.

Second, the advancement of HSR technology will create positive spillovers to the technology development of other sectors. The key technologies of HSR development include system integration, body shell, bogie, traction converter, traction control system, traction transformer, traction motor, network control system, and braking system (Chan and Aldhaban, 2009). Every technological breakthrough for HSR is closely related to telecommunication, automatization and materials science. In other words, the developments of HSR technology will not only affect HSR and the transportation sector, but also facilitate the leapfrogging of other industries, given that the better and more advanced technologies brought by the HSR
development can be utilized relatively cheaply in these areas. This effect has been identified in a general sense (e.g., Acemoglu et al., 2007; Bloom et al., 2013), but never put into the framework of assessing a particular HSR project. This line of research has important policy implications, because it can potentially change the conclusion on whether it is worthwhile to develop HSR in a particular country.
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Appendices

Appendix A: Appendix for Chapter 2

A.1 Effects of airline-HSR cooperation on market structures, traffic volumes, welfare and consumer surplus levels

We summarize, in Tables A1 and A2, the market structures before and after the airline-HSR cooperation, as well as the impact of the cooperation on traffic volumes, welfare and consumer surplus levels under different combinations of $\gamma$ and $k$. Note that the cutoff value when comparing $(8 - 4\gamma - \gamma^2)/[4(4 - \gamma^2)]$ and $\gamma$ is not exactly $\sqrt{2} - 1$, but it is very close. We neglect this small range for the sake of presentation clarity, but incorporating it will not alter our propositions.

Table A1: Effects of airline-HSR cooperation when $> \sqrt{2} - 1$.

<table>
<thead>
<tr>
<th>$k (= \frac{K}{\alpha})$</th>
<th>Pre-cooperation market equilibrium</th>
<th>Post-cooperation market equilibrium</th>
<th>Traffic-volume impact</th>
<th>Welfare and consumer-surplus impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k \leq \frac{\gamma}{4}$</td>
<td>Airline serves HSR-inaccessible market only</td>
<td>HSR-accessible market is served by HSR only, and only the flight-HSR connecting service exists in the connecting market</td>
<td>$\bar{q}_1^A &lt; \bar{q}_1^A$ $\bar{q}_2^p = \bar{q}_2^p$ $\bar{q}_3^{AR} &gt; 0$</td>
<td>$\bar{W} &gt; \bar{W}$ $\bar{CS} &lt; \bar{CS}$</td>
</tr>
<tr>
<td>$\frac{\gamma}{4} &lt; k \leq \frac{8 - 4\gamma - \gamma^2}{4(4 - \gamma^2)}$</td>
<td>Airline serves both the HSR-inaccessible and HSR-accessible markets, but is not able to cover the connecting market</td>
<td>HSR-accessible market is served by HSR only, and only the flight-HSR connecting service exists in the connecting market</td>
<td>$\bar{q}_1^A &lt; \bar{q}_1^A$ $\bar{q}_2^R &lt; \bar{q}_2^A + \bar{q}_2^R$ $\bar{q}_3^{AR} &gt; 0$</td>
<td>$\bar{W} &gt; \bar{W}$ $\bar{CS} &lt; \bar{CS}$</td>
</tr>
<tr>
<td>$k \left(= \frac{K}{\alpha}\right)$</td>
<td>Pre-cooperation market equilibrium</td>
<td>Post-cooperation market equilibrium</td>
<td>Traffic-volume impact</td>
<td>Welfare and consumer-surplus impact</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>$\frac{8 - 4y - y^2}{4(4 - y^2)} &lt; k \leq \gamma$</td>
<td>Airline serves all three markets, but is still constrained by hub capacity</td>
<td>HSR-accessible market is served by HSR only, and only the flight-HSR connecting service exists in the connecting market</td>
<td>$\bar{q}_1^A \geq \hat{q}_1^A$ $\bar{q}_2^R &lt; \bar{q}_2^A + \bar{q}_2^R$ $\bar{q}_3^{AR} &gt; \bar{q}_3^{AA}$</td>
<td>$\hat{W} &gt; \hat{W}$ $\mathcal{C}_S &lt; \mathcal{C}_S$</td>
</tr>
<tr>
<td>$\gamma &lt; k \leq \frac{3 + \gamma}{2(2 + \gamma - y^2)}$</td>
<td>Airline serves all three markets, but is still constrained by hub capacity</td>
<td>Both the airline and HSR serve the HSR-accessible market, but only the flight-HSR connecting service exists in the connecting market</td>
<td>$\bar{q}_1^A \geq \hat{q}_1^A$ $\bar{q}_2^A + \bar{q}_2^R &lt; \bar{q}_2^A + \bar{q}_2^R$ $\bar{q}_3^{AR} &gt; \bar{q}_3^{AA}$</td>
<td>$\hat{W} &gt; \hat{W}$ $\mathcal{C}_S &lt; \mathcal{C}_S$</td>
</tr>
<tr>
<td>$\frac{3 + \gamma}{2(2 + \gamma - y^2)} &lt; k \leq \frac{5 + \gamma}{2(1 + \gamma)}$</td>
<td>Airline serves all three markets, but is still constrained by hub capacity</td>
<td>All available services are provided, but the hub airport is still under capacity constraint</td>
<td>$\bar{q}_1^A &gt; \hat{q}_1^A$ $\bar{q}_2^A + \bar{q}_2^R &lt; \bar{q}_2^A + \bar{q}_2^R$ $\bar{q}_3^{AA} + \bar{q}_3^{AR} &gt; \bar{q}_3^{AA}$</td>
<td>$\hat{W} &gt; \hat{W}$ $\mathcal{C}_S &lt; \mathcal{C}_S$</td>
</tr>
<tr>
<td>$\frac{5 + \gamma}{2(1 + \gamma)} &lt; k \leq \frac{8 + 3\gamma}{2(2 + \gamma)}$</td>
<td>Airline serves all three markets, but is still constrained by hub capacity</td>
<td>Airport does not face capacity constraint</td>
<td>$\bar{q}_1^A &gt; \hat{q}_1^A$ $\bar{q}_2^A + \bar{q}_2^R &lt; \bar{q}_2^A + \bar{q}_2^R$ $\bar{q}_3^{AA} + \bar{q}_3^{AR} &gt; \bar{q}_3^{AA}$</td>
<td>$\hat{W} \geq \hat{W}$ $\mathcal{C}_S &lt; \mathcal{C}_S$</td>
</tr>
<tr>
<td>$k &gt; \frac{8 + 3\gamma}{2(2 + \gamma)}$</td>
<td>Airport does not face capacity constraint</td>
<td>Airport does not face capacity constraint</td>
<td>$\bar{q}_1^A = \hat{q}_1^A$ $\bar{q}_2^A + \bar{q}_2^R &lt; \bar{q}_2^A + \bar{q}_2^R$ $\bar{q}_3^{AA} + \bar{q}_3^{AR} &gt; \bar{q}_3^{AA}$</td>
<td>$\hat{W} \geq \hat{W}$ $\mathcal{C}_S &lt; \mathcal{C}_S$</td>
</tr>
</tbody>
</table>
Table A2: Effects of airline-HSR cooperation when $\gamma < \sqrt{2} - 1$

<table>
<thead>
<tr>
<th>$k$ ($= \frac{K}{a}$)</th>
<th>Pre-cooperation market equilibrium</th>
<th>Post-cooperation market equilibrium</th>
<th>Traffic-volume impact</th>
<th>Welfare and consumer-surplus impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k \leq \frac{\gamma}{4}$</td>
<td>Airline focuses on the HSR-inaccessible market only</td>
<td>HSR-accessible market is served by the HSR only, and only the flight-HSR connecting service exists in the connecting market</td>
<td>$q_1^A &lt; q_1^A$</td>
<td>$\bar{W} &gt; \hat{W}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$q_2^R = q_2^R$</td>
<td>$\bar{C} &lt; \hat{C}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$q_3^{AR} &gt; 0$</td>
<td></td>
</tr>
<tr>
<td>$\frac{\gamma}{4} &lt; k \leq \gamma$</td>
<td>Airline serves both the HSR-inaccessible and HSR-accessible markets, but is not able to cover the connecting market</td>
<td>HSR-accessible market is served by the HSR only, and only the flight-HSR connecting service exists in the connecting market</td>
<td>$q_1^A &lt; q_1^A$</td>
<td>$\bar{W} &gt; \hat{W}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$q_2^R &lt; q_2^A + q_2^R$</td>
<td>$\bar{C} &lt; \hat{C}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$q_3^{AR} &gt; 0$</td>
<td></td>
</tr>
<tr>
<td>$\gamma &lt; k \leq \frac{8 - 4\gamma - \gamma^2}{4(4 - \gamma^2)}$</td>
<td>Airline serves both the HSR-inaccessible and HSR-accessible markets, but is not able to cover the connecting market</td>
<td>Both the airline and HSR serve the HSR-accessible market, but only the flight-HSR connecting service exists in the connecting market</td>
<td>$q_1^A &lt; q_1^A$</td>
<td>$\bar{W} &gt; \hat{W}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$q_2^A + q_2^R &lt; q_2^A + q_2^R$</td>
<td>$\bar{C} &lt; \hat{C}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$q_3^{AR} &gt; 0$</td>
<td></td>
</tr>
<tr>
<td>$\frac{8 - 4\gamma - \gamma^2}{4(4 - \gamma^2)} &lt; k \leq \frac{3 + \gamma}{2(2 + \gamma - \gamma^2)}$</td>
<td>Airline serves all three markets, but is still constrained by hub capacity</td>
<td>Both the airline and HSR serve the HSR-accessible market, but only the flight-HSR connecting service exists in the connecting market</td>
<td>$q_1^A \geq q_1^A$</td>
<td>$\bar{W} &gt; \hat{W}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$q_2^A + q_2^R &lt; q_2^A + q_2^R$</td>
<td>$\bar{C} &lt; \hat{C}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$q_3^{AR} &gt; q_3^{AA}$</td>
<td></td>
</tr>
<tr>
<td>$k \left(= \frac{K}{\alpha}\right)$</td>
<td>Pre-cooperation market equilibrium</td>
<td>Post-cooperation market equilibrium</td>
<td>Traffic-volume impact</td>
<td>Welfare and consumer-surplus impact</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>----------------------------------</td>
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<td>----------------------------------</td>
</tr>
</tbody>
</table>
| $\frac{3 + \gamma}{2(2 + \gamma - \gamma^2)} < k \leq \frac{8 + 3\gamma}{2(2 + \gamma)}$ | Airline serves all three markets, but is still constrained by hub capacity | All available services are provided; but the airport is under capacity constraint | $\bar{q}_1^A \geq \bar{q}_1^\ddagger$  
$\bar{q}_2^A + \bar{q}_2^B < \bar{q}_2^\ddagger + \bar{q}_2^B$  
$\bar{\bar{q}}_3^{AA} + \bar{q}_3^A$  
$> \bar{q}_3^{\ddagger A}$ | $\hat{\mathcal{W}} > \mathcal{W}$  
$\bar{\mathcal{C}}S < \mathcal{C}S$ |
| $\frac{8 + 3\gamma}{2(2 + \gamma)} < k \leq \frac{5 + \gamma}{2(1 + \gamma)}$ | Airport does not face capacity constraint | All available services are provided; but the airport is under capacity constraint | $\bar{q}_1^A < \bar{q}_1^\ddagger$  
$\bar{q}_2^A + \bar{q}_2^B < \bar{q}_2^\ddagger + \bar{q}_2^B$  
$\bar{q}_3^{AA} + \bar{q}_3^{AR}$  
$> \bar{q}_3^{\ddagger A}$ | $\hat{\mathcal{W}} > \mathcal{W}$  
$\bar{\mathcal{C}}S < \mathcal{C}S$ |
| $k > \frac{5 + \gamma}{2(1 + \gamma)}$ | Pre-cooperation market equilibrium | Post-cooperation market equilibrium | $\bar{q}_1^A = \bar{q}_1^\ddagger$  
$\bar{q}_2^A + \bar{q}_2^B < \bar{q}_2^\ddagger + \bar{q}_2^B$  
$\bar{q}_3^{AA} + \bar{q}_3^{AR}$  
$> \bar{q}_3^{\ddagger A}$ | $\hat{\mathcal{W}} > \mathcal{W}$  
$\bar{\mathcal{C}}S \geq \mathcal{C}S$ |
A.2 Simulation estimations

A.2.1 Estimation of the utility function

Behrens and Pels (2012) use revealed preference data and estimate two logit models (the nested multinomial logit and the mixed multinomial logit) to examine the demand patterns of two types of passengers (leisure and business). They thus obtain four groups of estimation results. In addition, they look at six airport-airline pairs that give different estimates (Heathrow/Air France, Heathrow/British Airways, Heathrow/British Midland Airways, Gatwick/British Airways, Luton/easyJet, and City/Air France). We exclude the Luton/easyJet pair because easyJet, a low-cost carrier, does not adopt the hub-and-spoke network considered in our model. The City/Air France pair is excluded due to low traffic volume.

The cross elasticities of air demand with respect to the HSR fare are defined as \( \varepsilon_{AR} = \frac{\partial Q_A}{\partial P_R} \left( \frac{P_R}{Q_A} \right) \), where \( A \) represents an airport/airline pair and \( R \) represents the HSR. They are equal to \( \frac{P_R}{\gamma Q_A} \) in our model after adjustment with the own elasticities. The elasticities, the average fares and the traffic volumes are all reported in Behrens and Pels (2012), so \( \gamma \) can be easily estimated. We are able to obtain one \( \gamma \) for every airport/airline combination in every choice model. Subsequently we use the traffic volumes as a weight to obtain a weighted-average value for every model. The four weighted average \( \gamma \)'s are 0.60 (nested-business), 0.81 (nested-leisure), 0.58 (mixed-business) and 0.84 (mixed-leisure). Taking weighted average again gives 0.71 as our final estimate.

Given the estimation of \( \gamma \) and the other information provided by Behrens and Pels (2012) – i.e., average fares and traffic volumes of different modes – we can easily obtain \( \alpha \) by fitting the linear demand functions of our model. With the average traffic volume per hour, we obtain that \( \alpha \) is around 600.

Taking into account the heterogeneity of passengers, we separate the estimates for business and leisure passengers. In particular, we establish that \( \gamma = 0.59 \) for leisure passengers and \( \gamma = 0.825 \) for business passengers. If a linear relationship is imposed between the business passenger percentage (\( \phi \)) and weighted average \( \gamma \), we have \( \gamma = 0.825 - (0.825 - 0.59)\phi = 0.825 - 0.235\phi \). A similar approach is adopted to obtain the relationship between \( \phi \) and the
The procedure to estimate $\beta$ is very similar to the one used to obtain $\gamma$, but with own elasticities instead of cross elasticities. The estimation of $\delta$ is straightforward when the other parameters are given.

A.2.2 Estimation of the cost functions

Brueckner and Spiller (1994) estimate linear marginal cost for airlines, which can be directly used for our purpose. Campos and de Rus (2009) detail the operating statistics and the operating costs for 11 types of high-speed train in four European countries (namely, TGV Réseau, TGV DUPLEX and THALYS in France; ICE-1, ICE-2, ICE-3, ICE 3 Polyc. and ICE/T in Germany; ETR 500 and ETR 480 in Italy; and AVE in Spain). We assume that these high-speed train technologies have an identical cost structure and we estimate this cost structure based on the variability in seat capacities of these train models.
Appendix B: Appendix for Chapter 6

B.1 Contractual relationship between regional and network airlines

To fully incentivize the regional airlines to maximize their profit, the network airlines can try revenue/profit sharing. Since in the presence of the cost differences between the regional and network airlines we normalized marginal cost of regional airlines to zero, revenue sharing and profit sharing mechanism will become identical in our models, thus, we can use them interchangeably.

Let’s assume the network airline offers a revenue/profit sharing contract in which the network airline receives share $\alpha$ from the overall profit of each regional airline, and share $(1 - \alpha)$ is left for the regional airline. For any value of $\alpha$, the regional airlines will have full incentive to maximize their own profit, this argument is true even for the case that $\alpha$ converges to 1, thus $(1 - \alpha)$ converges to zero.

The value of $\alpha$, depends on the bargaining power of each part – i.e. regional airlines and network airlines. It is logical to believe that $\alpha$ is large and close to 1 due to three reasons. First, although the US regional airlines have been consolidating over the years, there are substantially more regional airlines than network airlines at any time. Second, the current business model of the US regional airlines relies heavily on the network airlines, which puts them in a very weak position in negotiation (Infosys, 2013). Third, the past decade has been particularly bleak for the US regional airlines and has seen quite a few of them going bankrupt or defunct. The evolution of regional jet technology has also undermined the regional airlines’ bargaining power in front of the network airlines (CAPA, 2011).

Under this contractual structure, the results we found throughout the paper will be asymptotically the same as when we consider revenue sharing structure and include $\alpha$ into our models. It must be noted that should $\alpha$ be considerably less than 1, the assumption that network airline’s optimal decision will guarantee profit maximization outcomes we calculated in the paper would no longer be valid. One extreme case would be $\alpha = 0$. Under this somewhat unrealistic assumption, the regional airlines keep all the profits for themselves. Under this scenario the profit of regional airlines will be completely absent in the network.
airlines profit maximization function. We tried to enter $\alpha$ in our analysis but it was a bit challenging to deal with. Moreover, we did not have any information on the value of $\alpha$ for our empirical studies. As a result we left it for future studies.

Another type of contract that can result in fully incentivizing the regional airlines to maximize their profit is designing a stepwise lump sum reward-based contract. In this type of contract the regional airlines receive fix payments based on the Quantity they offer and the fix payments increase and capped by the quantity that maximizes the profit of the regional airlines. By correctly implementing this type of contractual mechanism, the regional airlines will have full incentive to choose the quantity that maximizes their profit and will be rewarded best when hitting that profit maximization target. Entrance of the fix payments in the equations will not enter any of the results of the models.

It is possible that more types of contracts result in fully incentivizing the regional airlines to maximize their own profit. This is perhaps even more valid if we think about the game as a repetitive game – i.e. only the regional airlines that perform the best will have the chance to be contracted with in future. By changing our time-horizon from a one-shot game to a repetitive game, even without imposing any contractual agreement in our models, the regional airlines may have full incentive to adhere to their profit maximization performance.

B.2 Predictions of strategic effects

In this section we focus on the first-order strategic effects of the decision variables at the first two stages of the game structure discussed in Section 6.2.

We will first study the first order strategic effect of $\sum Q_j$ (the total quantity of passengers served by all network airline airlines) on $Q_i$ (the total quantity of passengers served by a specific network airline).

We can simply solve the first order conditions introduced in equation (6.8) or (6.19) for $Q_i$ to find the strategic effect of $\sum Q_j$ on $Q_i$. 
It can easily be verified that \( Q_l = \frac{A-C_l-\sum_{j \neq l} Q_j-\Sigma q}{2} \)

In other words, in the second stage the decision variable of each airline, \( Q_l \), is negatively correlated with everybody else's decision.

We can replicate the same methodology to measure the strategic effect of the number of regional airlines each network airline contracts with on the decision of each network airline. The first order effect of \( \sum_{j \neq i} \delta_j \) on \( \delta_i \) can be found by solving the first order condition of the profit function of network airline airlines at the first stage - fixing all other values.

It is easy to verify that \( \delta_i = \frac{A-C_l-\delta_j \sum_{j \neq i} q_j-\Sigma q}{2q_l} \)

In other words we can see that \( \delta_j \)'s are negatively correlated with \( \delta_i \).

B.3 Non-linear demands

We try different demand functions to test the validity of the predictions of our theoretical models in more general settings. The only tractable demand functions from which we can get closed form solutions are linear demand functions. Here we show our computations for two demand families.

B.3.1 \( P = Q_T^\epsilon \)

We first try constant elasticity demand family. Even for the case of 2 homogenous network airlines we are not able to identify any closed form solutions. Assume the marginal cost is fixed and is \( C \).

We can write \( Q_T = Q_1 + Q_2 + \sum_{j=1}^{\delta_1} q_{1,j} + \sum_{j=1}^{\delta_2} q_{2,j} \).

Each regional airline's profit can be written as:

\( \pi_{i,j} = (P - Q_T) q_{i,j} \)
\[
\frac{\partial \pi_{i,j}}{\partial q_{i,j}} = -C + Q_T^{-1-\varepsilon}(Q_T - \varepsilon q_{i,j})
\]

We cannot find a closed form solution for the first order condition of the profit function of each regional airline, and that stops us from further analysis.

B.3.2 \( P = A - \frac{1}{Q_T^n} \)

\( n=2 \) is the easiest case to study. If we assume that there are only two homogenous network airlines competing, by constructing the profit functions of regional airlines and solving the first order conditions we will find that each regional airline will choose to serve the following number of passengers:

\[
q_{i,j}^* = \frac{(1 - 3(\delta_1 + \delta_2))(Q_1 + Q_2) + \sqrt{(Q_1 + Q_2)^2 + 3(\delta_1 + \delta_2)(-2 + 3(\delta_1 + \delta_2))}}{\delta_1 + \delta_2)(-2 + 3(\delta_1 + \delta_2))}
\]

Entering these findings into the profit function of the network airline carriers and computing the best response for each network airline carrier led to very cumbersome expressions and precludes us from further analysis of such types of demand functions.

B.4 Data construction

In this appendix, we discuss our methods and assumptions involved in constructing our dataset from the Airline Origin and Destination Survey (DB1B) database and other supplementary sources. DB1B is a 10 percent random sample of tickets sold by U.S. airlines for domestic travel in a quarterly period.\(^{146}\) There are three subcomponents to the DB1B database, which are the DB1B coupon table, the DB1B market table, and the DB1B ticket table. Among the three, the coupon table contains the most detailed information of a trip, which indicates the itinerary of a passenger and essentially identifies a segment of travel. Even though the DB1B is only a 10 percent random sample, each quarterly period of the DB1B database contains a very large amount of data. For further reference, see the BTS’s website (http://www.transtats.bts.gov).

\(^{146}\) The DB1B database is part of TranStats, the Bureau of Transportation Statistics’ (BTS) online collection of databases, and contains coupon-specific information. A coupon indicates the itinerary of a passenger and essentially identifies a segment of travel.
allowing readers to identify every flight (coupon) involved in a trip (including every leg of a connecting flight). Besides, ticketing carrier and operating carrier for a flight are separately identified in this table. Therefore, we are able to infer how a network airline operates on a route – through self-operation or by contracting with one or more regional airlines. In particular, we define self-operation to be the case when the ticketing carrier is the same as the operating carrier, and contracting with a regional airline as the case when the ticketing carrier is a network airline while the operating carrier is a regional airline. The DB1B database also contains other information that is useful for our analysis. For example, the number of passengers for each coupon is reported, from which we can derive the total number of passengers on a particular route and also the market share of a particular network airline on this route. Besides, the non-stop distance of an OD pair is also available.

We focus on the five largest network airlines in the United States, namely, American Airlines, United Airlines, Delta Air Lines, Continental Airlines and US Airways, because these network airlines use regional airlines to operate in some of their markets. We include other airlines, including the smaller network airlines such as Alaska Airlines and Hawaiian Airlines, Low Cost Carriers such as Southwest and JetBlue, as well as the independently operating regional airlines such as SkyWest Airlines and Republic Airlines. These carriers

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147 It is true that under some conditions interlining itself does not infer contractual relationship. For example, travel agents like Orbitz may create an interlining service to passengers, which will show in DB1B as one observation. However, this situation is rather rare. Besides, it is more unusual in our context, since regional airlines seldom operate under their own brand in the US. Therefore, we believe that the dataset can be a good source for our purpose with acceptable precision.

148 The integration of Northwest Airlines into Delta was completed on January 31, 2010, thus there were still a small number of flights under the code for Northwest in our dataset. Those records are all recoded as Delta flights.

149 Continental Airlines is still an independent company in the first quarter of 2010; United and Continental announced their merger on May 3, 2010.

150 Alaska airlines does partner with Horizon Airlines as a feed carrier on smaller low-density routes.

151 A few large-scale regional airlines such as SkyWest operate flights under their own brands in some markets, while they contract with network airlines to fly for them in other markets. In such cases, we treat these airlines as independent companies for the first type of markets, and contracting regional airlines for the second type of markets.
seldom adopt the strategy of using other airlines to operate under their brand names but they have an impact on the markets where they are present. As argued by Forbes and Lederman (2009), the regional airlines will normally have the maximum range of 1500 Miles. Therefore, for greater distances, contracting with regional airlines is not in the decision set of network airlines. For that we only focused on flights with distances of 1500 Miles and below.

A market is defined as a direct Origin Destination (OD) pair, with a suppression of directionality.\textsuperscript{152} We do not differentiate direct traffic from feed traffic; in other words, passengers flying from A to B that end their trip at B are not treated differently than passengers who fly to B for a connecting flight. This is because there will normally be both types of passengers on a flight. For notational simplicity, the larger airport (the one with more total traffic) is considered the origin, and the smaller airport the destination. Different from Forbes and Lederman (2007, 2010), we have included all airports and both direct and connecting flights in our data sample. In other words, other than the fact that we limit our observations to markets with distance up to 1,500 miles, we do not impose any restriction to the data sample. This treatment is in line with our theoretical model and should serve our purpose better.

We supplement the DB1B dataset with U.S. census data for demographic information, including GDP and population. Besides, we also construct three dummy variables to identify market characteristics – whether the market involves an airport that is a hub of the network airline, whether the market involves an slot-controlled airport, as well as whether the market is a leisure route. The first two are directly available from public sources such as Wikipedia.\textsuperscript{153} To construct the last variable, we follow Gerardi and Shapiro (2009) and take the following steps: For each airport in our data, we calculate the ratio of accommodation earnings to total nonfarm earnings corresponding to the metropolitan area (MA) containing that particular airport for each year over the period 2001-2004 and then take the median

\textsuperscript{152} In the empirical model, we use airport pairs instead of city pairs.

\textsuperscript{153} The slot-controlled airports in the first quarter of 2010 include New York JFK, New York LaGuardia, Newark Liberty and Reagan National.
value. We then sort these ratios in descending order and label as a leisure route each route that includes an airport in an MA above the 85th percentile. In addition to the airports in the 85th percentile, we include a few airports from U.S. territories for which we have no MA earnings data. These airports, which include San Juan, St. Croix, and St. Thomas, are included in the BTS’s definition of domestic and thus appear in the DB1B.