TRANSPORT NETWORK STRUCTURE: COMPETITION AND POLICY IMPLICATIONS

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Transport Network Structure: Competition and Policy Implications

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CERTIFICATE OF ORIGINALITY

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ABSTRACT

Transport systems are closely related to the development of transport networks, which are reflected in both spatial structure and industrial structure. The research consists of four topics with reference to transport network structure at different levels, i.e. regional spatial structure level, national spatial structure level and industrial structure level.

The first topic is to explore the evolution of a port network system from the regional spatial structure level. The main issues are the competition among multi-port regions and the expansion of transport networks. It addresses the evolution of regional port system and the development of transport network structure in South China. This study helps to understand the unique process of Pearl River Delta port system, which went from one gateway port to two and now is undergoing regionalization with specialization.

The second topic explores a joint analysis of the rail and air transport networks in China, to reveal the competition and complementarity between transport terminals in shaping transport network hierarchy. Panel data models are applied to estimate on the aggregate terminal passenger traffic data. Empirical results show that the speed acceleration of railway has a negative impact on the passenger growth of air transport, while improvement of rail does not reduce the airport passenger traffic as a whole.

The third topic concerns the railway network at the industrial structure level. It aims at comparing different industrial structures of the railway sector, in order to provide some guidance for the China Railway reform. The study of railway industrial structure reform issue is conducted through economic models primarily characterized by three features: vertical /horizontal separation, cost information asymmetry and strategies to eliminate the asymmetry.

The fourth topic explores the market competition behavior of airport and carrier in multi-airport regions. It addresses the issue of the competition between hub and secondary airports in the intra-European market by using econometric estimation of airport choice structure. The results show the different preference patterns of business and leisure passengers in frequency, flight fare, hub airport and low cost carrier.

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Chapter 1 Introduction

1.1 Background

China's transport facility had long lagged behind and been the bottleneck for economic development. Since the 1990s, transport infrastructures have experienced a rapid development period, and transport network has now taken shape in spatial layout. The rail transport has developed into a grid network (Wang et al., 2009), with the length exceeding 112,000 kilometers by 2014. Among it, high-speed rail was over 16,000 kilometers, which is more than the rest of the world's high-speed rail length combined[1]. China's highway transport network had a total length of 4,356,200 kilometers by 2013, and *National Trunk Highway System* became the world's largest expressway network, exceeding 104,400 kilometers[2]. Among the world's busiest ports, China has 8 ports ranked top 10 by total cargo volume and 7 ports by container throughput over 10 million TEUs[3].

In contrast, the infrastructure in aviation transport network is insufficient. China has the fastest growing air passenger market in the world. The current 202 commercial airports cannot fulfill the needs of increased traffic volume, particularly in the shortage of feeder transit service. Chinese air transport network is still at an early stage of development and has been unbalanced, with growth mainly driven by domestic routes linking a few major airports (Zhang, 2010; Fu et al., 2012). Therefore the expansion of airport infrastructures will continue.

As the scale of network infrastructures is reaching maturity, the upgraded transport service is becoming important. Integrated transport system is advocated in *"The 12th Five-Year Development Plan"* by China State Council. It includes, but not limited to, establishing inter-city transport networks, strengthening public transport network and

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[1] Data of rail lengths were released by *China Railway Corporation* and are collected from website, "China boasts world's largest high speed railway network". Xinhua. 30 January 2015.

[2] Data of highway lengths are collected from *National Bureau of Statistics of China*, which can be obtained from the official website (http://www.stats.gov.cn/english/Statisticaldata/AnnualData/).

[3] Data of port traffic is from "World Port Rankings 2013" released by *American Association of Port Authorities*.

developing the integrated transport hubs. This process is both driven by market mechanism, as well as required by government. . It calls for optimizing transport organizations and reform the government regulations.

Given the above background, this dissertation addresses issues regarding transport network structure of China based on two considerations. First, China is the first country with a GDP per capita below US$7,000 to have invested in developing a comprehensive transport network. The circumstances in China in terms of long distances, high density of population generate distinctive features in transport network structure from that of developed countries. We will explore transport network issues based on China, using development of transport network in developed countries for reference.

Second, most research on transport network structure focuses on one single mode of transport. As transport networks are interdependent (e.g., public transport system), there is a growing awareness on the potential modal shift and mutual interference between different modes of transport. We will study the competition and coordination for players both in the same mode of transport, or in different modes.

1.2 Transport Network Structure

The use of network is the most common way to represent the supply of transport infrastructure and services (Willumsen, 2008). A network in its simplest form is a set of nodes or vertices joined together in pairs by links or edges. Transport network is considered as the framework of nodes and links which is identified as routes within the transport system. Figure 1.1 depicts a typical transport network. A route is the link between two nodes. A node which handles a substantial amount of traffic and acts as concentrated passage for traffic is referred to as a hub. A feeder is the node linked to a hub. Transport network belongs to a wider category of spatial networks as its design and evolution are physically constrained, which distinguish it from non-spatial networks such as internet, social network and biological systems such as neuronal network (Gastner and Newman, 2006; Rodrigue et al., 2013).

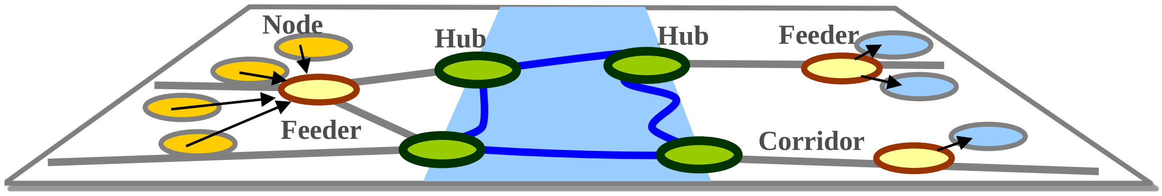


Figure 1.1 Transport network

Nevertheless, the physical forms of transport network vary depending on the transport modes. Rail and road transport networks are composed of tangible routes, i.e. the track infrastructure, while air and maritime transport networks consists of less intangible routes due to higher spatial flexibility. The routes of air and maritime transport are essentially scheduled services provided by carriers. Therefore, from the perspective of industrial organization, transport networks are made up of infrastructures (e.g. rail, highway and terminal) and carriers (e.g. airline, shipping line).

The evolution of transport network structure reflects the impacts of technological innovations and is interdependent of spatial, economic, and social changes. Considering the spatial structure and organization of transport infrastructures and carriers, we propose to analyze the transport network from two dimensions: spatial structure and industrial structure.

1.2.1 Spatial structure

From a spatial perspective, transport geography concerned with the explanation of the socio-economic, industrial and settlement frameworks within which transport networks develop and transport systems operate. Throughout history, transport networks have structured space at different scales. The influence on the spatial structure is specified at the local, regional and global levels.

The spatial structure contains the point-to-point model, point-to-multipoint model and the hub-and-spoke model. The point-to-point network refers to a transport system in which a plane, bus, or train travels directly to a destination, rather than going through a central hub. It is used widely in road transport and rail transport. Also, the point-to-point network is used by low cost carriers, e.g., Southwest Airlines in the US and Ryanair and easyJet in Europe.

The hub-and-spoke network is a system that all traffic moves along spokes connected to the hub at the center. It is applicable to several forms of transport, such as sea transport, full service airlines and cargo airlines. The emergence of hub-and-spoke network is the result of network development rationalizing limited volumes through a limited number of routes. If the traffic becomes sufficient, direct point-to-point services will be established as the result of user preferences (Rodrigue et al., 2013).

The transport networks are the outcome of spatial changes marked by various strategies adopted, such as providing access and mobility to a region, integrating upstream or downstream nodes. These strategies are relevant to the competition and cooperation relationship of corridor and terminal operators in different levels of transport network.

From the vertical view, hub-feeder cooperation and hinterland access is a critical network strategy for transport nodes. From the horizontal view, nodes at the same stage of transport chain have more complicated relationships. It can be the inter-terminal competition, e.g., the competition between adjacent hub ports. However, it is difficult to tell the relationship between different transport nodes. For instance, the relationship between air hub and nearby rail station can either be competitive or complimentary. Bogart (2009) noted that few studies exist about the complementarity between different transport systems. His study of the co-evolution of roads, canals, and ports in the industrial revolution identified interdependencies among the different nodes and networks.

1.2.2 Industrial structure

The industrial structure also plays an important role in shaping transport networks. Different from spatial structure, the industrial structure focus on the organizations and relationships among different hierarchies on the transport network, rather than the location / connection of the facility or the movement of passenger and cargo. Generally, the industrial structure has two dimensions: vertical structure dealing with downstream and upstream relationship, and horizontal structure dealing with competitors situating on a same hierarchy.

Among the major transport modes, the industry practice in the shipping / port, rail and aviation sectors calls for a deep research addressing the issues such as

- how to balance the trade-off between economies of scale and introduction of competition;
- how to choose between vertical separation / integration and horizontal separation / integration;
- how to improve regulations; and
- how the competition goes between different kinds of service level.

This dissertation addresses the aforementioned issues. Regarding the shipping and port sector, we focus on the specialization and cooperation mechanism among ports in the Pearl River Delta. Regarding the rail sector, through a modeling approach, the emphasis is put on which vertical / horizontal structure has higher efficiency and what policy should the regulator adopt to eliminate the information asymmetry on the operator's cost. Regarding the aviation sector, much research work has been done on the effect of liberalization on the airline competition and hub-and-spoke network structure (Oum et al., 2009; Forbes and Lederman, 2010; Bilotkach et al., 2012). We further focus on the effect of emergence of low-cost carriers on the airports competition in the multi-airport region.

1.3 Theoretical Background

This section gives an introduction of theoretical background of distinct research methodologies from different research areas, particularly transport geography, transport economics, industrial organization and regulatory economics.

1.3.1 Transport geography

Transport geography is a branch of economic geography concerning about the mobility of people, freight and information. The role of transport geography is to understand the spatial relations that are produced by the transport networks. It pursue and investigate the spatial organization of mobility by considering its attributes and constraints related to the origin, destination, extent, nature and purpose of movements (Rodrigue et al., 2013).

Transport geography developed as a discipline in the second half of the twentieth century. In the 1960s, transport costs were formalized as a key factor in location theories, and transport geography began to rely increasingly on quantitative methods, particularly over network and spatial interactions analysis (Pred, 1967).

From the 1970s, the reduction in high transportation costs provided a new impetus to decentralization within regions. In particular, the metropolitan portions of public transport systems opened up vast suburban areas for low-density home and work places (Hanson and Giuliano, 2004). The container port system in the US was also observed traffic deconcentration in the time-span 1970-1985 (Hayuth, 1988). Transport geography became a niche concerned with the transport network itself in response to economic and industrial development (Taaffe and Gauthier, 1994).

Since the 1990s, transport geography has got renewed attention and tended to cover a much broader interactions of production system and distribution flows. With the convergence of logistics and information technologies, the issues of mobility, production and distribution became interrelated in a complex geographical setting (Hoyle and Knowles, 1998). The global supply chains and trade globalization supported the development of complex air and maritime transport networks. Transport is not solely considered as a derived demand due to logistical integration, but as a component of integrated demand that physical distribution and materials management are interdependent (Hesse and Rodrigue, 2004).

1.3.2 Transport economics

Transport economics is a branch of economics that deals with the allocation of resources within the transport sector. Transport economics differs from some other branches of economics in that the assumption of a spaceless, instantaneous economy does not hold, i.e. the passenger and cargo flow over the networks at certain speeds (Button, 2010).

Taking the moving speed into account, how to match demand and supply becomes a key issue. The uncertainty of network effects and choices among different goods, however, make it difficult to forecast the demand for transport facilities. In order to address this issue, discrete choice models were developed to estimate the likely choices between such goods involved in transport decisions (McFadden, 1980).

In addition to the demand forecasting, other research also address the issue that the regulator can modify the travel demand with various policies such as spatial planning (Salet et al., 2003). The regulator can also affect the mode choice through improved public transport (Buehler, 2011).

There are also researchers focusing on the forms and effects of competition between operators in the transport market. Under specific market structure, production differentiation is one of the common competition behaviors as well as price competition (Small and Yan, 2001). Hoteling model is a typical location (spatial) approach to describe the competition among companies facing consumers with different preferences (Tirole, 1988). There are also studies shedding light on the effect of a modern industrial organization on the transport efficiency, i.e. how the transport industry is organized, how it could be organized, and how it should be organized (Quinet and Vickerman, 2004).

1.3.3 Industrial organization

In economics research, industrial organization analyzes the structure and boundaries between firms, market organization and competition behavior under the condition of imperfect competition. The theory of industrial organization is employed to study the transport network structure by a few existing literatures (Quinet and Vickerman, 2004).

In some industries with imperfect competition, only a few number of firms exist for the reason of pursuing economies of scale. Therefore this cannot reach the economic efficiency as in free competition. Different theories in institutional economics give explain to the contradiction and trade-off between economies of scale and perfect competition. Some research applies the structure-conduct-performance method to the transport industry (Evans and Kessides, 1993).

The theory of contestable markets proposed by Baumol et al. (1982) believes that markets served by a small number of firms are characterized by competitive equilibrium due to the existence of potential short-term entrants. The potential-entry or newcomer limits the behavior of existed firms in the market, and thus reduces the negative impacts of monopoly. Specifically in the air transport industry, low-cost carriers remain a commonly referenced example of a contestable market. The emergence of low-cost carriers serves as a way to induce a more competitive market. The reasons supporting this argument are that entrants have the possibility of leasing aircraft and be able to respond to high profits by quickly entering and exiting (Morrison and Winston, 1987). However, the aviation market also exist barriers to entry and exit, for instance, the flight schedule and airport slots of landing and takeoff.

The *Theory of Transaction Cost* is another famous foundation theory in explaining the theory of the firm. The transaction cost is creatively proposed by Coase in 1930s, which consists of search and information costs, bargaining cost and contract cost (Coase, 1937). Williamson (1981) further used the transaction cost approach to the study of economic organization regarding the transaction as the basic unit of analysis. The theory of transaction cost provides theoretical foundation for the market structure organization. The existing of transaction cost limits the firm boundary, and thus forms industrial structure for perusing economic efficiency. It calls for the implementation of regulatory policy and institutions to decrease the transaction costs.

1.3.4 Economics of regulation

Due to public service features, the study of transport structure often involves in the economics of regulation, which is about the application of law by government or an independent agency for various purposes, such as centrally-planning an economy, remedying market failure, enriching well-connected firms, or benefiting politicians (Kahn, 1991).

The regulatory mechanism involves setting a fixed price that the regulated firm will be permitted to charge, which is called fixed price contract or price-cap mechanism (Lehman and Weisman, 2000). The second regulatory mechanism is pricing on access charge for the carriers (Ivaldi and McCullough, 2007; Lang et al., 2013).

A major reason why regulation is needed is information asymmetry, i.e. the firms have private information on their operation costs, which create barrier from regulation and social supervision (Baron and Myerson, 1982; Lewis and Sappington, 1988; Hooper, 2008). One of the regulatory mechanisms under information asymmetry is screening for the adverse selection (Gagnepain and Ivaldi, 2002; Hooper, 2008). The other way in which regulators can effectively reduce firms' information advantage is by using competitive benchmarks or yardstick competition in the price setting process (Shleifer, 1985).

The transport industry, especially the air and railway, had a wave of deregulation since 1970s. For example, the United States removed many regulations on rail rate setting in

1976 and passed Air Cargo Deregulation Act of 1977 and Airline Deregulation Act of 1978. Regulatory reforms in general aimed at moving to liberal policies companying with privatization and commercialization during1980-1990s.

In the air transport sector, deregulation is the process of removing government-imposed entry and price restrictions on airlines affecting, in particular, the carriers permitted to serve specific routes. The research of European aviation industry by Berechman and de Wit (1996) demonstrated that airlines intensified the use of hub-and-spoke networks and preferred to select a specific main hub under the deregulation of European aviation market. Kole and Lehn (1999) found that after deregulation equity ownership was more concentrated in US airline industry. The process also indicated that though it was costly to abruptly change organizational capital, governance structures gradually influenced firm performance.

Railway had long been strictly bound by certain government regulations due to its monopoly position. With the competition from rapid rise of highway and civil aviation industries, railway gradually loses the advantage in transport market. Since 1970s, railway has been deregulated in America, Japan and European countries (van de Velde, 1999). The measures of deregulation include market liberalization represented by the ease of market entry and exit, privatization, and industrial restructuring. In Chapter 4, we shall study the choice of regulatory mode in rail sector facing information asymmetry, to discuss whether deregulation is good or not through a modeling approach.

1.4 Research Topics and Objectives

This dissertation explores several competition and organization topics in transport industry covering port, aviation and railway market. It consists of four topics (Figure 1.2) with reference to transport network structure from specific levels: regional and national structures are all spatial structure level, and industrial structure level.

The first topic examines the evolution of a regional port network system. From regional spatial level, it addresses the evolution of regional port system and the development of transport network structure in South China. In the port system, the main focuses are the competition between adjacent ports and the expansion of transport networks. The research questions are: how do the container hubs be established and evolved? From the view of transport network, what strategies, cooperation or competition do the hub ports adopt in the development process? We capture the dynamic changes of ports and explain the evolution from one to two gateway ports, and to identify the driving forces and anticipate the developments of container ports.

The second topic explores a joint analysis of the two transport networks in order to reveal the competition and complementarity between transport routes and terminals in shaping transport network hierarchy. From national level, we consider the rail and air transport network in China at the terminal level. We targets to answer the following questions: what is the impact of railway improvement on the airport passenger traffic? If the number of passenger increases, whether the increasing demand at the rail station has an impact on the neighbored airport? From the perspective of transport network structure, is there any difference between the influences on the hub airport and on the regional airport?

The third topic concerns the railway network from the industrial structure level. This chapter aims at comparing different industrial structures of the railway sector, in order to provide some guidance for the China Railway reform. We study the structure reform issue of the railway industry though presenting an economic model primarily characterized by three features: vertical / horizontal separation, cost information asymmetry and strategies to eliminate the asymmetry. We explore major industrial structures regarding the railway governance and operation. Some structures are proved to be dominated by the others. Through a modeling approach, the analytical solution is derived to assist parametric analysis. We contribute to the existing literature that vertical separation mostly is better than horizontal separation, and a regulator shall also apply soft policies, such as screening, to eliminate the information asymmetry. Furthermore, if there is no information asymmetry, full regulation dominates partial, and vertical integration dominates separation in terms of the social welfare.

The fourth topic explores the market competition behavior of carrier and airport in the emerging market. It focuses on the issue of the competition between low-cost airlines serving primary and secondary airports in the intra-European market by using econometric estimation of airport choice structure.

1.5 Research Approaches

Research interest in the spatial structure of transport network dates back to the prosperity of economic geography in 1960s (Haggett and Chorley, 1969). The graph theoretical methods are then applied to analyze the structure of transport network, by proposing concepts and measures about topology of networks (Garrison and Marble, 1974). The advancement of complex network theory, mostly led by physicists, generates as a recent approach in understanding features of transport network structure (Guimera and Amaral, 2004; Li and Cai, 2004; Danila et al., 2006; Wang et al., 2011). The study of transport network is at a crossroads between various scientific disciplines. So far, there remains little overlap and interaction between the different approaches. This research attempts to explore structure of specific transport network from a multi-disciplinary approach.

The first topic (Chapter 2) is conducted in order to gather more development dynamics about PRD port sector. It follows the traditional conceptual model on port system development in transport geography. Specifically, there is an attempt to find and learn about the differences with other regional port system and underling reasons. Also information about the port network strategies is gathered by field investigation.

The second topic (Chapter 3) is an empirical study using panel data model. Two models are formulated to examine the effects of rail acceleration and hub concentration. The data used concludes annual passenger traffic data from China's air and rail transport yearbook and economic data from several databases. Random effects and fixed effects models are applied for estimation.

The third topic (Chapter 4) is conducted by a modelling approach and analytical framework comparing different railway industry structures. Some structures are proved to be dominated by the others. For those structures that cannot be proved dominated, analytical optimal solutions are derived. Through a numerical study and parametric analysis, more regulatory and managerial implications are obtained.

For the research of the fourth topic (Chapter 5), we adopt discrete choice models to investigate heterogeneous preferences of travelers for airport and airline choices. We use stated preference survey data of international air passengers in European aviation market for estimation.

The rest of the dissertation is organized as follows. Chapter 2 examines the process of

PRD port system from one gateway port to two gateway ports, by investigating the container traffic pattern and geography setting. Chapter 2 ends with identifying the driving forces and anticipating the developments of PRD container ports.

Chapter 3 studies the issue of competition between different transport networks on a context of transport nodes. It examines the impact of railway improvement on the airport passenger traffic in China, taking into account the railway speed acceleration and the effect of passenger traffic at neighbored rail station.

Chapter 4 studies the structure reform issue of the railway industry though presenting an economic model. It compares different industrial structures of the railway sector, in order to provide some guidance for the China Railway reform.

Chapter 5 explores the issue of the competition between low-cost airlines serving primary and secondary airports in the intra-European market by using econometric estimation of airport choice structure.

Chapter 6 concludes and points directions for future research.

Chapter 2 Evolution of Spatial Network Structure in Multi-port System

We shall firstly study in this chapter the transport network structure issues on the regional spatial structure level, examining the process of Pearl River Delta port system from one gateway port to two gateway ports by investigating the container traffic pattern and geography setting.

2.1 Introduction

Since the 1980s, the substantial expansion in containerization and the increasing bargaining power of global shipping alliances have greatly changed the maritime market structure and reduced the dependence of shipping lines on particular ports. Consequently, these changes have further aggravated regional port competition. In recent years, the logistics integration and network orientation in the port and maritime industries have redefined the functional role of ports in transport chains and have generated new patterns of port hierarchy (Notteboom and Rodrigue, 2005). Meanwhile, the competition between adjacent ports is becoming fiercer, e.g., the adjacent ports in North Europe, Japan, and South China. No single port has a lasting overwhelming superiority over other ports in a contestable hinterland (de Langen, 2007). The spatial structural development of a port system warrants an in-depth investigation because other port regions may face similar development if the world container traffic continues to increase. The competition among major container ports in the Pearl River Delta (PRD) of South China is a typical example. In the last two decades, the container port system in the PRD has undergone rapid growth and expansion.

The PRD region houses thousands of manufacturing plants and generates cargo traffic of tens of millions of containers. The region covers nine cities of Guangdong province and is the manufacturing hub of both Guangdong province and China. The area accounted for 83.3% of GDP, 96.6% of import value, and 95.8% of export value of Guangdong province in 2009. Since export-oriented industries were built in the PRD in the 1980s, the Hong Kong port has had dominance in South China as an international hub port and gateway for China (Rimmer, 1996). The hub port herein refers to a port as central point for the collection, distribution and transshipment of goods. The gateway port is defined as a port of entry (exit) where shipments are cleared through customs before reaching its final destination (after leaving its origin). A gateway port offers accessibility to a large system of circulation of freight, passengers or information (Rodrigue and Notteboom, 2010). Hong Kong has long been viewed as a gateway because it generally commands the entrance to and the exit from China.

With the ever-growing trade in PRD, Hong Kong recorded a double-digit throughput growth and established itself as the busiest container port in the world from 1986 to 1996. Since the late 1990s, Hong Kong has been facing an increasingly competitive environment with challenges from other regions, for example Singapore in its global hub role, and from other cities within the region, especially Shenzhen's role as gateway to PRD. Within the PRD from only one gateway port, there are now three, which are the Hong Kong port (HKP), Shenzhen port (SZP), and Guangzhou port (GZP).

SZP now comprises four groups of international container terminals, namely Shekou container Terminals (SCT), Chiwan Container Terminals (CCT), Dachan Bay Container Terminals (DBCT), and Yantian International Container Terminals (YICT). YICT began operations in 1993, and since then, the container throughput of SZP has increased sharply. This increase is gradually shaping SZP into a gateway port. GZP is the largest comprehensive hub port in PRD, but it started late in the international container market. Due to its geographical disadvantages, 100 km inland along the Pearl River, GZP plays the role of regional hub port and prioritizes domestic trade. After the addition of the Nansha terminals to GZP, the container throughput of GZP reached over 11 million TEU in 2008 and it then ranked in the top 10 busiest ports in the world.

Port competition in PRD attracts extensive attention in literature because of the intensive localized and regional competition and hence interesting dynamics. The issue of PRD port competition aroused heated discussion around year 2000. One of the focuses of the previous studies was on whether the position of HKP would be overtaken by SZP, but different preferred views of future were developed, e.g. the independent development of SZP (Cheng and Wong, 1997) and cooperative developments of SZP and HKP (Song, 2002). After 2002, there should be no further study to examine whether the competition evolves as the previous studies predicted. Therefore, we investigate the special features of PRD port development process and the underlying forces driving the transition. We examine two fundamental issues for port development that were overlooked in the previous studies. The first issue deals with how the port system of competing gateway ports changes, especially when one of the ports has been well developed. The second issue is how the port competition is driven by which major forces, in particular when competing ports are developing at different stages.

This chapter has two major objectives: (1) to capture the dynamic changes of PRD ports in order to explain the evolution from gateway ports, and (2) to identify the driving forces of the evolution and anticipate the future developments of major ports in the region. The remainder of this chapter is organized as follows. Section 2.2reviews previous studies on the stages model of port development and its application to the ports in South China. Section 2.3 applies the stages models to the PRD by exploring the development stages of the PRD port system and related changes in container traffic patterns. Section 2.4 discusses the driving forces underlying the port development process in the region. Section 2.5 discusses the future development of PRD port system. Finally, Section 2.6 concludes the present study.

2.2 The Theory of Container Port System Development

Taaffe et al. (1963) provided an initial insight on port development in a region. He proposed a six-stage port system development model. The six stages are (1) scattered ports, (2) penetration and port concentration, (3) development of feeders, (4) interconnection, (5) complete interconnection, and (6) emergence of high-priority main corridors. The key idea here was the effect of inter-port competition on the relative size of the port. Over time some ports won trade at the expense of others.

Hayuth (1981) re-expressed this thinking for the era of containerization, recognizing five phases which are (1) conventional port, (2) container port, (3) port concentration and inland penetration, (4) load center, and (5) port decentralization. The first three phases were similar to the Taaffe model (1963), but with the addition of the load center concept in the fourth stage which refers to the dominant seaports within a container port system. In other words, the container traffic concentrated to a limited number of large ports.

Finally, Hayuth (1981) recognized that congestion in load centers could result in decentralization and relocation of container traffic to smaller ports.

Slack (1990) extended the effect of competition in the Taaffe model by appending a further concentration of traffic flows to major corridors due to intermodal systems so that redundant nodes situated off the main routes began to appear.

The Hayuth (1981) model has been widely adopted in examining the development path of ports (Notteboom, 1997; Wang, 1998; Wang and Slack, 2000; Lee et al., 2008). Notteboom (1997) examined port concentration and de-concentration tendencies, and load center development in Europe by statistically analyzing the concentration ratio of the European continental port range from 1980 to 1994. He confirmed that the concentration tendency would eventually reach a limit and de-concentration would possibly follow.

Notteboom and Rodrigue (2005) extended the Hayuth (1981) model into the era of logistics and supply chain management by adding port regionalization as the sixth phase. Port regionalization emerges as a higher level of integration between gateway ports and inland transport network so that a “regional load center network” is formed. Functional interdependency and joint development of a specific load center and multimodal logistics platforms in the hinterland strengthen the port at the focus of regionalization. Rodrigue and Notteboom (2010) further elaborated this conceptual structure by introducing the foreland-based regionalization and discussing the evolving role of intermediate or transshipment hubs in the shipping network. The foreland-based regionalization refers to the capture of foreland of the intermediate hub as supplies and the integration of intermediate hubs in regional shipping networks.

The models outlined above have been applied to the studies of PRD port system as well. Wang (1998) divided the evolution of HKP from the 1970s to 1995 into three stages. HKP changed from an initial container port (first stage) to a sole container hub (second stage), and at the third stage the terminal operators of HKP penetrated into other mainland ports. Wang and Slack (2000) investigated the changing roles of HKP and other ports in PRD. They concluded that a regional system of multiple ports was taking shape with SZP and HKP as two deep-sea direct service ports. Rodrigue and Notteboom (2010) listed that SZP-HKP cluster as an example of hinterland- dominated regionalization.

Many research studies have been carried out to understand and interpret the evolution of the PRD port system. Wang and Slack (2000) identified the major forces as the cost-based competition, the impact of the "one-country two-systems" policy, the impact of globalization and container standardization, and the impact of multi-modal accessibility. Song (2002) confirmed the cooperative and competitive relations between PRD ports and highlighted integration between Hong Kong and South China would be a driving force for the formation of port system. Loo and Hook (2002) argued market forces cannot fully explain the container port development and political and other policy considerations would become more important. On another track of research, the port system evolution has been discussed from the logistics and urban planning perspectives. For examples, Lee and Ducruet (2009) pointed out that cross-border integration is a major factor in shaping the hub port cities, and Hong Kong is changing its role to a leading node of urban system of South China. Wang and Cheng (2010) presented a new view that Hong Kong is in the transformation process from a freight-transport hub city to a global supply chain management center.

From the above review, this chapter will complement existing research on the PRD by discussing the recent and current trends with empirical evidence as well as a decline of developed gateway port. The purpose of the current research is to extend and deepen the understanding of evolution in a port system by incorporating the recent changes in the PRD, and in the process generalize a model of port development.

2.3 Port Development Model Applied to the PRD

2.3.1 Issues in recent PRD port development

The development stages of PRD ports can be summarized in the port spatial development model (Figure 2.1). In Stage 1 (before 1970s), there are only some scattered traditional ports (like GZP and HKP) serving general cargoes. The initial container port emerged in HKP in 1970s driven by the containerization technology and economy development (Stage 2). The fast growth in export processing industry generated large amounts of containerized cargoes to HKP. Since the implement of "open-door" policy in China from 1978, HKP as the single gateway port had fast growth stimulated by the export-oriented economy. During the Stage 3 (1980s-1994), over 90% of China's containers shipped via

HKP, which turned into the busiest port in the world. With the operation of SZP from 1994, the PRD port system enters a “two-port load center” stage (Stage 4, late 1990s-2003). SZP had a dramatic rise in a short time, and HKP terminal operators penetrated to hinterland by investing terminals in PRD. In Stage 5 (2004-late 2000s), the emergence of Nansha port in GZ further diverted a portion of container flow; container traffic disperses from the original core to periphery. After decade of fast growth of export-oriented economy, Guangdong now meets a bottleneck of economic growth and faces the pressure of industrial structure adjustments. With the manufacturing migration, SZP and GZP are more active in developing business in landlocked provinces. The Stage 6 is referred as regionalization (2008-present). SZP and GZP are dominated by hinterland-based regionalization with integrating inland transport network, while HKP undergoes foreland-based regionalization as a transshipment hub.

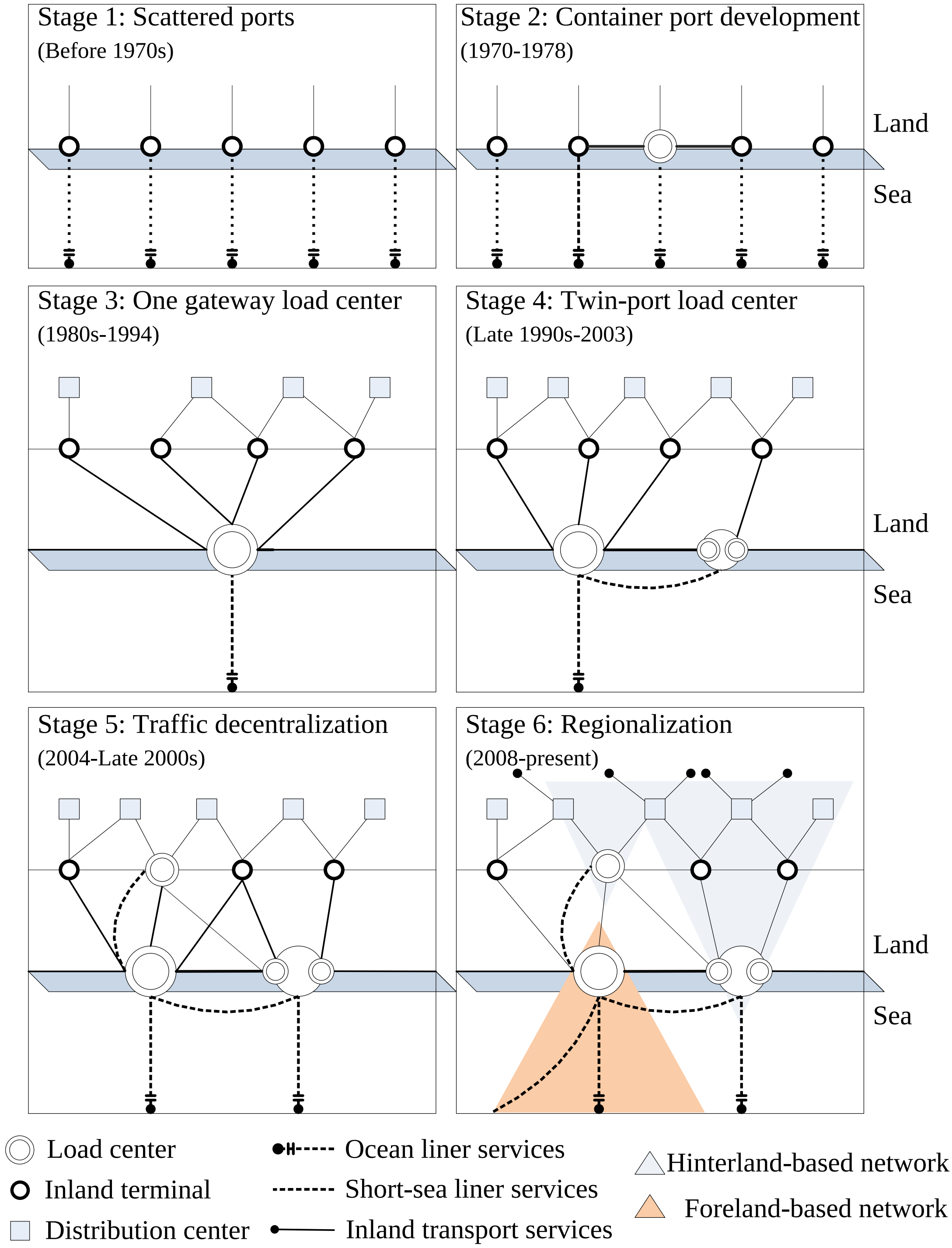


Figure 2.1 Geographic configurations of port structure

This research suggests there have been several important trends in the PRD that need to be considered in understanding its development. First, the individual ports in a port system can overlap in development stages. For instance, HKP established the role of a single gateway port in the 1980s (Stage 3 in Figure 2.1). As HKP was experiencing an inland penetration process in the late 1990s, SZP evolved into a second gateway port. Then container flows continued to decentralize into three-port competition. These different paths of port development reflect the changes in both the regional economy as well as changes in international trade. Second, port regionalization in the area is not necessarily homogenous, especially when there are more than one port. The regionalization processes of the ports are moving in separate directions, which involve different hinterland and foreland integration. Section 2.3.2 discusses these two special spatial developments.

2.3.2 Overlapping developments at regional ports

A growth rate versus market share diagram (Figure 2.2) shows the evolving competition among the three ports in PRD. Although the total container throughput is still in the lead, HKP has kept a slow growth rate and gradually lost its market share in competing against the other two ports from 1994. After a decade of dramatic increase, SZP now accounts for about 40% of the market and steps into a mature stage. The gap of market share between SZP and HKP has greatly narrowed. GZP is still growing at a fast rate as the market share is less than 15%.

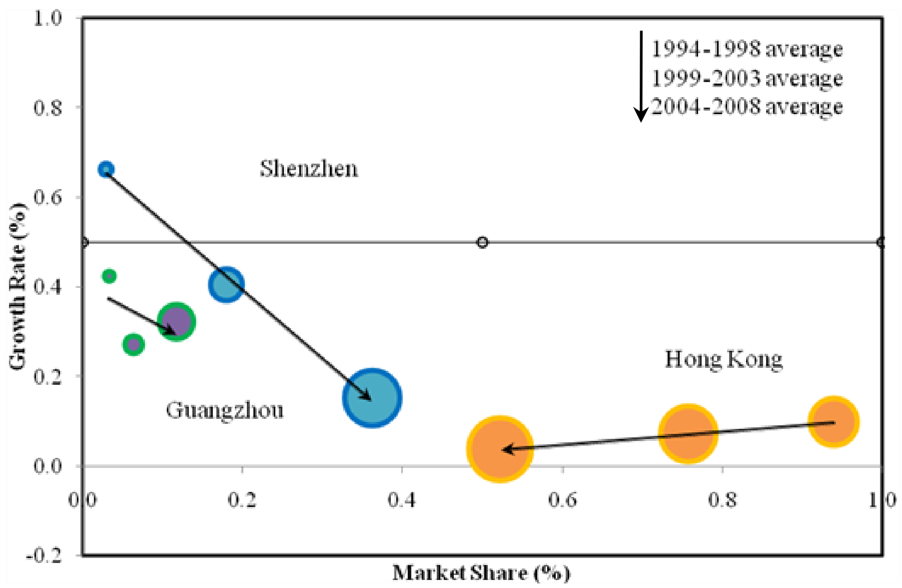


Figure 2.2 Growth rate versus market share of three ports

Note: the size of bubbles denotes relative port throughputs.

Table 2.1 reflects the changing composition of container flows from South China among the three major ports in from 2003 to 2009[4]. HKP faced a decreasing proportion of hinterland container traffic when compared to the other two gateway ports, especially in import and export traffic. This was partially due to the inferior hinterland accessibility compared with SZP and GZP and the constraints of inland transport networks. The cross-boundary constraints for Hong Kong restricted the collection and distribution of containers to and from the Mainland. In the meantime, SZP substantially strengthened its role in the South China container market. SZP's market share of export from South China has been over 70% since 2003 (Table 2.1). This signed SZP evolved into a second gateway port.

Table 2.1 Composition of container throughput generated in China by port

	2003	2004	2005	2006	2007	2008	2009
Total TEU of GZP	2,769	3,304	4,683	6,656	9,259	11,001	11,200
Domestic trade	1,530	1,800	2,872	4,144	5,934	7,321	7,430
	(55%)	(54%)	(61%)	(62%)	(64%)	(67%)	(66%)
Import and export	1,239	1,504	1,811	2,512	3,253	3,161	3,270
	(45%)	(46%)	(39%)	(38%)	(35%)	(29%)	(29%)
International	-	-	-	-	72	519	500
transshipment	-	-	-	-	(1%)	(5%)	(4%)
Total TEU of SZP	10,650	13,615	16,197	18,468	21,100	21,416	18,250
Domestic trade	633	675	715	838	913	975	1,003
	(6%)	(5%)	(4%)	(5%)	(4%)	(5%)	(5%)
Import and export	8,953	11,391	13,458	15,112	17,344	16,529	14,581
	(84%)	(84%)	(83%)	(82%)	(82%)	(77%)	(80%)
International	1,064	1,549	2,024	2,518	2,843	3,913	2,666
transshipment	(10%)	(11%)	(12%)	(14%)	(13%)	(18%)	(15%)
TEU of HKP from China	7,057	7,550	8,176	8,755	8,734	9,006	7,848
Import and export	2,465	2,533	2,888	3,337	2,857	2,900	2,514
	(35%)	(34%)	(35%)	(38%)	(33%)	(32%)	(32%)
International	4,592	5,017	5,288	5,418	5,877	6,105	5,334
transshipment	(65%)	(66%)	(65%)	(62%)	(67%)	(68%)	(68%)

Notes:

(1) GZP=Guangzhou Port, SZP= Shenzhen Port, HKP=Hong Kong Port.

(2) The throughput of HKP only contains container flow generated in South China.

(3) The container throughput of HKP is a rough estimate by *X*/ (1-*Y*), where *X* denotes laden container statistics (source: China Port Yearbook, Hong Kong Shipping Statistics), and *Y* denotes percentage share of empty containers (source: Summary Statistics on Port Traffic of Hong Kong).

[4] The proportion of hinterland container traffic to HKP is decreasing through the years. The data from 2003 to 2009 is used to keep consistent with the results of field investigation did in 2010.

The emergence of the GZP reshaped the landscape of the PRD port system as it diverted portion of container flow generated in the hinterland. Since Nansha terminals became operational in 2006, GZP has developed rapidly. In terms of container throughput from China, GZP first surpassed HKP in 2007 (Table 2.1). The total container throughput reached 11 million TEU and ranked among the top three in China and the top ten in the world in 2008. Hence GZP drove the PRD region from a two-gateway pattern into a three port competition. The region's container traffic continued to decentralize.

Nevertheless, the data also confirms that SZP and GZP are different from each other. The first difference lies in the functional positioning. In general, SZP is for international trade and GZP for domestic trade. In 2009, the percentage of ocean containers of GZP and SZP were 33% and 95%, respectively. Another difference is the relationship with HKP. Hong Kong is the independent port centered on Asia due to its role as a gateway for South China and international hub in East Asia (Ducruet and Notteboom, 2012). GZP and SZP were long the two major feeder ports to HKP (Table 2.2). With the maturity in SZP's role, the exchange container throughput between SZP and HKP began to reduce and was surpassed by GZP since 2007. In other words, SZP was developing into a more independent port as more shippers chose to export their cargoes directly through SZP[5].

Table 2.2 Exchange containers between HKP and PRD ports

	From PRD				To PRD			
	Total	GZP	SZP	Feeder ports	Total	GZP	SZP	Feeder ports
2003	2,237	385	776	1,076	1,694	291	311	1,092
2004	2,567	457	1,047	1,063	1,975	285	424	1,266
2005	2,753	467	1,046	1,240	1,928	391	437	1,100
2006	2,774	437	862	1,475	2,232	496	455	1,281
2007	2,712	572	877	1,263	2,504	498	386	1,620
2008	2,861	683	912	1,266	2,344	274	357	1,713
2009	2,484	886	627	971	2,376	659	325	1,392

Source: Hong Kong Shipping Statistics, 2003-2009
Unit: '000 TEU
Notes:
(1) PRD = Pearl River Delta, GZP=Guangzhou Port, SZP=Shenzhen Port.

[5] The opinion was collected from an interview with terminal operators (e.g. Yantian International Container Terminals) in 2010.

(2) Feeder ports are ports where freight is consolidated or redistributed to a deep-sea service port by short sea shipping service. Here the feeder ports refer to other PRD ports besides GZP and SZP.

The changes in composition of container flows indicate that the container traffic in PRD has become decentralized and three regional hub ports have developed. However, currently these three gateway ports are in different developmental stages: SZP was dependent on HKP but is not now; SZP and HKP have developed into independent load centers, while GZP is dependent on SZP and HKP. HKP is regarded as developed port and SZP and GZP developing ports.

2.3.3 Changes in port regionalization

In the last few years, changes in the container traffic composition in PRD were observed. The changes lie in the specialization of container traffic flows and the formation of a regional load center network. Figure 2.3 illustrates the container flow network in South China based on 2009 data. As shown in Figure 2.3, over half of the containerized cargoes from the PRD region flowed through SZP to export, while HKP was dominant in importing containers into South China. GZP shared the smallest proportion of direct ocean containers because the majority of the traffic was domestic. Figure 2.3 also contains information on the exchange containers between the three load centers and feeder ports. Regarding exchange containers between HKP and other ports, GZP had the greatest contribution to the export and outward transshipment containers of HKP. By contrast, almost half of the import containers from HKP were shipped to feeder ports.

Along with the formation of this specialized container traffic pattern, the three major ports are currently developing different regionalizations of their traffic. The regionalization of SZP and GZP accompanies the development of multimodal logistics platforms in their hinterland. SZP and GZP are all engaged in enhancing the inland transport network, such as barge and railway connections. One representative example is the establishment of the South China Common Feeder Alliance in 2003[6]. Aimed at attracting barge freight from western PRD, the shuttle barge service has now developed into a waterway network

[6] The barge liner services were first launched by terminal operators (SCT and CCT) in 2001, aimed to connect the Western SZP with river ports along the Pearl River. With the increasing coverage of service and feeder network came into shape, the South China Common Feeder Alliance is then founded at 2003. More information is available at http://www.sccfa.com/ev/

covering 14 port cities and 32 river and coastal terminals in Guangdong and Guangxi provinces. This development has diverted substantial western PRD container flow from HKP. Besides, from 2008, the terminal operators in Guangzhou and Shenzhen began to engage in developing rail-sea intermodal transport to expand hinterland[7]. These projects enabled ports to provide door-to-door logistics services to importers and exporters in the Guangdong province and five landlocked provinces.

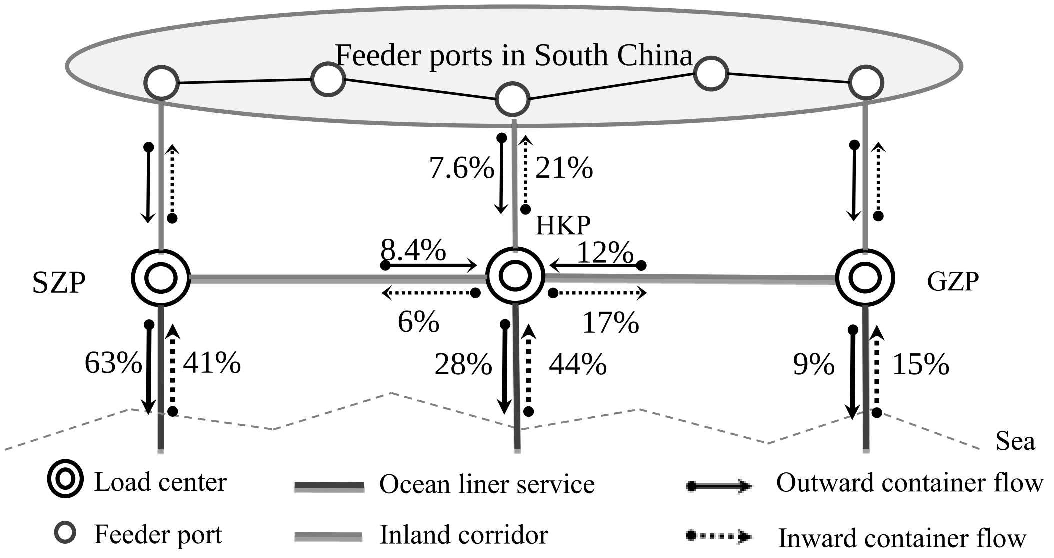


Figure 2.3 International container flow network in South China

Source: Data are compiled from Hong Kong Shipping Statistics (2009) and China Port Yearbook (2009).
Note: The null market shares of containers between feeder ports and SZP/ GZP are due to the throughputs between ports unavailable.

SZP has also attempted foreland regionalization though comparatively disadvantageous to HKP. In 2005, Shenzhen constructed the Yantian Harbor Free Trade Logistics Park, which is one of a few Free Trade Zones (FTZ) connected directly to railways, highways, and ports. The Yantian Harbor Free Trade Logistics Park performs the function of both a logistics distribution center and a platform for intermediary trade. It enables export manufacturers or shippers to get export tax rebates once their cargoes are delivered to the FTZ without waiting for the departure of container vessels. In addition, the simplified

[7] The rail-sea intermodal services are offered by YICT of SZP and Guangzhou container terminal of GZP. They have opened businesses in Guangdong and inland areas such as Chongqing, Hubei, Hunan, Jiangxi and Yunnan. Information are available at http://www.yict.com.cn/2006en/changyan/index.asp; http://www.gct.com.cn/index.htm

customs clearance procedures greatly reduced the uncertainty of clearance time and facilitated the transshipment.

By contrast, HKP is undergoing the foreland-driven regionalization. With the phenomenal developments of SZP and GZP, HKP has lost its monopoly as the sole gateway port of South China. The terminal operators of Hong Kong are enhancing their transshipment functions. For instances, a container terminal improves transshipment efficiency to shipping lines by transferring transshipment cargoes from one ship to another while the loading and unloading of other cargos are also taking place on both vessels at the same time (HIT, 2009). This transshipment service allows shipping lines to lower costs by making fewer calls to other ports. HKP also provides higher value-added activities, such as banking and financial support, in addition to the conventional logistics activities, such as consolidation, labelling, and processing.

The transshipment hub is marked by large share of international transshipment. HKP has exerted effort to attract more international transshipments. Table 2.3 shows that worldwide transshipments contributed to over half of the total laden containers of HKP. This percentage even increased to 64% in 2009. From 2007, the total percentage of transshipment accounted for over 50% and outward transshipment surpassed 60% in HKP. This figure proves the HKP is now as a transshipment center, a role that is more significant than its role as an export and import gateway in South China.

Table 2.3 Laden container of the Hong Kong port

	2003	2004	2005	2006	2007	2008	2009
Total throughput	16,532	17,883	18,453	19,344	19,907	20,272	17,726
Direct	7,998	8,396	8,302	8,379	7,711	7,454	6,299
	(48%)	(47%)	(45%)	(43%)	(39%)	(37%)	(36%)
Import	3,526	3,732	3,730	3,855	3,591	3,531	3,136
	(21%)	(21%)	(20%)	(20%)	(18%)	(17%)	(18%)
Export	4,472	4,664	4,572	4,523	4,120	3,922	3,164
	(27%)	(26%)	(25%)	(23%)	(21%)	(19%)	(18%)
Transshipment	8,534	9,487	10,151	10,965	12,196	12,818	11,427
	(52%)	(53%)	(55%)	(57%)	(61%)	(63%)	(64%)
Inward	4,084	4,751	5,265	5,511	5,934	6,309	5,565
	(25%)	(27%)	(29%)	(28%)	(30%)	(31%)	(31%)
Outward	4,450	4,736	4,886	5,454	6,262	6,509	5,862
	(27%)	(26%)	(26%)	(28%)	(31%)	(32%)	(33%)

Source: Hong Kong Shipping Statistics, 2003-2009
Unit: ’000 TEU
Note: Only laden container are statistically specified by import, export and transshipment.

3.2.3 Summary of recent geographic changes

The significant changes in the PRD container port system in the past 13 years can be summarized in three points. The first point is that, with the development of SZP and GZP, ocean container traffic generated in the PRD has greatly decentralized from HKP. The second point is the two-gateway load center situation formed around 2003 is transforming into a three gateway system among HKP, SZP, and GZP. The third point is that the PRD port system is currently at the stage of regionalization. The regionalization of SZP and GZP are dominated by hinterland regionalization with an integrated inland transport network, while HKP is undergoing foreland-based regionalization as a transshipment hub. The next section explores the strategies of firms and governments that are major influencing factors behind these changes.

2.4 Major Forces Reshaping Port Development in the PRD

2.4.1 Carriers

Shipping lines are critical influences upon inter-port competition (Slack, 1985; Heaver, 2002; Tongzon and Sawant, 2007). Moreover, the globalization of container liners, by mergers, takeovers, and alliances has resulted in greater market power for the alliances and more choices in calling at ports (Heaver et al., 2000). Shipping lines are the decision makers who select ports of call and the call sequence on a trade route. A shift in port-call pattern reflects changes in port competitiveness (Notteboom, 2009). Wang and Ng (2011) regarded the international shipping liner services as a key criterion in deciding a port’s international connectivity and layer in the hub-and-spoke system.

In the PRD shipping lines have contributed to the restructuring of inter-port competition outlined in Section 2.3.2 by providing more liner services at SZP and GZP. This force can be observed in Table 2.4. From 2004 to 2007, the number of international container lines calling at SZP increased by nearly 50% to 186, while those calling at GZP increased from 5 to 24. A primary reason for the change was to meet customer preferences for extended network coverage. The PRD region generates a great volume of containers, which is sufficient for shipping lines to build up new service routes. That build up is a response to two pressures. One is to expand the geographical span of their network and two is provide more direct routes to ports. The shipping lines response to these pressures has directly speeded up the evolution of SZP as a load center. The other reason that attracts carriers to choose SZP and GZP instead of HKP is the benefits of lower operational costs.

More shipping lines now prefer SZP compared to HKP for their liner services to HKP, as can be seen in the data in Table 2.4. This provides a detailed analysis of the liner services at GZP and SZP. SZP is divided into the eastern terminals of SZP (E-SZP) and the western terminals of SZP (W-SZP), and the proportions of liner services which also call at HKP are given. In the major trade routes (i.e., American and European routes), the percentage of joint calls has been decreasing. Especially in W-SZP, the liner services of European routes only calling at SZP now account for about a half of the total. The changing port-calling pattern reflects the enhanced competitiveness of SZP over HKP and also shows that shippers now favor direct exports from SZP.

Some of the outcomes discussed in this section above reflect shipping line influence on port development via investment in container terminals. For example, the Maersk Group is one of the major shareholders in the first and second phase of GZP. Such ownership or control provides shipping lines, which have sufficient volumes of traffic, with better opportunities to integrate the schedules of their ships with terminal operations (Heaver, 2002). For container terminals, the investment by shipping lines guarantees container traffic and thus, results in competitive advantages on certain routes.

Table 2.4 International liner shipping routes in terms of ports of call

Liner shipping routes	2004 Total calls at HKP (%)	2005 Total calls at HKP (%)	2006 Total calls at HKP (%)	2007 Total calls at HKP (%)	2008 Total calls at HKP (%)	2009 Total calls at HKP (%)
America						
E-SZP	36 (94%)	42 (95%)	41 (93%)	39 (90%)	35 (89%)	32 (88%)
W-SZP	17 (100%)	24 (96%)	27 (93%)	28 (96%)	24 (92%)	22 (86%)
GZP	0 (0%)	1 (100%)	2 (100%)	4 (75%)	3 (100%)	4 (75%)
Europe						
E-SZP	21 (90%)	21 (86%)	29 (76%)	30 (80%)	29 (76%)	28 (79%)
W-SZP	23 (74%)	29 (76%)	26 (65%)	40 (50%)	30 (47%)	25 (56%)
GZP	0 (0%)	2 (100%)	5 (80%)	8 (63%)	7 (71%)	9 (67%)
Asia						
E-SZP	6 (83%)	6 (83%)	8 (100%)	8 (100%)	7 (100%)	14 (64%)
W-SZP	32 (91%)	37 (92%)	42 (86%)	60 (80%)	56 (80%)	65 (72%)
GZP	4 (75%)	5 (80%)	7 (71%)	8 (75%)	6 (100%)	8 (75%)
Africa						
E-SZP	1 (100%)	1 (100%)	2 (100%)	3 (100%)	2 (100%)	2 (100%)
W-SZP	3 (67%)	2 (50%)	3 (67%)	6 (50%)	7 (43%)	7 (57%)
GZP	0 (0%)	0 (0%)	1 (0%)	2 (50%)	5 (60%)	2 (100%)

Source: Data during 2004-2008 are compiled from China Port Yearbook (2005-2009); data of 2009 are compiled from websites of each terminal.

Remark: As HKP is the port offered the largest number of liner services in the region, almost all of liners calling at SZP also call at HKP. Table 2.4 demonstrates the changing position of SZP and GZP, assuming HKP be the reference port.

Notes:

(1) HKP = Hong Kong Port; E-SZP = east terminals of Shenzhen Port; W-SZP=west terminals of Shenzhen Port; GZP=Guangzhou Port

(2) The percentage in parentheses means the percentage of liner shipping route that also calls at

HKP in total calls of X-port.

2.4.2 Market access

There is no doubt that container traffic is driven by the economic environment, international trade, and geographical distribution of production. In the early 1990s, port investment and construction in PRD were the results of the shift in production base from Hong Kong to neighboring Guangdong province in the 1980s. This manufacturing migration was mainly due to the comparatively low costs in Mainland China. This development model was widely described as the “front-shop-back-factory” model (Yang, 2004). The development of SZP is majorly benefited from the manufacturing migration and cross-border integration of cities.

Hong Kong terminal operators responded to this new set of circumstances by devoting efforts to penetrate the Mainland China market (Wang, 1998). For example, Hutchison Port Holdings (HPH) started investing in the PRD container port development projects in 1993 (Airriess, 2001). The burgeoning set of terminals and feeder ports in PRD took the shape of a strategic layout of a container port system in South China. This port investment and expanded operations enabled the Hong Kong terminal operators to continue to influence the container flow in South China and keep a step ahead of the port competition emerging from SZP and later GZP. However, HKP faced disadvantages in land availability for expansion, high land and labor costs, and the bottleneck of cross capacity on the land border with China. The increased port traffic caused heavy traffic congestion problems for HKP and detracted from its competitiveness of HKP (Song, 2002).

At the same time, SZP experienced a dramatic growth in port throughput. SZP enjoyed competitive advantages compared with other China ports due to an early introduction of investment and advanced management from Hong Kong terminal operators as well as the cost advantage compared to Hong Kong. Moreover, SZP has a superior location. The SZP has better access to the hinterland than HKP, while still accessible by international shipping routes.

The emergence of GZP is also driven by the container supplies. The export-oriented manufacturing industry as a pillar of PRD economy stimulates the huge logistics demands and investments in container terminals. Facing squeeze from hub ports in the system, smaller ports are tempted to invest in infrastructures because they believe that a lack of investment will certainly not attract container traffic (Slack, 1993). GZP has prevailing connections with the hinterland but being the container supply for HKP for a long time. To avoid the container trade outflow, GZP invested in Nansha terminal and thus accelerated the decentralization of container traffic of PRD.

2.5 New Perspectives in Regional Port System Development

The discussion above highlights two key factors in the modern development of regional port systems. However, these yet cannot explain the decline of gateway port. This section provides some new insights for the port system evolution discussed at the start of the paper. The network strategy further interprets the interaction of ports and the formation of a port system structure.

2.5.1 Changing roles of gateway ports

The following two factors explain the emergence of a second gateway port in one region. First, port users have diverse locational preferences for ports. New ports have emerged where adequate shipping demand exists. The export-led light manufacturing industries in Pearl River Delta region drive the trade flows to and from the PRD. The development of advanced logistics parks in Shenzhen and Guangzhou which facilitates the trade flows. These factors stimulate the development of original feeder ports. Second, differentials in costs among the ports are the major reason influencing the choices of port users. These differences may reflect limits on space for expansion, or it could result from investment by shipping lines and new facilities in a new port. These differences trigger the shifts in port market share. The HKP illustrates this case. The HKP has both locational disadvantages in land shortage and constraints in cross-boundary capacity. However it retains a gateway function for some services.

2.5.2 Shifts in demand

The fortunes of a port system can also be influenced by shifts in patterns of economic development within its region. After a long period of rapid development, the role of PRD as a global manufacturing base now faces bottlenecks due to constraints of resources, labor cost and environment concerns. The costs of producing low margin commodities have greatly increased. In response, the Guangdong provincial government in 2008 put forward a strategy to upgrade the economic structure and build a higher value-added industrial system.

The *Reform and Development Planning for Pearl River Delta Region* published by the National Development and Reform Commission (2008) further set a definite objective for the development of a modern service industry, such that the percentage of value added services to GDP would reach 53% by 2012, and 60% in 2020. With increasing production costs, in dustrial structure adjustments and environmental-protection requirements, a substantial number of manufacturing companies will probably migrate from PRD to the northern part of Guangdong, or to the adjacent Jiangxi and Hunan Provinces. A survey by Chinese Manufacturer's Association of Hong Kong (CMA, 2008) revealed that 36.3% of reported Hong Kong manufacturing firms planned to relocate somewhere else beyond the PRD region. In terms of the relocation place, over half of those firms would like to choose the northern part of Guangdong. Liao and Chan (2011) explored the spatial relocation strategies of Hong Kong manufacturing firms in the PRD. They concluded that the traditional front-shop-back-factory model had been expanded and transformed in the new context in light of the market orientation and the manufacturing relocation.

This development has resulted in the movement of container origins and destinations from easy to reach coastal locations to inland areas. These forces will be felt in the industrial structure adjustments in the Guangdong province and will gradually slow down the export growth in PRD. This will lead to further intensified competition among ports for access to the cargo sources in the economic hinterland.

2.5.3 Network strategy

The spatial decentralization of port systems results in the rise of port networks (van Klink, 1998). In the formation of port networks, there exist port interdependencies rather than just competition. A network strategy involves the vertical functional integration of activities along the transport chain across three spatial scales, namely, integration of feeder ports, network extension of land transport, and ocean shipping liner services.

One example is strategic cooperation between inland ports, barge operators, and hub ports. The cooperation with the barge operators enables lower transaction costs for both shippers and shipping lines by reducing searching and negotiating costs for feeder services. Furthermore, common information platforms for services to and from feeder ports enhance connections between shipping lines and barge operators. The benefits to shipping lines can be a reduction in the operation costs of returning the empty containers, and an increased market area. In this network approach the major hub ports (like SZP and GZP) benefit from the increased supply from feeder ports and so have access to economies of scale.

The network extension of land transport involves highway network and rail transport network. Particularly, the rail transport network can largely extend the port catchment to remote hinterland through sea-rail intermodal transport and utilization of dry port. For instance, the initial impact of the enterprise migration trend can be seen in the decisions of ports to acquire inland markets in adjacent provinces (Hunan, Jiangxi) and south-western China (Sichuan). The rail-sea intermodal transport project of 2008 has enabled ports of Shenzhen to provide door-to-door logistics services to importers and exporters in the Guangdong province and landlocked provinces. Hong Kong is also enhancing its connectivity to PRD cities. The Hong Kong–Zhuhai–Macao Bridge (HZMB) will operate in 2016. It is generally believed that this bridge will improve inland transport network of Hong Kong and attract more cargoes from western PRD.

The outcome of a network strategy involves opportunities to attracting more liner shipping services by offering the broader set of onward linkages. The port authorities of Guangzhou and Shenzhen have used the transport network and the information-sharing platforms to provide shipping lines with more convenient services. This service has prompted shipping lines to change the calling port on some routes or move part of their operation to SZP in particular. A feature of the network stage is that ports can develop specializations and rely on connections with different markets, and one another, to develop traffic.

2.5.4 Looking to the future

The following is a conjecture on the way that the three forces outlined above (Section

2.5.1-2.5.3) will be felt in the future development of PRD container ports. SZP will continue to act as a regional load center with expansion in inland transport connections to the new industrial areas and acceleration hinterland-networking activities. These will come from an improvement of the Pearl River barge network. In addition, the upstream vertical integration with inland ports will be promoted through shared participation, joint venture, and mergers. The transformation of SZP into an international hub will be maintained as more international shipping lines call.

GZP will continue to perform the function of an inland load center for the PRD port system in the future. It is the largest comprehensive port in South China and as part of the regional network it has a dominant advantage of cargo collection and distribution from/to the hinterland. It will continue to be an important complementary inland load center to the other two gateway ports.

HKP role will tend to emphasize its current strength in international transshipment. Even though the dynamic development of container terminals in Shenzhen and Guangzhou has reduced this role, HKP terminal operators are attracting transshipment cargoes from other Asian ports. HKP will remain a vital international trade center and a global transshipment hub for the broader Asian market. That function will be felt in continued growth in the provision of high-end maritime services in its role as a shipping service center.

2.6 Conclusions

This chapter investigated the recent development dynamics of the PRD port system and analyzed the underlying reasons. It is clear that the PRD port system has evolved from a one-gateway hub to two-gateway port, and then to a three port competition among HKP, SZP, and GZP. These broad changes were related to container traffic dispersion with increasing operation costs in the original hub port. They were also influenced by the process of container traffic decentralization, initially in the coastal regions, but now to inland locations. That has led to stringer network connections between ports, port operations and shipping lines, which have changes the focus of port development. In effect, the major parts are developing specializations with links to different markets, along with links to one another. This outcome is reflected in changes in the calling patterns of shipping lines, and the growth in hinterland penetration via collaboration with local sea and inland rail services. The overall effect is a regionalization with specialization. In that new context the three ports have particular riles, but will retain interdependencies. SZP and GZP will tend towards from hinterland-dominated regionalization to a more balanced regionalization via a better liner network, while HKP with a strong globally foreland regionalization may become a pure global transshipment hub, if the transport network cannot be enhanced.

Chapter 3 Competition of Nodes within Intra-modal Passenger Transport Network

Furthering the study of Chapter 2, this chapter continues the study of transport network on the national spatial structure level, focusing on the issue of competition between railway and airport.

3.1 Introduction

In China, rail transport is becoming a viable alternation for air passengers. The recent development of railway brings great challenges for air transport, especially after the construction of High-Speed Railway (HSR). Rail is also an environmentally acceptable alternative to air transport, and efforts are made to encourage passengers to move from air to rail. Meanwhile, rail is also a necessary complement for air transport. Different modes of transport can be seen as simultaneous complements and substitutes. The objective of this chapter is to examine the impact of railway improvement on airport passenger traffic in China.

Since the civil aviation reforms started in 1987, China has experienced considerable average annual growth rate of air passenger volume and great expansion of air transport network. Despite the rising role of air transport in China, the air transport network is characterized by regional inequality and still at the initial stage of a hub-and-spoke system (Wang et al., 2011). First, the spatial distribution of passenger traffic is concentrated in China's eastern large cities. Research on the productivity and efficiency changes in China's airports of different sizes during 1995-2004 indicated that international hub airports were the most efficient on average followed by regional hub airports, and that non-hub airports were relatively the least efficient (2008). Moreover, the air transport network continues to feature connections between city pairs with undeveloped sub-networks and insufficient feeder lines.

In addition, the air passenger traffic is highly correlated with geo-economic and competitiveness factors from the other transport alternatives (Jin et al., 2004). Figure 3.1 shows a historical trend of passenger throughput at airports in Northern China compared with that at rail stations. China is now undergoing a HSR building boom. The largest, advanced HSR system in the world will appear in China by 2020, with a total length of 16,000 miles. HSR service will be competitive in city-pairs of short to medium distance due to the network connectivity, total travel time and cost efficiency (Fu et al., 2012). It can be expected that the rapid development of railway will bring strong impact on the traffic pattern of air passenger transport.

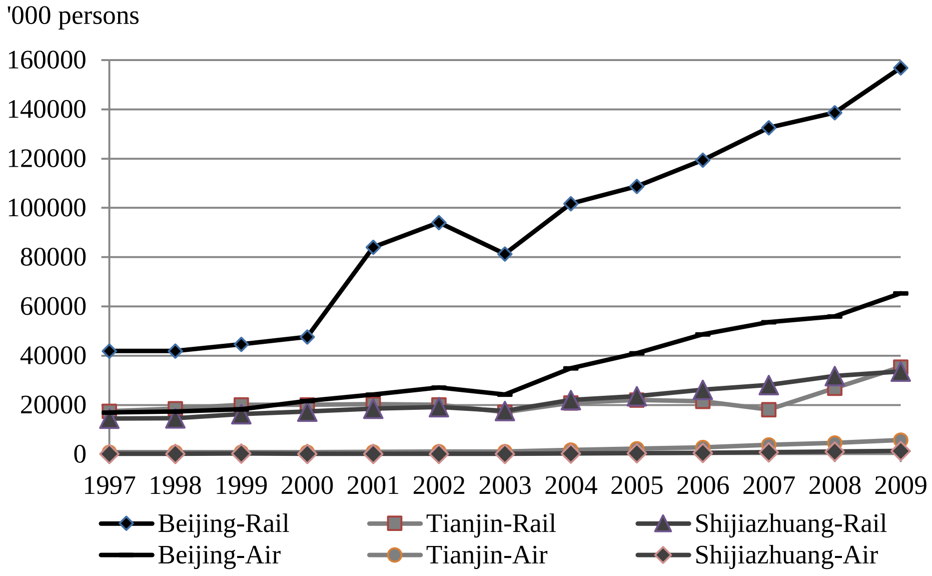


Figure 3.1 Air and rail passenger throughputs in cities of Northern China 1997-2009

Most of the studies on determinants of air travel demand were conducted using the city-pair data of certain routes (Fridström and Thune-Larsen, 1989; Rengaraju and Arasan, 1992; Jorge-Calderon, 1997; Yao and Morikawa, 2005). In general, the literature categorized the driving factors into two groups: service-related factors and geo-economic factors (Jorge-Calderon, 1997). The service-related factors refer to the quality and price characters of airline products, while the geo-economic factors are elements outside the control of airlines. The latter describes the economic activities and locational characteristics of the areas around the airports involved. The common economic-activity variables in the literature include population, gross domestic product (GDP) and income. As for locational factors, the most common factors concerned are distance, intra-modal and inter-modal competition. More recently, some studies have gone into greater detail on inter-modal competition factors. A series of studies were conducted to estimate the impact of HSR on domestic air travel demand in different regions, using different forms of discrete choice models (Mandel et al., 1994; González-Savignat, 2004; Park and Ha, 2006). But most of the transport literature from a mode choice view only looks at mode alternatives in competition with each other, while neglecting the complementarity effect in terms of intermodal cooperation between them.

Concerning the substitutive and complementary relationships between air transport and rail transport, we focus on the examining the impact of railway improvement on the airport passenger traffic. Different from the city-pair transport demand analysis, this study focuses on airport and rail station passenger traffic based on the city level.. It would be easier to illustrate the overall impact of railway improvement on the pattern of airport passenger traffic.

This chapter is organized as follows: Section 3.2 interprets complementarity and substitution effects of railway to air transport and also plays a role of literature review. In Section 3.3, the econometric models are specified based on the development of hypotheses. Section 3.4 presents the data description and estimation results. Section 3.5 concludes the paper, and we briefly discuss some policy implications.

3.2 Literature Review

In this section, we discuss the substitution effect as well as complementarity effects between air and rail transport.

From the perspective of travelers, substitution is referred to the travelers' ability to choose one mode in preference of the other mode of transport. And complementarity denotes the traveler's ability to utilize both air and rail transport modes. Complementarity exists with two modes of transport complementarity when their successive utilization is either necessary or simply preferred to the utilization of a single transport mode for a journey between two cities. In this sense, rail is a necessary complement to and occasionally a substitute for air transport to travelers. Moreover, the relationship between air and rail passenger transport is in dynamic due to the modification of transport products and changes of related environment factors. Shocker et al. (2004) discussed that the complementarity and substitution relationships between products in different but related categories and pointed out that such relationships are in transition over time. It meant that complements might become substitutes for the original products or originally imperfect substitutes become to coexist as complements.

On the substitution aspect, rail transport competes with air transport within certain distance ranges (generally accepted travel distance is from 350 km to l, 000 km). It is also considered as a substitute of feeder air services to main hub airports, especially after the development of HSR. From the historical experience, a transport modal shift is expected to happen due to rapid development of HSR. González-Savignat (2004) investigated the effect of a HSR corridor between Barcelona and Madrid in Spain and concluded that HSR would obtain an important diversion of air travelers, as travel time and costs are the two competitive drivers. Park and Ha (2006) forecasted the market share of airline and HSR after the introduction of the Korea Train Express (KTX) on the Seoul-Deagu route in 2004. Both the estimated result and actual revealed demand showed a significant decline of aviation demand, over 70 percent in that year. Ortúzar and Simonetti (2008) investigated the negative influence of high-speed train on the medium distance air travelers' demand in the Santiago-Concepción market. Behrens and Pels (2012) studied the inter- and intra-modal competition in London–Paris passenger market using revealed preference data. Considering the large market share of the HSR and the withdrawal of aviation alternatives indicate that competition will decline in the long-run, they concluded that HSR is a strong competitor for both conventional and low-cost airlines. HSR service will be competitive in city-pairs of short to medium distance due to the network connectivity, total travel time and cost efficiency (Fu et al., 2012).

On the complementarity aspect, railway interconnections supplies airports with concentrated passenger flows and complement the air travel service with the expansion of platforms. The last two decades witnessed many airports get interconnected with the rail network to extend the catchment area. The COST 18 study (European Commission, 1998) examined the effects of railway stations at airports to investigate the interactions between HSR and air passenger transport. By using four case studies and expert interviews of European HSR corridors, the results indicated that the improved rail access showed positive social benefit for large hub airports but balanced or negative for the medium-sized airports. Givoni and Banister (2006) investigated the intermodal integration of air and rail transport and suggested that airlines could be benefited from the freed slots as a result of using railway services instead of the existing feeder airline services. The complementarity effect deserves more in-depth studies.

There are substitution and complementarity effects between two transport modes. These two effects are reflected by choice of travelers and finally at an aggregate level in passenger traffic at transport nodes.

3.3 Hypothesis Development and Model Specifications

The theoretical background of our analysis is based on the transport geography and economics. In transport geography, gravity model has long served as an approach to determine the interaction between two locations. The common variables to predict passenger numbers between two places are population and distance variables in simple gravity models (Taaffe, 1962). Later studies modified to embrace other variables such as gross domestic product (GDP), income, education level, etc. Matsumoto (2007) analyzed the international air network structures and revealed the degree of air traffic density for major cities. The significant explanatory variables are GDP, population and distance. Grosche et al. (2007) estimated air passenger traffic between city-pairs, employing variables such as GDP, buying powder index, travel time, population and distance.

Complex network theory is also widely applied to analyze the air transport network (Liu et al., 2009; Wang et al., 2011). They selected distance, population and GDPs to examine the factors influencing China's air transport network connections and passenger volume. The results showed that geophysical factors such as distance and population were not significant, while economical level of the city, especially the GDP in service sector was highly related.

In economic demand analysis, the literature generally categorizes the driving factors of air transport demand into tw` o groups: service-related factors and geo-economic factors (Jorge-Calderon, 1997). The service-related factors refer to the quality and price characters of airline products, while the geo-economic factors are elements outside the control of airlines. The geo-economic factors describe the economic activities and locational characteristics of the areas around the airports involved. The common economic-activity variables used in the literature include population, GDP and income (Anderson and Kraus, 1981; Fridström and Thune-Larsen, 1989; Jorge-Calderon, 1997; Abed et al., 2001). As for locational factors, the most common factors concerned are distance, intra-modal and inter-modal competition. One aspect of intra-modal competition, for example, is the proximity of the airport to competing airports in other cities (Wang and Song, 2010). More recently, some studies have gone into greater details on inter-modal competition factors. A series of studies were conducted to estimate the impact of HSR on domestic air travel demand in different regions, using different forms of discrete choice models (Mandel et al., 1994; González-Savignat, 2004; Park and Ha, 2006). But most of the transport literature from a mode choice view only looks at mode alternatives in competition with each other, while neglecting the compatible relation in terms of intermodal cooperation between them.

To measure the effect of enhancement of railway on air passenger transport, we choose the change of aggregate demand at airports and rail stations for econometrical analysis. The change of annual airport passenger throughput is taken as the explained variable. On the basis of above literature, the explanatory variables are chosen from two categories: socioeconomic factors and geographical or locational factors. The economic causal variables are specified as provincial GDP, provincial population density, and average provincial transport expenditure. The breakout of SARS epidemic in 2003, which is presumably has a negative impact on the air travel passenger, is also taken into consideration. We specify the basic model as a benchmark:

$$\begin{aligned}\Delta AIRPASS_{it} = {} & \beta_0 + \beta_1 \Delta GDP_{it} + \beta_2 \Delta EXPENSE_{it} + \beta_3 \Delta POPU_{it} + \beta_4 D\_SARS \\ & + v_i + u_{it}\end{aligned} \tag{3.1}$$

where subscript i denotes the i-th airport, and t the year. $\Delta AIRPASS_{it}$ denotes the annual change in the number of air passenger throughput at the i-th airport. ΔGDP_{it}, $\Delta EXPENSE_{it}$ and $\Delta POPU_{it}$ respectively describe the annual change in the Gross Regional Product, residents' expenditure on travel, population density of the province where the i-th airport is located in. D_SARS is a dummy variable for the breakout of SARS epidemic in 2003.

We present two hypotheses below and develop two models to test the hypotheses accordingly.

Hypothesis 3.1: The speed acceleration of railway has a negative impact on the growth of air passenger traffic.

The inter-modal competition is considered to be one type of locational factors influencing the growth of airport passenger traffic. The nationwide rail speed acceleration is added as a dummy to the explanatory variables. Another explanatory variable is the change of passenger traffic of the nearby rail station. It reflects the changing travel demand of residents and thus presumably affects the passenger traffic at the airport in the same city. Based on the above discussion, Model 3.2 is specified to estimates the impact of rail improvement on the change of air passenger traffic.

$$\begin{aligned}\Delta AIRPASS_{it} = \beta_0 + \beta_1 \Delta GDP_{it} + \beta_2 \Delta EXPENSE_{it} + \beta_3 \Delta POPU_{it} + \beta_4 D\_SARS \\ + \beta_5 \Delta RAILPASS_{it} + \beta_6 D\_SPDACCE_t + v_i + u_{it}\end{aligned} \tag{3.2}$$

Where $\Delta RAILPASS_{it}$ denotes the annual change in the number of rail passenger throughput at the rail station nearby the *i*-th airport. $D\_SPDACCE_t$ is added as a dummy that reflect whether this year is under the influence of the rail speed acceleration.

Hypothesis 3.2: The increase of passengers at rail stations has a positive effect to the concentration at hub airports but a negative effect to regional airports.

Spatial variation of airports which forms the hub-and-spoke system is also a crucial determinant for air passenger traffic as another type of locational factors. In Model 3.3, regional airport is included as dummy that reflects the difference between the hub airports and regional airports. Moreover, the increase of rail travel passenger is hypothesized to affect the changes of air passengers of hub airports and regional airports in a different way.

$$\begin{aligned}\Delta AIRPASS_{it} = \beta_0 + \beta_1 \Delta GDP_{it} + \beta_2 \Delta EXPENSE_{it} + \beta_3 \Delta POPU_{it} + \beta_4 D\_SARS \\ + \beta_5 \Delta RAILPASS_{it} + \beta_6 D\_SPDACCE_t + \beta_7 D\_REG_i + \beta_8 D\_REG_i \\ \times \Delta RAILPASS_{it} + v_i + u_{it}\end{aligned} \tag{3.3}$$

Where D_REG_i is a dummy variable that denotes whether the airport is a regional airport. $D\_REG_i \times \Delta RAILPASS_{it}$ reflects the difference of impact of the rail passenger growth on the hub airports and regional airports. The β is used to represent the coefficients give an indication of the way in which the variable is hypothesized to affect the changes of air passenger. Table 3.1 lists the measurements of variables in models and the expected sign.

Table 3.1 Variable definition

Variables	Measurement
Explained variable	
$\Delta AIRPASS_{it}$	Annual change in the number of air passenger throughput at the *i*-th airport.
Explanatory variables	
Socioeconomic factors	
ΔGDP_{it}	Annual change in the Gross Regional Product of the province where the *i*-th airport is located in. (+)
$\Delta EXPENSE_{it}$	Annual change in the residents' expenditure on travel of the province. It is calculated by per capita annual household transport expenditure by region divided by CPI (Consumer Price Indices) of intercity traffic fare by region. (+)
$\Delta POPU_{it}$	Annual change in the number of population density in the province where the i-th airport is located in. It is calculated by number of residents by square kilometers. (+)
D_SARS	Year=2003; the breakout of SARS (Severe Acute Respiratory Syndromes) (-)
Locational factors	
$\Delta RAILPASS_{it}$	Annual change in the number of rail passenger throughput at the rail station nearby the *i*-th airport. (+ or -)
$D\_SPDACCE_t$	1 if the year is under the influence of the rail speed acceleration, 0 otherwise. (-)
D_REG_i	1 if the airport is a regional airport, 0 otherwise. (-)
$D\_REG_i \times \Delta RAILPASS_{it}$	The difference of impact of the rail passenger growth on the hub airports and regional airports.
i	Airport index (1 to 24)
t	Year (1997 to 2009)

3.4 Data Description and Estimation Results

3.4.1 Data description

This chapter uses annual data from 1997 to 2009 that consist of 24 major airports. Figure 3.2 and 3.3 depict the air and rail passenger distribution pattern by cities in China. We select airports that locate in cities currently ranked Top 40 in China by both air and rail passenger throughput. Most of the airports chosen are in the capital of province and located respectively in six regions shown in Table 3.2.

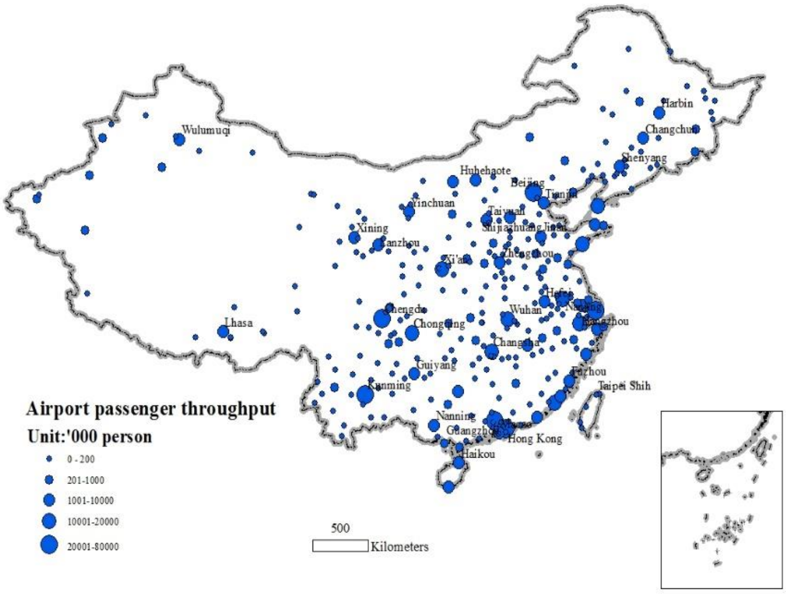


Figure 3.2 Air passenger volume handled by cities in China 2009

Source: Data are compiled from China Aviation Statistics (2010).

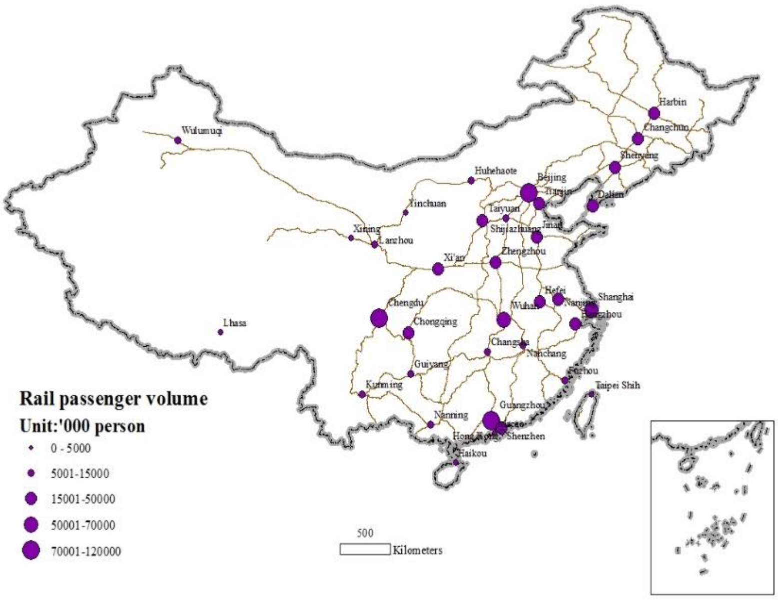


Figure 3.3 Rail passenger volume handled by cities in China 2009

Source: Data are compiled from China Railway Yearbook (2010).

Notes: Rail passenger volume is the number of passengers dispatched from principal rail stations.

Table 3.2 Sample airports

Region	Hub airport	Regional airports
Northern China	Beijing (PEK)	Tianjin (TSN), Shijiazhuang (SJW), Taiyuan (TYN)
Eastern China	Shanghai (SHA and PVG)	Nanjing (NKG), Hangzhou (HGH), Nanchang (KHN), Jinan (TNA)
Southern China	Guangzhou (CAN)	Shenzhen (SZX), Zhengzhou (CGO), Wuhan (WUH), Changsha (CSX)
Northeastern China	--	Shenyang (SHE), Haerbin (HRB), Changchun (CGQ)
Southwestern China	Chengdu (CTU), Kunming (KMG)	Chongqing (CKG), Guiyang (KWE)
Northwestern China	Xi'an (SIA)	Lanzhou (LHW), Urumchi (URC)

Note: The airports are categorized according to the 12th Five Year Plan of CAAC (2010).
Airport code in parentheses.

The passenger traffic data used come from the terminal passenger throughputs of *China Aviation Statistics* and *China Railway Yearbook*. The data for GDP and EXPENSE were gathered from the *Yearbook* and the *Survey of Family Income and Expenditure of China* from 1998 to 2010. From 1997-2009, there are six nationwide railway speed acceleration launched in April 1997, October 1998, October 2000, October 2001, April 2004 and April 2007 respectively. The speed acceleration is assumed to have major influence on the current year if performed in April and on the next year if performed in October. The hub airports are selected according to the 12th Five Year Plan of CAAC (2010). They contain three national hubs, i.e. Beijing (PEK), Shanghai (SHA and PVG) and Guangzhou (CAN), and regional hubs in the western region including Chengdu (CTU), Kunming (KMG) and Xi'an (SIA).

3.4.2 Basic model

Table 3.3 presents the estimation results of the basic model. The growth of GDP is founded to have positive and strong influence on the increase of air passenger traffic. Also, the increase of average travel expenditure shows a positive effect on the air passenger increase. However, the increase of population density is not significant even at the 10% level. It reflects that the air passenger growth is not largely derived from the population growth, but more related to the economic factors. This result also backs up the previous research result by Liu et al. (2009).

Table 3.3 Estimates of the basic model (Model 3.1), 1998-2009

Explained variable:	$\Delta AIRPASS_{it}$
Explanatory variable	
ΔGDP_{it}	5.341***
	(5.65)
$\Delta EXPENSE_{it}$	9.741*
	(2.35)
$\Delta POPU_{it}$	3.386
	(1.01)
D_SARS	-912.6***
	(-3.49)
Constant	337.8*
	(2.49)
Observations	288
R^2	0.489
Adjusted R^2	0.436
F-statistics for FE	14.03***

Note: t-statistics in parentheses.
*** Significant at the 1% level, **at the 5% level, * at the 10% level.

3.4.3 Effects of rail acceleration

Table 3.4 presents the estimation results of Model 3.2 for the effect of railway improvement. Hypothesis 3.1 is tested through fixed effect (FE) Model 3.2 C, and Model 3.2A and 3.2B are basic models for comparison. The F-statistics are all significant at the 1% level that indicates the fixed effects model is preferred to pooled regression. Further, the result of Hausman test indicates that there is no systematic difference between random effects (RE) and fixed effects and thus the fixed effects model is more feasible.

Table 3.4 Estimates of the railway improvement model (Model 3.2), 1998-2009

	Explained variable: $\Delta AIRPASS_{it}$			
	Fixed Effect (FE)			Random Effect (RE)
Explanatory variable	3.2A	3.2B	3.2C	3.2D
ΔGDP_{it}	5.360***	4.142***	3.489***	2.835***
	(5.68)	(4.41)	(3.78)	(3.53)
$\Delta EXPENSE_{it}$	9.010*	7.044*	8.138*	14.77***
	(2.21)	(1.79)	(2.13)	(3.92)
D_SARS	-900.498***	-443.022	-810.690**	-781.016**
	(-3.45)	(-1.66)	(-2.97)	(-2.72)
$\Delta RAILPASS_{it}$		0.110***	0.122***	0.150***
		(4.88)	(5.55)	(6.94)
$D\_SPDACCE_t$			-626.423***	-674.098***
			(-4.26)	(-4.35)
Constant	369.270**	281.736*	701.013***	624.825***
	(2.79)	(2.20)	(4.43)	(3.57)
Observations	288	288	288	288
R^2	0.487	0.530	0.561	
Adjusted R^2	0.435	0.481	0.513	
F-statistics for FE	6.386***	4.896***	4.976***	
Hausman test ($\chi^2(4)$)				155.200***

Note: t-statistics in parentheses.
∗∗∗ Significant at the 1% level, ∗∗at the 5% level, ∗ at the 10% level.

The goodness-of-fit statistics R2 and adjusted R2 of Model 3.2 are all above 43%. Hypothesis 3.1 is confirmed according to the results of Model 3.2. The speed acceleration of railway diverts passenger throughputs from air transport. Therefore, it has a negative and highly significant impact on the growth of airport passenger traffic. As indicated by the statistically significant of ΔGDP and $\Delta EXPENSE$ for all specifications, the growths of GDP and average travel expenditure have positive and strong influence on the increase of air passenger traffic. The negative sign of D_SARS denotes a negative impact of infectious diseases to the public air travel.

What we are interested in is the positive sign of the variable $\Delta RAILPASS$. From Model 3.2D, 100 more rail passengers will be associated with 15 more air passengers at an airport in the same city. As discussed in Section 3.2, railway has both substitution and complementarity influence on air passenger transport. The negative effect is represented by the competition of the two alternatives for attracting passengers, while the positive effect is derived from two components. First, the airport and rail station passenger throughputs generally have the same growth tendency due to the influences from economic environment and other unobserved factors. Second, the rail station is a necessary complement to air transport network from the view of intermodal transfer. Such positive and negative effects will be further determined in Section 3.4.4.

3.4.4 Estimation of hub concentration

Model 3.3 assumes that differences across airports have some influence on the passenger throughput, such as the obvious distinctions of function and on-service airlines between the hub and regional airports. Thus we consider the random effects model. Moreover, random effects which assume error term is not correlated with the predictors allow for the D_REG dummy as a time-invariant variable to be an explanatory variable. To justify whether random effects exist, we conduct Breusch-Pagan Lagrange multiplier test and verify the preference of RE specification.

Hypothesis 3.2 relating to the hub concentration effect is tested through Model 3.3A and the results are reported in Table 3.5. RE model 3.3B is the estimate using GLS method and RE model 3.3C is the estimate by FGLS method.

The variable D_REG is negative and significant at 1% significance level. It indicates that regional airports have significant gap in the growth of air passenger traffic from hub airports. Accordingly, the total increase of airport passenger throughput is greatly contributed by hub airports. The interaction term $D\_REG \times \Delta RAILPASS$, which captures the difference of impact of the rail passenger growth on the hub airports and regional airports, also shows a negative sign. That means the passenger traffic of regional airport will decrease with the increasing traffic at the nearby rail station. It is partially resulted from the shift of passengers from air to rail transport for feeder service as the railway improvement. From the operators' perspective, it can be viewed as an extension of competition of the airline and railway at the terminals. Since the variable $\Delta RAILPASS$ is positive and clearly significant to the explained variable $\Delta AIRPASS$, it can be inferred that the air passenger traffic at the hub airports will also increase if passenger flow keeps growing at the nearby rail stations. As a consequence, the rail station accompanying with the improvement of railway services enhances the traffic concentration of hub airports.

Table 3.5 Estimates of the hub concentration model (Model 3.3), 1998-2009

	Explained variable: $\Delta AIRPASS_{it}$		
	Fixed Effect (FE)	Random Effect (RE)	
Explanatory variable	3.3A	3.3B	3.3C
ΔGDP_{it}	4.645***	3.549***	2.471***
	(5.02)	(5.04)	(8.63)
$\Delta EXPENSE_{it}$	7.447*	14.005***	5.667***
	(2.03)	(4.07)	(4.05)
D_SARS	-1030.449***	-1063.832***	-216.777**
	(-3.85)	(-3.88)	(-2.73)
$\Delta RAILPASS_{it}$	0.172***	0.186***	0.186***
	(7.21)	(8.40)	(3.95)
$D\_SPDACCE_t$	-591.7***	-639.6***	-269.1***
	(-4.17)	(-4.39)	(-6.52)
D_REG_i		-941.1***	-720.9***
		(-4.86)	(-3.44)
$D\_REG_i \times \Delta RAILPASS_{it}$	-0.194***	-0.192***	-0.153**
	(-4.57)	(-4.60)	(-3.17)
Constant	710.2***	472.8**	223.6***
	(4.66)	(3.06)	(5.31)
Observations	288	288	288
Wald ($\chi^2(7)$)		264.680***	262.410***
B-P test ($\chi^2(1)$)		7.24**	

Note: t-statistics in parentheses.

∗∗∗ Significant at the 1% level, ∗∗at the 5% level, ∗ at the 10% level.

3.5 Conclusion

This study examines the impact of railway improvement on the airport passenger traffic in China, taking into account the railway speed acceleration and the effect of passenger traffic at neighbored rail stations. Panel data models are applied to estimate on the aggregate terminal passenger traffic data. Empirical results show that the speed acceleration of railway has a negative impact on the passenger growth of air transport, while improvement of rail does not reduce the airport passenger traffic as a whole, which is inconsistent with expectation. More specifically, the increase of passengers at rail stations has a positive effect to the concentration at hub airports but a negative effect to the regional airports. It indicates that the improvement of railway encourages the passenger traffic to converge on hub airports and enhances the passenger concentration of hub airports.

These findings show some policy implications for air transport network. In an emerging and rapid-developing market of high speed rail like China, a transport modal shift is expected to happen due to the increased speed and service of railway. On one aspect, for the airlines, some routes of feeder service linking of regional airports will be negatively influenced by the operation of HSR. Due to the regional development inequality and high construction cost of HSR, there left more expansion space for airlines to develop domestic feeder service in the Northwestern and Southwestern regions.

On the other aspect, the passenger traffic in hub airports will continue to rise contributed by the development of HSR. The concentration of passenger traffic will put great pressure on the hub airports. The potential problems such as capacity constraints, distribution of public resources and airport congestions should be taken into consideration.

Generally speaking, an improvement of one transport mode may have two different effects on another model. The passenger traffic will be more concentrated at hub airports when other transport modes are better developed, as the complementation effects will be enhanced. At the same time, the regional airports will become less competitive against hub airports, as the substitution effects are contributed from the competing transport modes.

Chapter 4 Reform of Railway Industrial Structure in China

While Chapter 2 and 3 focus on regional / national spatial structure level, this chapter focuses on the industrial structure's impact on the transport network. Specifically, we shall put emphasis on the railway sector, at shedding light on the China Railway reform which is now undergoing.

4.1 Introduction

The industrial structural reform in the railway sector has been undergone in Japan and European countries from 1980s. The railway reform was motivated by improving efficiency and performance within the railway sector, and enhancing competitiveness to other transport modes and huge debts. However, the railway reform concerning the vertical structure is still a controversial issue.

In China, railway still has a large market share and plays a critical role in both passenger and cargo transport due to the huge passenger and cargo flow. The railway of China has long been a national monopoly, and private firms are not allowed to operate to the network infrastructure. The government has been trying to improve regulation and liberalize the railway market in the last decade. The vertical structure choice has been a bone of contention for China's railway reform, which is also the focus of this chapter. In the year 2013, the Railway Ministry of China was dissolved and its duties were divided and taken up by the Ministry of Transport (regulation) and China Railway Corporation (construction and management). This reform was a first attempt to transform a governmental monopoly to a firm monopoly in China.

The structural reform of the railway industry is an issue of firm boundary in the Industrial Organization and Firm Theory (Zhao, 2005). For traditional railway as a state-owned monopoly, the key issues are how to restructure to reduce the power of the rail monopoly and how to introduce competition mechanisms on account of transaction costs among firms and regulators.

Another aspect of the reform in railway industry is the role of governmental regulation. As a regulated industry, any change requires government approval, such as the opening of new services, or the closure of existing railway lines. If deregulate to a more liberalized market, new problems would be triggered in terms of principal-agent issues because of double marginalization and information asymmetry. For the regulator, the objective is how to design the incentive mechanism for governance and monitoring and for eliminating the cost of information asymmetry.

The approaches of railway regulatory reform has provoked a lot of studies worldwide (van de Velde, 1999; Profillidis, 2001; Holvad et al., 2003; Nash, 2008). Generally, the railway industry has been restructured on two levels: (1) the vertical dimension, which covers the relationship between infrastructure and carriers, and (2) the horizontal dimension, which involves the relationship between carriers using infrastructure to supply the final consumers.

The first structure is vertical separation of network infrastructure from the transport operation and introduction of competition between carriers. The carriers, under a regime of regulated access to the track infrastructure, compete either for integrated track-plus-train services or just for train services alone. This is the predominant form of competition for passenger services in many European Union countries (OECD Council, 2011). The vertically integrated structure has positive efficiency effects such as the removal of double-marginalization, which occurs when both the upstream and downstream firms have monopoly power and each firm reduces output from the competitive level to the monopoly level, creating two deadweight losses. One the other hand, however, the vertically integrated structure is criticized for negative effects on competition, such as price squeezes and market foreclosure, which is the exclusion that results when a downstream buyer is denied access to an upstream supplier or when an upstream supplier is denied access to a downstream buyer (Tirole, 1988). The vertical separation of railway increases competition in the carrier's level by facilitating the entry of more carriers on a single route.

The second structure is horizontal separation of vertically-integrated railway monopoly, which introduces an indirect competition among regional railway firms on their own tracks. The representative example is the reform of Japan National Railway (JNR) (van de Velde, 1999). The Japanese government took steps to separate the national monopoly JNR into six passenger companies and a nationwide freight companies. The six passenger railway companies were horizontally separated by region, but forced by the government to reduce operating cost using other companies' cost level as a benchmark. This is the so-called yardstick competition, which is a regulatory instrument that can be used if direct competition between firms does not exist or does not lead to desirable outcomes. The regulator rewards the firms based on their relative performance and therefore generates incentives for efficiency (Shleifer, 1985). Through the horizontal separation reform, empirical analysis on the Japanese railway industry shows that the rail companies' variable costs decrease (Mizutani, 1997; Mizutani et al., 2009).

Based on the aforementioned controversy on the railway structural reform, this chapter is aiming at addressing the research issue that which case for railway industry is better in terms of social welfare, and which way of structural reform and regulatory policy should China adopt. This chapter attempts to evaluate the different railway structures in a framework and explain their rationality of existence from a game-theoretic approach. In particular, we aim at discussing which way is better for the passenger railway reform in China, with the social welfare as measurement. We will model the decision behavior of infrastructure and regulator considering incomplete information to the regulator.

In the following sections of this chapter, Section 4.2 reviews the existing research on railway reform, industry organization, and contract theory. Then we will enumerate all the potential cases of structure of the railway industry in Section 4.3. Regarding the cases that cannot be proved dominated, models are setup to conduct further analysis. Section 4.4 derives the optimal decisions in each case, and with the help of a numerical case study and parametric analysis in Section 4.5, we will be able to obtain more managerial insight addressing the aforementioned research questions. Section 4.6 concludes the modeling results by linking with the railway industry practice, and explore some of the potential future research directions.

4.2 Literature Review

4.2.1 Railway structure reforms

Railway had long been a state-owned dominant and strictly regulated industry because of the property of natural monopoly. With the competition from rapid rise of highway and civil aviation industries, railway gradually loses the advantage in transport market. Since 1970s, railway has been deregulated in America, Japan and European countries (van de Velde, 1999). The measures of deregulation include market liberalization represented by the ease of market entry and exit, privatization, and industrial restructuring. This section reviews alternatives of railway reform and liberalization in different countries. The reform of railway structure in terms of vertical relationship is our focus.

To conform to the industrial organization tradition, we say that the upstream firm is vertically integrated if it absorbs the downstream firm or controls all the decisions made by the vertical structure. The vertically integrated solution is typically used as a benchmark because it demonstrates which decisions the monopolist would like the downstream firm to make in contrast to directly control. In the railway industry, vertical integration denotes that single companies maintain control of both railroad track and the trains running over the track. Vertical separation refers to the introduction of competition among different train operating enterprises over a single set of track. There are three options as follows.

The first option, namely the vertical integration structure, assumes that a single entity manages and owns all the infrastructure facilities and the operating and administrative functions. This is the form of traditional railway industry (Sánchez, 2001).

The second option is vertical separation. European Union (EU) introduced and reinforced the principle of separation between infrastructure and transport operations (Directives 91/440/EC and 14/2001). The EU directives oblige national railway systems to implement vertical unbundling. This unbundling requires separate companies (Germany, Italy, France), but not necessarily separate ownership (UK and Sweden). Whether this choice implies gains depends on whether scale economies from independent control of access are larger than the costs saving from competitive transport market. UK implemented a complete vertical separation, which the track owner is not permitted to vertically participate in the business of train operation.

Vertical separation facilitates competitive entry and creates incentives for efficient cost recovery. It also helps to improve capacity allocation and responding to users' needs (Di

Pietrantonio and Pelkmans, 2004). However, it runs into other problems. First, the separation loses economies of scale. This is partly due to the train scheduling and coordination. It is testified by a number of studies on the economics of vertical separation using European data (Sánchez, 2001; Growitsch and Wetzel, 2009). Another criticism is that the vertical separation results in excessive transaction costs in terms of the negotiation and contracts between train operator and the track. However, there is no conclusive proof that vertical separation has an advantage over the other structure.

Cantos et al. (2010) analyzed the effects of these structural reforms on efficiency, productivity, and technical change in sixteen national railway systems in Europe. Results indicate that in general, the reforms appear to have been beneficial in terms of efficiency and productivity, and particularly when measures of vertical separation are combined with the entry of new carriers in the freight sector.

The third option is horizontal separation as the case of Japan. To strengthen competition in the short-distance transport market, Japan separated the national monopoly Japanese National Railways (JNR) into six passenger companies and a nationwide freight companies. The six passenger railway companies were horizontally separated by region. However, Japan excluded direct competition between the six regional companies, but only introduced yardstick competition as indirect competition allowed to avoid ruinous competition (Terada, 2001). Obermauer (2001) evaluated the effect of regulatory reforms in Japan and EU in terms of level of competition. It was discovered that the Japan railway's competitiveness has improved through indirect competition among regional companies, while the EU railway achieves less efficiency than Japan railway despite the market-oriented measures. The reason is that the already exist competition, though maybe indirect, let Japan railway focus on internal restructuring rather than market opening measures.

4.2.2 Regulation mechanisms of natural monopolist

The first regulatory mechanism involves setting a fixed price that the regulated firm will be permitted to charge, which is called fixed price contract or price-cap mechanism (Lehman and Weisman, 2000). It starts with a particular price and then adjusts this price based on exogenous changes. This mechanism provides incentives for inducing managerial effort and eliminates the costs associated with managerial moral hazard.

The second regulatory mechanism is pricing on access charge for the carriers (Ivaldi and McCullough, 2007; Lang et al., 2013). Thompson (2003) discussed access charge regime after deregulation. Lang et al. (2013) built a game-theoretic model of access charge in vertically separated rail market. Their analysis showed that an increased number of competitors in the freight or passenger segment reduces prices per kilometer and increases total outputs.

As a natural monopoly, the railway industry faces with a problem of information asymmetry, i.e. the firms have private information on their operational costs, which create barrier from regulation and social supervision (Hooper, 2008). Information asymmetry and regulation mechanisms have a rich research basis in the economics field (Baron and Myerson, 1982; Lewis and Sappington, 1988). Specially, Joskow (2007) studied the regulation of natural monopoly. To date, however, there have been few applications of the theory of Information Economics in the field of railway. Iossa and Stroffolini (2012) studied the influence of private demand information on the vertical structure, and found that vertical integration generates greater welfare in new markets where little demand information is available, infrastructure cost is low, or investment is highly risky.

One of the regulatory mechanisms under information asymmetry is screening for the adverse selection. Gagnepain and Ivaldi (2002) examined the effects of incentive regulatory policies on public transit systems in France using data on a panel of French municipalities, and showed that fixed-price policies performs between fully informed and uninformed second best schemes. Hooper (2008) gave a summary review on the regulatory mechanism including screening and suggested aspects of transport contracting that merit future research.

The other mechanism which regulators can effectively reduce firms’ information advantage is by using competitive benchmarks or yardstick competition in the price setting process. Shleifer (1985) showed that if there are multiple non-competing but identical firms, an efficient regulatory mechanism is to set the price for each firm based on the costs of the other firms. Mizutani (1997) and Mizutani et al. (2009) conducted empirical analysis of yardstick competition in the Japanese railway industry, and they concluded that yardstick competition reduces variable costs.

4.3 Model Formulation

Based on the existing research on the choice of the railway structure, most of which is conducted by empirical study, this chapter is going to setup analytical models to obtain substantial understanding on this issue. In this section, we will describe the market players and enumerate the potential cases of structure of the railway industry, to provide basis for modelling in the next section.

4.3.1 Market players and their decisions

The modeling analysis involves the following market players in the railway industry:

- Regulator (R): sets the transfer payment T for the Infrastructure operator. Its objective is to optimize the social welfare under the constraint that the infrastructure provider's profit is nonnegative.
- The upstream Infrastructure operator (I), in this case the track, is characterized as a monopoly. Infrastructure maximizes its own profits by charging the access charge a to Carriers. Infrastructure is used as abbreviation for Infrastructure operator throughout the text.
- Carrier (K_{i}) decides the output q_i, $(i = 1,2, \dots, n)$. We assume the carriers, if any, on the same route provide homogeneous transport services, then the competition between a certain number of Carriers can be viewed as Cournot competition. The total output in the market $q = \sum_{i=1}^{n} q_i$, which influences the market equilibrium price p.
- Consumers decide to buy which transport service if the consumer surplus is not negative. Consumers do not have decision variables to optimize in the model.

The sequence of events is as follows:

- Regulator R decides the transfer payment T.
- Infrastructure operator I decides the access charges a.
- Carrier K_i decides service quantity $q_i (i = 1,2, \dots, n)$.
- Consumer decides whether to purchase the Carrier's service

4.3.2 Railway industry cases

The possible industry structures in railway sector are enumerated and summarized as the following eight cases.

4.3.2.1 Case 1: perfect information

We assume in this case that the cost information of the Infrastructure operator and Carrier is symmetric for the Regulator. Depending on whether the Regulator is integrated with Infrastructure and Carrier, we have the following two scenarios, namely full regulation and partial regulation scenario.

Scenario 1: regulator integrated with market player (Full Regulation Scenario)

The Regulator is integrated with Infrastructure and Carrier, there's no information asymmetry. The joint entity makes a jointly decision of transfer payment T and output q, aiming at maximizing the social welfare.

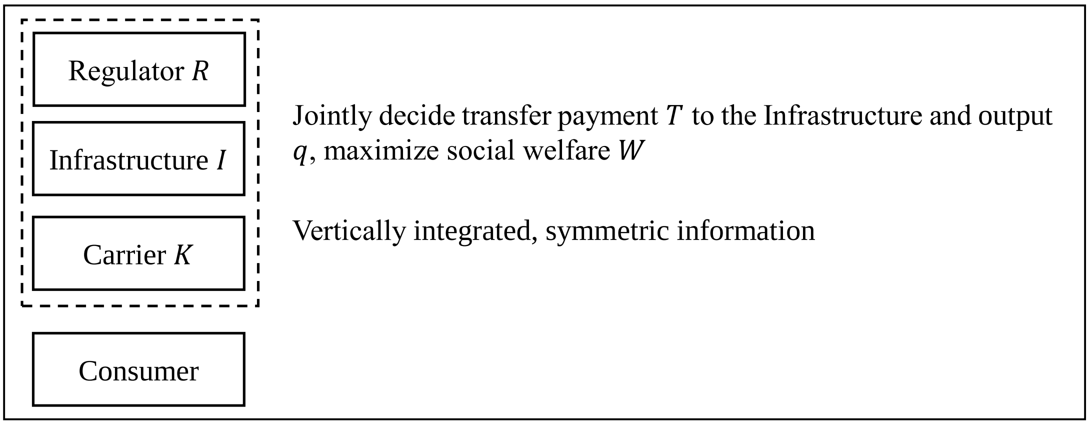


Figure 4.1 Perfect information case - full regulation scenario

Scenario 2: regulator separated from market player (Partial Regulation Scenario)

Figure 4.2 shows an evolution of the Full Regulation Scenario that the Regulator is separated from market players, that is, Infrastructure and Carrier, who are still integrated as one single firm (monopoly). The Regulator only decides transfer payment T to the Infrastructure, aiming at maximizing social welfare. The Infrastructure and Carrier integrated firm decides output q, aiming at maximizing its own profit. We shall show in the modeling section that the Partial Regulation Scenario is dominated by the Full Regulation Scenario.

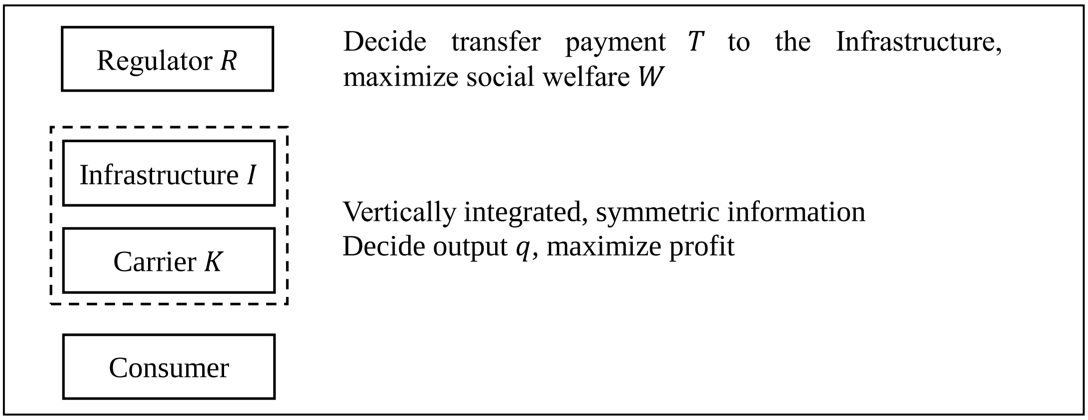


Figure 4.2 Perfect information case - partial regulation scenario

4.3.2.2 Case 2: vertical integration with imperfect information

In this case, it is assumed that the cost information of the Infrastructure and Carrier is asymmetric for the Regulator. This is the current situation of China railway industry demonstrated in Figure 4.3. The China Railway Corporation is now a monopoly in the railway market. The costs of Infrastructure and Carrier cannot be fully observed by the Regulator.

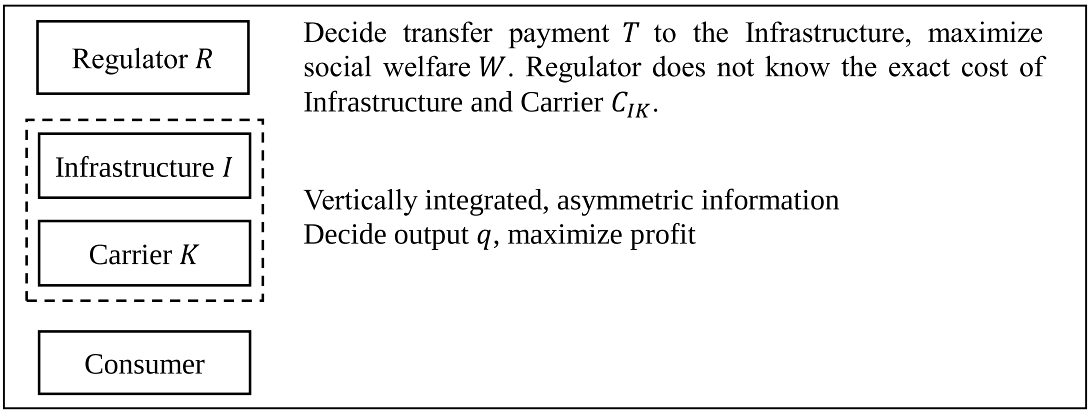


Figure 4.3 Imperfect information case - vertical integration (China)

4.3.2.3 Case 3: vertical separation with imperfect informationy

The railway structure of UK is a typical case of vertical separation. Figure 4.4 demonstrates the vertically separated railway market of the United Kingdom. The Regulator pushed the introduction of competition through separating the Carrier from the network Infrastructure and increasing number of competitors into the Carrier level. The separation increased competition in the Carrier market which benefits the social welfare.

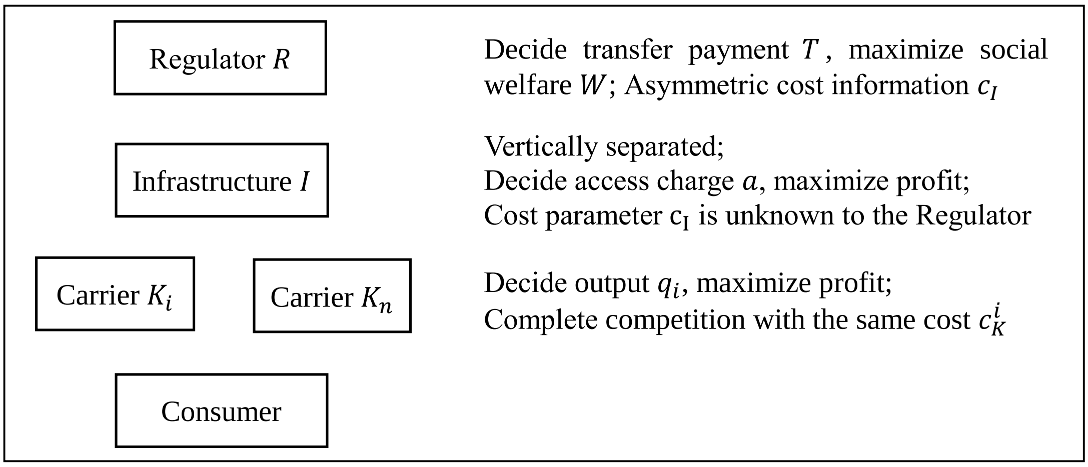


Figure 4.4 Imperfect information case - vertical separation (UK)

4.3.2.4 Case 4: horizontal separation with imperfect information (Japan Case)

This case can be observed in Japan. This railway market structure is demonstrated in Figure 4.5, where Infrastructure and Carrier are integrated but the national monopoly was horizontally separated to several regional firms. The regional firms are excluded from direct competition but are in yardstick competition, under which the regulator can use the costs of comparable firms to infer a firm’s attainable cost level.

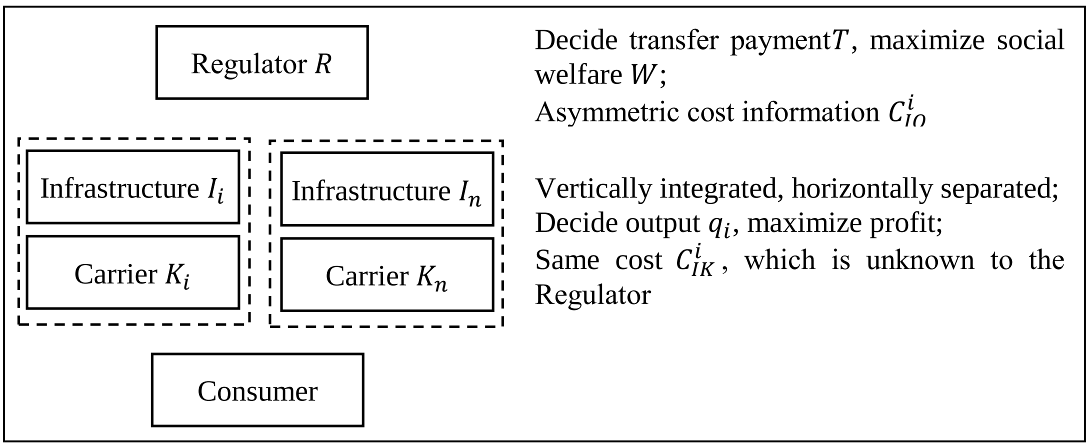


Figure 4.5 Imperfect information case - horizontal separation (Japan)

4.3.2.5 Other cases that are dominated

Case 5: Vertical and horizontal separation (Dual Separation Case)

This case shown in Figure 4.6 is further separating the Infrastructure from the Carriers based on the Japan Case. According to the argument in Section 4.3.3, this case is dominated by Japan Case. This is because Japan Case has fully eliminated the information asymmetry, while avoiding the double marginalization in this case that results in social welfare reduction.

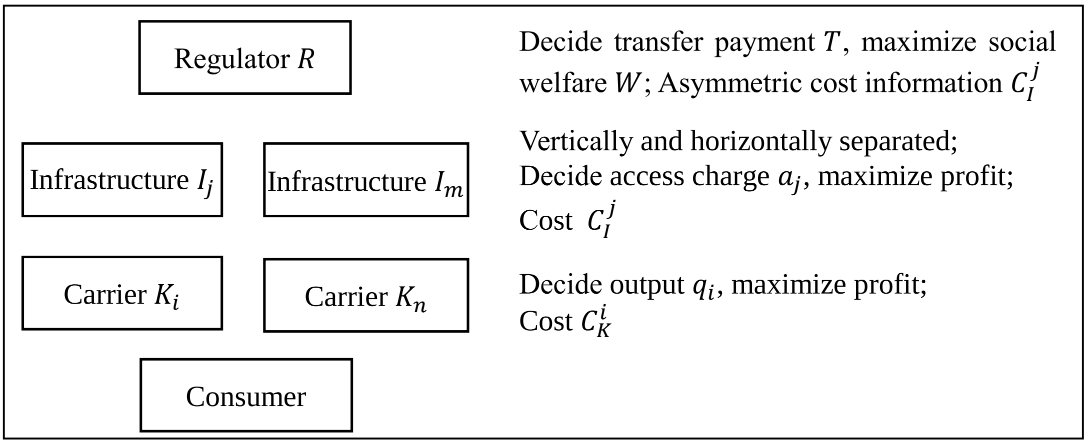


Figure 4.6 Dual separation case

Case 6: Vertical separation with multi-Infrastructures and single Carrier (Multi-Infrastructure-Single-Carrier Case)

Due to vertical separation, there is a double marginalization effect. Since it does not break the monopoly at the Carrier's level, it is dominated by the Dual Separation Case in Figure 4.7.

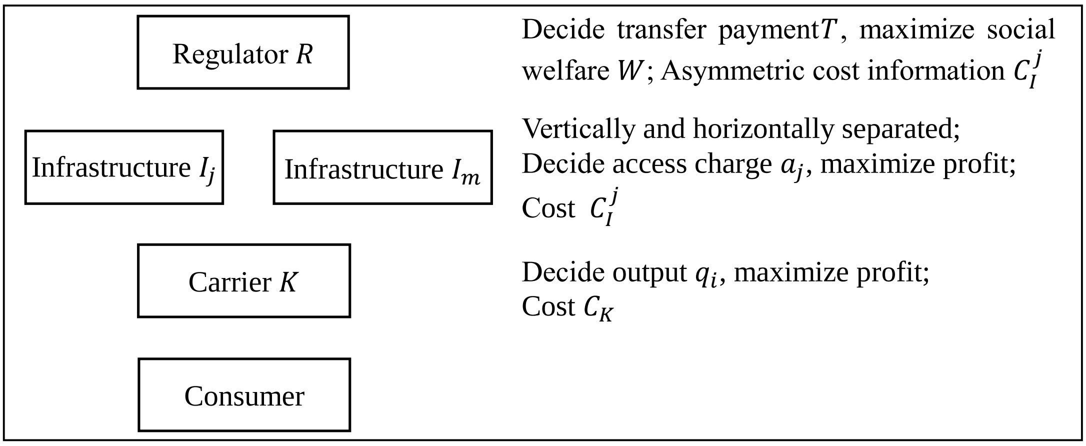


Figure 4.7 Multi-infrastructure-single-carrier case

Case 7: Horizontal separation with regionally competition (Full Separation Case)

This case (Figure 4.8) is developed based on Japan Case. There is more than one Carrier in one region, but are not competing with those in other regions. This case is dominated by Dual Separation Case, because the Carriers would have scale economics in a country-wide base service.

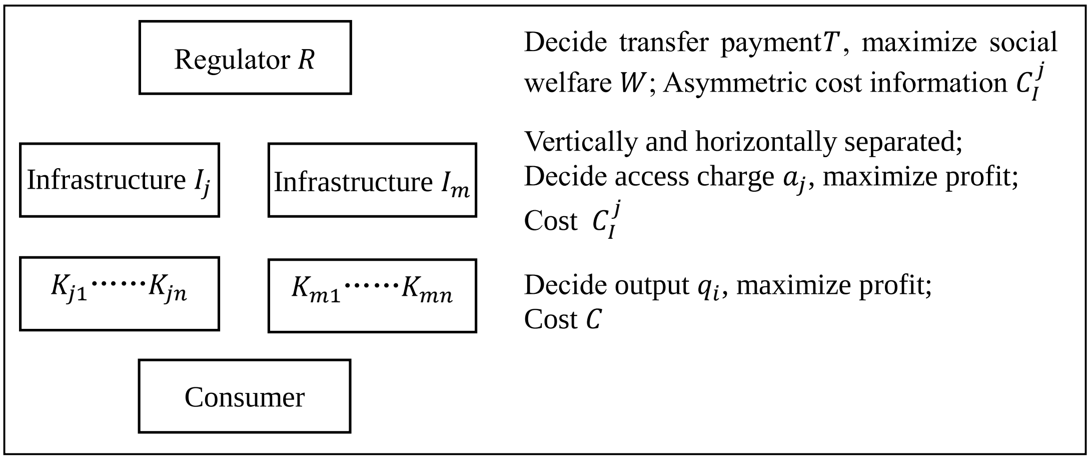


Figure 4.8 Full separation case

Up to now, we have enumerated all the possible cases in the railway industry. Since some cases are dominated, we will only model the Cases 1 to 4. By comparing the cases, it can be observed that monopoly and information asymmetry are the two main factors that contribute to the reduction of efficiency, measuring by social welfare.

4.3.3 Assumptions on costs

The costs of Infrastructure and Carrier are key factors affecting the performance of each market structure. We note the cost under each case as (the notation marked with upper tilde line represents the new cost after horizontal separation):

- c_{IK} represents the total costs of integrated Infrastructure and Carrier.
- $\tilde{c}_{IK}$ represents the total costs of horizontal-separated regional monopolies (in Japan Case). It is assumed that costs of each horizontal-separated regional monopoly are equal.
- c_I represents the cost of monopolistic Infrastructure.
- c_K represents the cost of Carrier after vertical separation. It is assumed that all the Carriers' costs are equal.

- $\tilde{c}_I$ represents the cost of regional Infrastructure with vertical and horizontal separation. It is assumed that costs of each horizontal-separated regional monopoly are equal.

- $\tilde{c}_K$ represents the cost of Carrier with vertical and horizontal separation. It is assumed that all the Carriers costs are equal.

Then the total cost in the Perfect information Case (Case 1) and China Case (Case 2) is c_{IK}; the total cost of Japan Case (Case 4) is $\tilde{c}_{IK}$; the total cost of UK Case (Case 3) is $c_I + c_k$; the total cost of Dual Separation Case is $\tilde{c}_I + \tilde{c}_K$.

It is assumed that $c_{IK} \sim \tilde{c}_{IK} \leq c_I + c_k \sim \tilde{c}_I + \tilde{c}_K$. The reasons are:

1. Economies of scale is assumed to exist in the vertical integrated structure (Sánchez, 2001; Growitsch and Wetzel, 2009), thus we have $c_{IK} \leq c_I + c_k$ and $\tilde{c}_{IK} \leq \tilde{c}_I + \tilde{c}_K$ respectively.

2. Horizontal separation will lose certain economies of scale, but we assume in this chapter that the loss is quite small as regional market segmentation will have little influence on the cost structure of railway firms, so that we have $c_{IK} \sim \tilde{c}_{IK}$ and $c_I + c_k \sim \tilde{c}_I + \tilde{c}_K$, meaning that the cost with upper tilde line is only slightly smaller than that without upper tilde line.

Assuming for the transfer payment between the Regulator and Infrastructure, there is cost of raising public funds associated with deadweight losses (Lang et al., 2013), and it is represented by parameter λ (Lang et al., 2013).

4.3.4 Assumptions on cost information

Information asymmetry between Infrastructure and Regulator is another key issue that should be taken into consideration. In a monopoly case, since the Regulator cannot fully observe the true costs of Infrastructure, the Infrastructure can enjoy an information rent. That is one of the main reasons for the low efficiency of monopolistic railway. The incentive regulation for the Regulator is the focus in our discussion.

- In perfect information Case, the cost information is fully symmetric.

- In China and Japan Cases, as the Infrastructure and Carrier are integrated, the costs of them are asymmetric information for the Regulator.

- In UK Case, the cost of Infrastructure is asymmetric for the Regulator.
- In UK Case, it is assumed that the Carrier's cost information is symmetric for the market players including other Carriers, Regulator and the Infrastructure. The reasons are: (1) for the other Carriers, as we assume that the Carriers are almost identical, so we can assume that Carrier knows each other's cost information. (2) Regarding the Infrastructure and the Regulator, suppose there's a scheme that the Infrastructure and the Regulator only serve or give permit to the Carrier who has the lowest announcing cost. Then the Carriers will compete on their revealing cost, which results in the real cost of the Carriers.

4.3.5 Summary of notations

Table 4.1 Summary of notations

Notation	Descriptions
a	Access charge of the infrastructure
c	Cost of the Infrastructure or Carrier
i	Subscript of the i^{th} Carrier
j	Subscript of the j^{th} Infrastructure
m	The total number of Infrastructures
n	The total number of Carriers
p	Market equilibrium price of the transport service
q_i	Production output of carrier i
T	Regulator's transfer payment to the Infrastructure
CS	Consumer surplus
W	Total social welfare
θ	The maximum price that consumer is willing to pay
λ	Public fund raising parameter

4.3.6 Summary of cases

The features of the market structures (Case 1 to Case 4) are summarized in Table 4.2.

Table 4.2 Summary of cases

Cases	**Perfect information Case** *Scenario 1: Full regulation*	**Perfect information Case** *Scenario 2: Partial regulation*	**Perfect information Case** *Scenario 3: Vertical separated with full regulation*	**Perfect information Case** *Scenario 4: Vertical separated with partial regulation*	**China Case** *Imperfect information*	**UK Case** *Vertical separation*	**Japan Case** *Horizontal separation*
Vertically integrated or not	integrated monopoly RIK	integrated monopoly IK	separated to RI and K_i	separated to I and K_i	integrated monopoly IK	separated to a single I and a number of K_i	integrated regional firms IK_j
Infrastructure cost symmetric or not	symmetric for R	symmetric for R	symmetric for R	symmetric for R	asymmetric for R	asymmetric for R	asymmetric for R
Choices for competition	N/A	N/A	Open-access competition between K_i for the tracks	Open-access competition between K_i for the tracks	N/A	Open-access competition between K_i for the tracks	Indirect competition between IK_i on their own tracks
Decisions	RIK decides T and q	R decides T and IK decides q	RI decides T and a; K_i decides q_i	R decides T; I decides a; K_i decides q_i	R decides T; IK decides q	R decides T; I decides a; K_i decides q_i	R decides T; IK_j decides q_i

4.4 Model

This section models the four market structures mentioned in Section 4.3.6.

4.4.1 Perfect information case

In this sub-section, we firstly model the perfect information Case to address the research questions:

1. Which one is better in terms of social welfare, separation or integration of government and firms (i.e. Partial Regulation or Full Regulation)?

2. Which one is better in terms of social welfare, separation or integration of Infrastructure and Carrier without information asymmetry?

3. Is there a dominant case if information is symmetric?

As described in model formulation section, the Full Regulation and Partial Regulation Scenario are named Scenario 1 and 2 respectively. Based on these two scenarios, we further explore the optimal decision and social welfare if the Infrastructure and Carrier are separated, which give rise to Scenario 3 and 4 respectively. After enumerating all the results, we have the Proposition 4.1 for the optimal solutions as follows.

Proposition 4.1***:*** *If the Regulator fully observes the asymmetric cost information of the Infrastructure and Carrier, the optimal solutions of the four scenarios are*

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
$\boldsymbol{T}^*$	$-\frac{\lambda(1+\lambda)}{(1+2\lambda)^2}(\theta - c_{IK})^2$	$-\frac{(\theta-c_{IK})^2}{4}$	$-\frac{n(1+\lambda)[\lambda(n+1)-1]}{[n+2\lambda(n+1)]^2}(\theta-c_I-c_K)^2$	$-\frac{n}{n+1}\left(\frac{\theta-c_I-c_K}{2}\right)^2$
$\boldsymbol{a}^*$	$-$	$-$	$\frac{[\lambda(n+1)-1](\theta-c_K)+(1+\lambda)(n+1)c_I}{n+2\lambda(n+1)}$	$\frac{\theta+c_I-c_K}{2}$
$\boldsymbol{q}^*$	$\frac{1+\lambda}{1+2\lambda}(\theta-c_{IK})$	$\frac{\theta-c_{IK}}{2}$	$\frac{n(1+\lambda)(\theta-c_I-c_K)}{n+2\lambda(n+1)}$	$\frac{n}{2(n+1)}(\theta-c_I-c_K)$
$\boldsymbol{p}^*$	$\frac{(1+\lambda)c_{IK}+\lambda\theta}{1+2\lambda}$	$\frac{\theta+c_{IK}}{2}$	$\frac{\lambda(n+2)\theta+n(1+\lambda)(c_I+c_K)}{n+2\lambda(n+1)}$	$\frac{(n+2)\theta+n(c_I+c_K)}{2(n+1)}$
$\boldsymbol{\pi}^*$	$\pi_{IK}^*=0$	$\pi_{IK}^*=0$	$\pi_I^*=0$ $\pi_K^*=\frac{n(1+\lambda)^2(\theta-c_I-c_K)^2}{[n+2\lambda(n+1)]^2}$	$\pi_I^*=0$ $\pi_K^*=\frac{n(\theta-c_I-c_K)^2}{4(1+n)^2}$
$\boldsymbol{W}^*$	$\frac{(1+\lambda)^2}{2(1+2\lambda)}(\theta - c_{IK})^2$	$\frac{3+2\lambda}{8}(\theta - c_{IK})^2$	$\frac{n(1+\lambda)^2}{2[n+2\lambda(n+1)]}(\theta-c_I-c_K)^2$	$\frac{n[3n+2\lambda(n+1)+4]}{8(n+1)^2}(\theta-c_I - c_K)^2$

with Scenario 1 denotes vertical integration with full regulation, Scenario 2 denotes *vertical integration with partial regulation, Scenario 3 denotes vertical separation with full regulation, and Scenario 4 denotes vertical separation with partial regulation.*

The expected optimal solutions are those taken expected on the asymmetric cost information c_{IK} (in Scenario 1 and 2) or c_I (in Scenario 3 and 4). In addition, the following observation can be obtained:

1) *Full Regulation dominates Partial Regulation;*
2) *Vertical integration of Infrastructure and Carrier dominates vertical separation of them in both Full Regulation and Partial Regulation Scenarios;*
3) *Vertical integration of Infrastructure and Carrier in the Full Regulation Scenario is the first-best of railway industry.*
4) *Only if $c_{IK} = c_I + c_K$ and Carrier's number n tends to infinity can the total social welfare of the vertical separation scenario approaches that of vertical integration scenario.*

Proof: Please refer to the Appendix A.4.1. □

From the optimal solutions shown in Proposition 4.1, we can also have some observation and the following proposition.

Proposition 4.2***:*** *If the Regulator fully observes the asymmetric cost information of the Infrastructure and Carrier, the optimal solutions have the following monotonicity with regard to the public fund raising parameter λ, the number of Carriers n, and the costs c_{IK}, c_I or c_K.*

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
$\boldsymbol{T}^*$	$\lambda:\downarrow$ $c_{IK}:\uparrow$	$\lambda:-$ $c_{IK}:\uparrow$	$\lambda:\downarrow$; $n:\downarrow$ $c_I:\uparrow$; $c_K:\uparrow$	$\lambda:-$; $n:\downarrow$ $c_I:\uparrow$; $c_K:\uparrow$
$\boldsymbol{a}^*$	$-$	$-$	$\lambda:\uparrow$; $n:\uparrow$ $c_I:\uparrow$; $a^*\downarrow$ in c_K if $\lambda \geq \frac{1}{n+1}$	$\lambda:-$; $n:-$ $c_I:\uparrow$; $c_K:\downarrow$
$\boldsymbol{q}^*$	$\lambda:\downarrow$ $c_{IK}:\downarrow$	$\lambda:-$ $c_{IK}:\downarrow$	$\lambda:\downarrow$; $n:\uparrow$ $c_I:\downarrow$; $c_K:\downarrow$	$\lambda:-$; $n:\uparrow$ $c_I:\downarrow$; $c_K:\downarrow$
$\boldsymbol{p}^*$	$\lambda:\uparrow$ $c_{IK}:\uparrow$	$\lambda:-$ $c_{IK}:\uparrow$	$\lambda:\uparrow$; $n:\downarrow$ $c_I:\uparrow$; $c_K:\uparrow$	$\lambda:-$; $n:\downarrow$ $c_I:\uparrow$; $c_K:\uparrow$
$\boldsymbol{\pi}^*$	$\lambda:-$ $c_{IK}:-$	$\lambda:-$ $c_{IK}:-$	$\pi_K^*\downarrow$ in λ; $\pi_K^*\downarrow$ in n *if* $\lambda \leq \frac{n}{2(n+1)}$ $\pi_K^*\downarrow$ in c_I, c_K	$\lambda:-$ $\boldsymbol{\pi}_{\boldsymbol{K}}^*\downarrow$ in c_I, c_K, n
$\boldsymbol{W}^*$	$\lambda:\uparrow$ $c_{IK}:\downarrow$	$\lambda:\uparrow$ $c_{IK}:\downarrow$	$\lambda:\uparrow$ if $\lambda \geq \frac{1}{n+1}$; $n:\uparrow$ $c_I:\downarrow$; $c_K:\downarrow$	$\lambda:\uparrow$; $n:\uparrow$ $c_I:\downarrow$; $c_K:\downarrow$

Proof: Please refer to the Appendix A.4.2. □

Based on Proposition 4.2, we can have the following observations:

Regarding λ:

- If the Carriers are separated from the Infrastructure, then the decisions of them are not affected by the public fund raising parameter λ, which only affects the social welfare. Generally, the social welfare is increasing in λ, because as the opportunity cost of raising public fund increasing, the power of the Regulator increases and has stronger control on the social welfare.

- In Partial Regulation Scenario where the Regulator separated from the Infrastructure, the transfer payment decision is irrelevant to the public fund raising parameter λ, because the Regulator aims at break-even of the Infrastructure.

- In Scenario 1 and 3, output and transfer payments are decreasing in λ, market equilibrium price and social welfare are increasing in λ. In Scenario 3, the access charge is increasing in λ, and the profit of the Carrier is decreasing in λ.

Regarding n:

- The market player under the direct regulation has zero profit. If the Carriers are separated from the Infrastructure, then they may retain certain profit, which actually does harm to the social welfare.

- The transfer payment and market equilibrium price are decreasing in n, while the output and social welfare are increasing in n. This is because a more intensive competition among Carriers benefits the whole society.

Regarding the costs:

- In Scenario 1, 2, and 4, if the costs of the Infrastructure and Carrier increases, the transfer payment, the output and the social welfare are decreasing, while the market equilibrium price is increasing.

- In Scenario 3, the profit of the Infrastructure and Carrier, the output and the social welfare is decreasing in the cost of the Infrastructure and Carrier, and the market equilibrium price is increasing in the cost of the Infrastructure and Carrier. The access charge is increasing in the cost of the Infrastructure.

- In Scenario 3, if $\lambda \geq \frac{1}{n+1}$, then the access charge is decreasing in the cost of the Carrier, and the transfer payment is increasing in the cost of the Carrier.

Regarding the performance in terms of output and profit:

- Other than Scenario 3, the Regulator is successful in squeezing the profits from the Infrastructure.
- The first best case, i.e. Scenario 1, has the largest output.
- In the above four scenarios, it has been prove that Scenario 1 and 2 dominates Scenario 3 and 4 respectively, which means that with information symmetry, it is always better to integrated the Infrastructure and Carrier to avoid double marginalization and gain the benefit of vertical economies of scale.

4.4.2 Vertically integrated monopoly with information asymmetry: China Case

In this case we further consider that the operating cost c_{IK} of the Infrastructure and Carrier is private information which is unknown to the Regulator. If there is information asymmetry, the Regulator can take one of the following measures (incentive regulation mechanisms):

1. Price-cap. The Regulator sets the higher cost of the Infrastructure and Carrier as a price-cap, which the Infrastructure and Carrier cannot exceed the cost of quote (the China Case before year 2013 reform).
2. Screening. The Regulator applies Contract Theory to design a menu of take-it-or-leave-it contracts related to access charge and transfer payment, so as to entice the true costs of their own choice and match transfer payment alternatives (the China Case).
3. Introduce competition for the Carriers to increase output (the UK Case).
4. Yardstick competition. By dividing the regional competition forced by Regulators, the integrated regional Infrastructures and Carriers report their true operating costs (the Japan Case).

This section will discuss the price-cap and screening mechanisms. Assume that the cost of the integrated Infrastructure and Carrier has two possible values: high cost c_h with probability β_h, and low cost c_l with probability β_l, with $\beta_h + \beta_l = 1$.

4.4.2.1 Price-cap

Price-cap reflects the railway regulatory structure of China before year 2013. The Railway Ministry of China engages in both the regulatory of the railway industry, as well as the infrastructure and carrier operational decisions, with an objective of maximizing social welfare W, but facing the cost information asymmetry.

If the Regulator takes Price-cap, then the integrated Infrastructure and Carrier with high cost will announce his own cost c_h, while the integrated Infrastructure and Carrier with low cost will cheat and also announce cost c_h, in order to get a higher transfer payment, but resulting in a loss of social welfare. Similar to the proof of Proposition 4.1 in appendix, we have remark 4.1.

Remark 4.1*: If the Regulator takes a Price-cap regarding the cost information asymmetry of the integrated Infrastructure and Carrier, then the optimal transfer payment is*

$$T^* = -\frac{\lambda(1+\lambda)}{(1+2\lambda)^2}(\theta - c_h)^2 \tag{4.1}$$

The optimal output for the integrated Infrastructure and Carrier is

$$q^* = \frac{1+\lambda}{1+2\lambda}(\theta - c_h) \tag{4.2}$$

The optimal social welfare is

$$W^* = \frac{(1+\lambda)^2}{2(1+2\lambda)}(\theta - c_h)^2 \tag{4.3}$$

From the modeling result we can see that if the Regulator takes Price-cap for the cost information asymmetry of the integrated Infrastructure and Carrier, then it has a probability of β_h that the optimal social welfare is lower than the perfect information Case.

4.4.2.2 Screening

Next, consider the Screening scenario. Without screening mechanism, the low-cost integrated Infrastructure and Carrier will report its own cost as c_h, and the high-cost integrated Infrastructure and Carrier can only truthfully report its cost c_h. If screening mechanism is adopted, the Regulator will design a contract menu (q_l, T_l) and (q_h, T_h), namely take-it-or-leave-it offer. Regarding the screening scenario, we have the following proposition:

Proposition* 4.3*: *If the Regulator cannot fully observe the asymmetric cost information of the Infrastructure and Carrier, by taking the screening strategy, the menu of contracts designed by the Regulator and offered to the integrated Infrastructure and Carrier is with the following output:*

$$q_l^* = \frac{1+\lambda}{1+2\lambda}(\theta - c_l) \tag{4.4}$$

$$q_h^* = \frac{1+\lambda}{1+2\lambda}\left[\theta - c_h - \frac{\beta_l}{\beta_h}\frac{\lambda}{1+\lambda}(c_h - c_l)\right] \tag{4.5}$$

and the following transfer payment:

$$\begin{aligned} T_l^* = -\frac{\lambda(1+\lambda)}{(1+2\lambda)^2}\Big[&(\theta - c_h)^2 + (c_h - c_l)^2 - \frac{1}{\lambda}(\theta - c_h)(c_h - c_l) \\ &+ \frac{\beta_l}{\beta_h}\frac{1+2\lambda}{1+\lambda}(c_h - c_l)^2\Big] \end{aligned} \tag{4.6}$$

$$T_h^* = -\frac{\lambda(1+\lambda)}{(1+2\lambda)^2}\left[\theta - c_h + \frac{\beta_l}{\beta_h}(c_h - c_l)\right]\left[\theta - c_h - \frac{\beta_l}{\beta_h}\frac{\lambda}{1+\lambda}(c_h - c_l)\right] \tag{4.7}$$

The corresponding market equilibrium price is:

$$p_l^* = \frac{\lambda\theta + (1+\lambda)c_l}{1+2\lambda}, \quad p_h^* = \frac{\lambda\theta + (1+\lambda)c_h + \frac{\beta_l}{\beta_h}\lambda(c_h - c_l)}{1+2\lambda}$$

In addition, the profit for the Infrastructure and Carrier with high cost is zero, while that for the Infrastructure and Carrier with low cost is positive as the information rent.

Proof: Please refer to the Appendix A.4.3. □

From Proposition 4.3, one can observe that the optimal output and market price of the low-cost type Infrastructure and Carrier is irrelevant to the probability β, and equal to those of information symmetry case. It means that the low-cost type obtains a fully incentive through the screening. The output of the high-cost type Infrastructure and Carrier is smaller than that without screening, because the screening mechanism in fact sacrifice the higher-cost type's interest, i.e. the profit for the Infrastructure and Carrier with high cost is zero.

4.4.3 Vertical separation: UK Case

In the perfect information Case, it has been proved that vertical integration of Infrastructure and Carrier dominates vertical separation. What if the information asymmetry is involved? This sub-section is going to address this issue. What we discuss here, namely UK Case, gets Carriers separated from the Infrastructure and introduces competition among Carriers. The Decision sequence is as follows. First, the Carriers i to optimize output q_i. Next, the Regulator designs a menu of take-it-or-leave-it offer (a, T) for the monopoly Infrastructure. We have the Proposition 4.4 regarding the optimal solutions of the UK Case.

Proposition 4.4*: If the Regulator cannot fully observe the asymmetric cost information of the Infrastructure, by taking the screening strategy, the menu of contracts designed by the Regulator and offered to the Infrastructure is with the following access charge:*

$$a_l^* = \frac{[\lambda(n+1)-1](\theta - c_K) + (1+\lambda)(n+1)\tilde{c}_l}{n+2\lambda(n+1)} \tag{4.8}$$

$$a_h^* = \frac{[\lambda(n+1)-1](\theta - c_K) + (1+\lambda)(n+1)\tilde{c}_h + \frac{\beta_l}{\beta_h}(\tilde{c}_h - \tilde{c}_l)}{n+2\lambda(n+1)} \tag{4.9}$$

and the following transfer payment:

$$\begin{aligned} T_l^* = -\frac{n}{(n+1)[n+2\lambda(n+1)]^2}\Bigg\{&\left[(1+\lambda)(n+1)(\theta - \tilde{c}_h - c_K) - \frac{\beta_l}{\beta_h}(\tilde{c}_h - \tilde{c}_l)\right]\left([\lambda(n+1)-1](\theta - \tilde{c}_h - c_K) + \frac{\beta_l}{\beta_h}(\tilde{c}_h - \tilde{c}_l)\right) + (1+\lambda)(n+1)[\lambda(n+1)-1](\theta - c_K - \tilde{c}_l)^2 \\ &- \left\{(1+\lambda)(n+1)(\theta - \tilde{c}_h - c_K) - \frac{\beta_l}{\beta_h}(\tilde{c}_h - \tilde{c}_l)\right\}\left\{[\lambda(n+1)-1](\theta - \tilde{c}_l - c_K) + \left[\frac{\beta_l}{\beta_h} + (1+\lambda)(n+1)\right](\tilde{c}_h - \tilde{c}_l)\right\}\Bigg\} \end{aligned} \tag{4.10}$$

$$T_h^* = -\frac{n}{(n+1)[n+2\lambda(n+1)]^2}\left\{(1+\lambda)(n+1)(\theta - \tilde{c}_h - c_K) - \frac{\beta_l}{\beta_h}(\tilde{c}_h - \tilde{c}_l)\right\}\left\{[\lambda(n+1) - 1](\theta - \tilde{c}_h - c_K) + \frac{\beta_l}{\beta_h}(\tilde{c}_h - \tilde{c}_l)\right\} \tag{4.11}$$

The optimal output for the Carrier i is:

$$q_{il}^* = \frac{(1+\lambda)(\theta - \tilde{c}_l - c_K)}{n + 2\lambda(n+1)} \tag{4.12}$$

$$q_{ih}^* = \frac{(1+\lambda)(\theta - \tilde{c}_h - c_K) - \frac{\beta_l}{\beta_h}\frac{\tilde{c}_h - \tilde{c}_l}{n+1}}{n + 2\lambda(n+1)} \tag{4.13}$$

The total output is:

$$q_l^* = \frac{n(1+\lambda)(\theta - \tilde{c}_l - c_K)}{n + 2\lambda(n+1)} \tag{4.14}$$

$$q_h^* = \frac{n}{n + 2\lambda(n+1)}\left[(1+\lambda)(\theta - \tilde{c}_h - c_K) - \frac{\beta_l}{\beta_h}\frac{\tilde{c}_h - \tilde{c}_l}{n+1}\right] \tag{4.15}$$

And the equilibrium market price is:

$$p_l^* = \frac{\lambda(n+2)\theta + (1+\lambda)n(\tilde{c}_l + c_K)}{n + 2\lambda(n+1)} \tag{4.16}$$

$$p_h^* = \frac{\lambda(n+2)\theta + (1+\lambda)n(\tilde{c}_h + c_K) + \frac{n}{n+1}\frac{\beta_l}{\beta_h}(\tilde{c}_h - \tilde{c}_l)}{n + 2\lambda(n+1)} \tag{4.17}$$

In addition, the profit for the Infrastructure with high cost is zero, while that for the Infrastructure with low cost is positive as the information rent.

Proof: Please refer to the Appendix A.4.4. □

From the above proposition, one can observe that the access charge, the optimal output and market equilibrium price of the low-cost type Infrastructure is irrelevant to the probability β, and equal to those of Symmetry Case. It means that the low-cost type obtains a fully incentive through the screening. The transfer for low-cost type is the transfer of the high-cost type plus a transfer of the low-cost type in Perfect information Case, and further plus an adjusting element. The output of the high-cost type

Infrastructure and Carrier is smaller than that without screening, because the screening mechanism in fact sacrifices the higher-cost type's interest, i.e. the profit for the Infrastructure and Carrier with high cost is zero.

4.4.4 Horizontal separation: Japan Case

In this horizontal separation case or namely Japan Case, the Infrastructure and the railway Carrier are integrated but horizontally separated by regions. Each integrated railway firm is a monopolist in the regional market. Since there is not enough competition in the market, the Regulator introduces yardstick competition to reduce the effect of dead weight loss, which is a loss of economic efficiency that can occur when equilibrium for a good or service is not achievable, caused by the monopolistic market structure. Under yardstick competition, a monopoly in one region is disciplined by comparing its activities to the activities of monopolists that operate in other regions (Shleifer, 1985).

In the Japan Case, we assume Infrastructure and the Carrier are separated into m regions, and the cost of each region is $\tilde{c}_{IK}$, and the Regulator does not know the information of $\tilde{c}_{IK}$. If the information is symmetric, then it will be the same with the Perfect information Case. If the information is asymmetric, the Regulator can take the following yardstick competition to make each regional Infrastructure and Carrier reported true cost. For the i^{th} regional Infrastructure and Carrier, which reports a cost c_i, the Regulator can calculate the average cost $\overline{c}_i$ in eliminating the i^{th} regional Infrastructure and Carrier as $\overline{c}_i = \frac{1}{m-1}\sum_{j\neq i} c_j$. And use the average as a "shadow cost". The regulator will transfer to the i^{th} regional Infrastructure and Carrier on the basis of the average cost $\overline{c}_i$. Then we can have the following proposition regarding the optimal solution of Japan Case.

Proposition 4.5*: If the Regulator takes yardstick competition for each regional Infrastructure and Carrier, then:*

1) There exists a unique Nash Equilibrium that each regional Infrastructure and Carrier reports $c_i = \tilde{c}_{IK}$, which means that through yardstick competition, the Regulator will obtain the real cost of each regional Infrastructure and Carrier;

2) The Regulator will not make the output decision for the regional Infrastructure and Carrier.

3) The optimal transfer payment $T^{*}=-\frac{(\theta-\tilde{c}_{IK})^{2}}{4}$*, the optimal output* $\frac{\theta-\tilde{c}_{IK}}{2}$*, the corresponding market equilibrium price* $\frac{\theta+\tilde{c}_{IK}}{2}$*, and the corresponding social welfare* $\frac{3+2\lambda}{8}(\theta-\tilde{c}_{IK})^{2}$*, which means that if* $\tilde{c}_{IK}\sim c_{IK}$*, the social welfare under the case of horizontal separation will approach to that of Scenario 2 with perfect information .*

Proof: Please refer to the Appendix A.4.5. □

Note that the yardstick competition has some limitations. First of all, regional Infrastructures and Carriers are required to be almost identical in cost structure among each other. In addition, the cost increment of horizontal separation should be rather small, which requires that horizontal separation does not have an obvious loss in economies of scale. Fortunately, these two requirements of yardstick competition are quite well conformed to in the railway sector than other sectors. In the railway industry, the investment and operational costs are almost the same among regions for the same transport standards. Besides, the horizontal separation mainly incurs increasing costs for the Regulator rather than the market players.

Besides, it is not intuitive that the Regulator in Japan Case cannot make an output decision even if it introduces a yardstick competition forcing the regional Infrastructure and Carriers to tell the true costs. The rationing behind this phenomenon is that the regional Infrastructure and Carriers do have private cost information as an advantage against the Regulator. In yardstick completion, we may notice that the Regulator offers the same contract $T(\overline{c}_i)$ and $q(\overline{c}_i)$ to those regulated, while in screening, the Regulator has a full discrimination. It means that the Regulator is equipped with more powerful tools in screening strategy than in yardstick completion. This modeling result helps explaining why in Japan the horizontal separation of Infrastructure and Carriers is seen combined with privatization.

4.5 Numerical Study and Parametric Analysis

In the modeling section, the optimal solutions of the four cases that cannot be told the dominance have been derived. Some of the optimal solutions are in complicated forms. Therefore in this section, we shall give a numerical case and analyze the impact of several important parameters.

4.5.1 A numerical case

In this section, we will conduct a numerical analysis for the modeling sections. We have the parameters values as follows:

Table 4.3 Dataset of numerical analysis

Notation	Meaning	Value
c_{IK}	The total cost when Infrastructure and Carrier are integrated	2
c_I	The cost of Infrastructure when it is separated from Carrier	1
c_K	The cost of Carrier when it is separated with Infrastructure	1
n	The number of Carriers when they are separated with Infrastructure	3
θ	The maximum price that consumer is willing to pay	4
c_l	The total costs of the integrated Infrastructure and Carrier of low-cost type in China Case	1.5
c_h	The total costs of the integrated Infrastructure and Carrier of high-cost type in China Case	2.5
$\tilde{c}_l$	The cost of the Infrastructure of low-cost type in UK Case	0.8
$\tilde{c}_h$	The cost of the Infrastructure of high-cost type in UK Case	1.2
$\tilde{c}_{IK}$	The total costs of the regional integrated Infrastructure and Carrier in Japan Case	2.1
β_l	The probability of low-cost type in China and UK Case	0.5
β_h	The probability of high-cost type in China and UK Case	0.5
λ	The public fund raising parameter	0.05

The values of the parameters are set as the above to make the sum of the expected costs of Infrastructure and Carrier in each case (other than Japan Case) are equal to 2, so that different cases can be compared upon identical basis. The numerical results for this case are as follows.

Table 4.4 Result of numerical case

Cases	**Mechanisms**	**Transfer T^***	**Access charge a^***	**Output q^***	**Price p^***	**Profit π^***	**Welfare W^***
Perfect information Case	Scenario 1: integration with full regulation	-0.1844	—	1.9091	2.0909	$\pi_{IK}^*=0$	**2.1298**
	Scenario 2: integration with partial regulation	-1.0625	—	1	3	$\pi_{IK}^*=0$	1.6469
	Scenario 3: Vertical separation with full regulation	0.8807	0.5294	1.8529	2.1471	$\pi_I^*=0$ $\pi_K^*=1.1559$	1.9650
	Scenario 4: Vertical separation with partial regulation	-0.7575	2	0.75	3.25	$\pi_I^*=0$ $\pi_K^*=0.1894$	1.2688
China Case	Price-cap	-0.0976	—	1.4318	2.5682	$\pi_{IK}^*=0$	**1.1276**
	Screening	$T_l^*=1.1152$ $T_h^*=-0.1575$ $E(T^*)=0.4788$	—	$q_l^*=2.3864$ $q_h^*=1.3864$ $E(q^*)=1.8864$	$p_l^*=1.6136$ $p_h^*=2.6136$ $E(p^*)=2.1136$	$\pi_{IK}^l=1.3864$ $\pi_{IK}^h=0$ $E(\pi_{IK}^*)=0.6932$	**2.0946**
UK Case	Vertical separation	$T_l^*=1.6869$ $T_h^*=0.4831$ $E(T^*)=1.0850$	$a_l^*=0.2824$ $a_h^*=0.8941$ $a^*=0.5882$	$q_l^*=2.0382$ $q_h^*=1.5794$ $E(q^*)=1.8088$	$p_l^*=1.9618$ $p_h^*=2.4206$ $E(p^*)=2.1912$	$\pi_I^l=0.6318$ $\pi_I^h=0$ $E(\pi_I^*)=0.3159$ $\pi_K^l=1.3848$ $\pi_K^h=0.8315$ $E(\pi_K^*)=1.1082$	**1.9470**
Japan Case	Horizontal separation with yardstick competition	-0.9714	—	0.95	3.05	$\pi_{IK}^*=0$	**1.5057**

This numerical case shows that:

1. Full regulation with integrated Infrastructure and Carrier has the first-best social welfare 2.1298, with the highest output level and lowest market price. Furthermore, the Regulator succeeds in squeezing profit from the Infrastructure and Carrier.

2. Screening outperforms price-cap in China Case. Through screening, the Regulator increases the social welfare at the expense of $E(\pi_{IK}^{*})$, which is the information rent pay to the Infrastructure and Carrier of low-cost type. It means that after the reform of separating regulator and firm, China Railway industry should at least seek to employ screening techniques to improve social welfare.

3. The UK Case is not as good as China case with screening, because a vertical separation between the Infrastructure and Carrier causes double marginalization and loses economies of scale, though it indeed introduces competition among Carriers.

4. Even though the total costs are just a little bit higher than integration, the social welfare of Japan Case is still smaller than UK Case. The reason is that Japan Case incurs a double marginalization with a deregulation between the Regulator and the Infrastructure, which in the UK Case the Regulator reinforces its relationship with the Infrastructure by offering a menu of take-it-or-leave-it contracts.

5. To sum, facing asymmetric information, it is better to adopt soft policies to force the asymmetric information holder, i.e. the Infrastructure and Carrier to tell the truth, rather than taking either vertical or horizontal separation. Besides, if one has to choose between vertical and horizontal separation for the railway industry, picks vertical and matching up with screening strategy would be the best policy.

4.5.2 Parametric analysis

In this sub-section, by changing one parameter and fixing the others, we shall explore the main factors that affect the performance of different cases.

Figures 4.9 to 4.13 compare price-cap and screening scenarios in China Case, changing the standard deviation $\sigma(c_{IK})$ of c_l and c_h. The standard deviation $\sigma(\cdot)$, as the representative of dispersion degree of cost, indicates asymmetric level of the cost information. Figure 4.9 shows that as the standard deviation of c_l and c_h increases, the transfer payment T^* in price-cap case increases, because the integrated Infrastructure and Carrier has more information advantages. In the screening case, the effect of information asymmetry on the transfer payment is not monotonic. The transfer payment T_l for low-cost type is mostly positive, firstly increasing and then decreasing in the standard deviation of c_l and c_h, while the transfer paymentT_h for high-cost type is negative and takes the opposite trend. The reason is that as asymmetry of the cost information increases, the integrated Infrastructure and Carrier of low-cost type gains more advantages on the private cost information. However, the profit (as shown in Figure 4.12) decreases due to over-production and price decline.

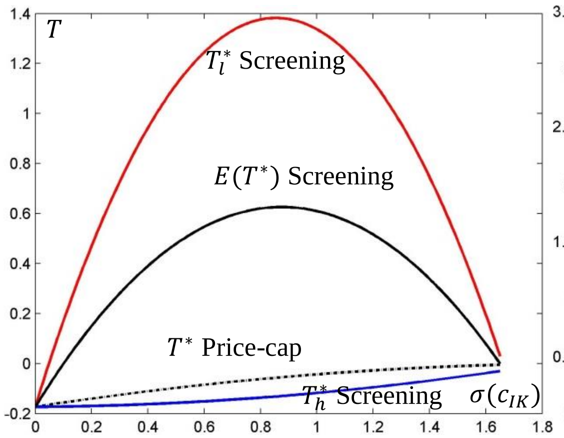


Figure 4.9 China case: T against $\sigma(c_{IK})$

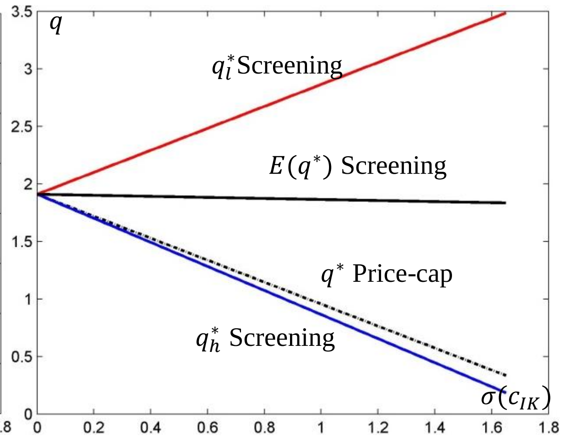
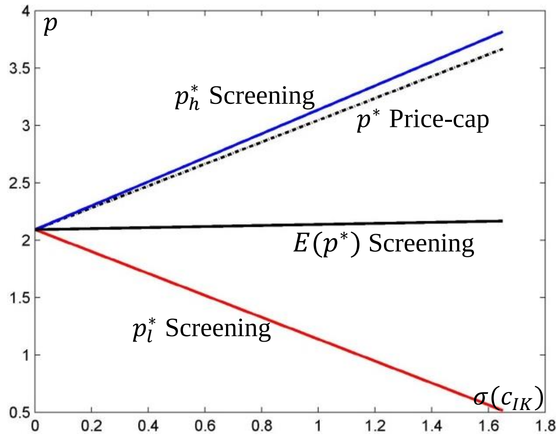


Figure 4.10 China case: q against $\sigma(c_{IK})$

Figure 4.10 shows that as the asymmetry of the cost information increases, the output q_l^* of the low-cost type increases since a lower marginal cost, while the output q_h^* of the high-cost type has an opposite trend. And the prices shown in Figure 4.11 have opposite trends due to similar reasons.

In Figure 4.12, as the standard deviation of c_l and c_h increases, the expected information rent $E(\pi_{IK}^*)$ firstly increases and then decreases. The reason is that as the cost of the low-cost type decreases, the integrated Infrastructure and Carrier gains more advantages on the private information, but the increasing output reduces its bargaining power against the Regulator.



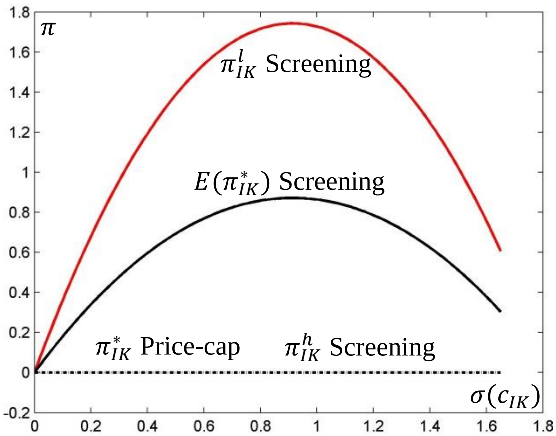


Figure 4.11 China Case: p against $\sigma(c_{IK})$ Figure 4.12 China Case: π against $\sigma(c_{IK})$

Figure 4.13 illustrates that screening is better than price-cap in terms of social welfare. The gap of welfare gets larger as the information asymmetry gets stronger. This is because the price-cap strategy only anchors at the higher cost. While the higher cost goes higher, the benefits of employing screening strategy becomes bigger.

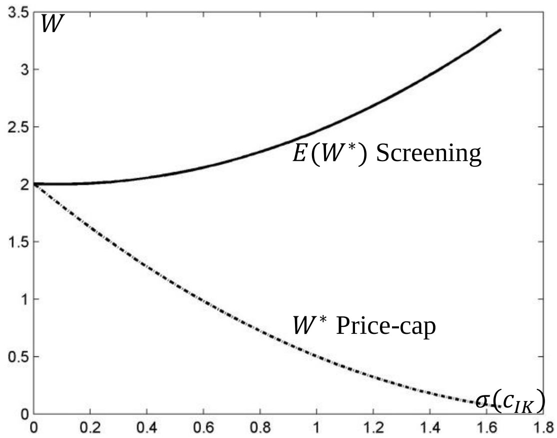


Figure 4.13 China Case: W against $\sigma(c_{IK})$

Figures 4.14 to 4.18 compare price-cap and screening scenarios in China Case, changing the standard deviation $\sigma(\beta)$ of β. Figure 4.14 shows that as the uncertainty of cost reduces, the transfer payment T reduces, since the Regulator gains more bargaining power against the regulated. The expected profit in Figure 4.17 has a similar trend.

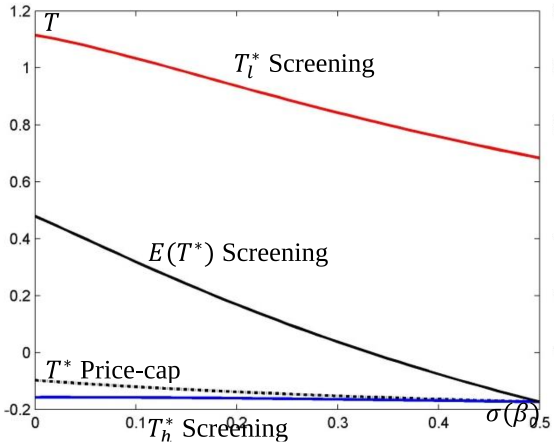


Figure 4.14 China Case: T against $\sigma(\beta)$

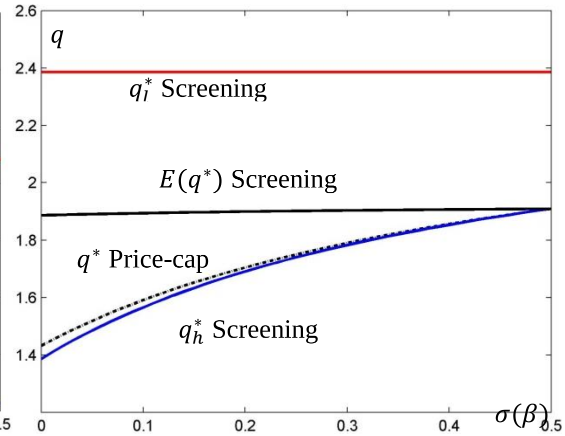


Figure 4.15 China Case: q against $\sigma(\beta)$

The output q in Figure 4.15 is increasing as the uncertainty of cost reduces.

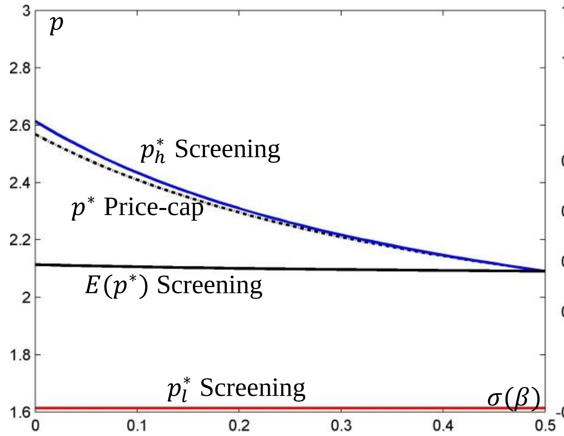


Figure 4.16 China Case: p against $\sigma(\beta)$

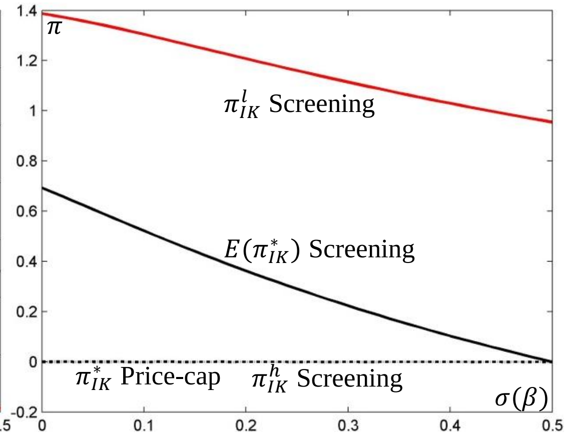


Figure 4.17 China Case: π against $\sigma(\beta)$

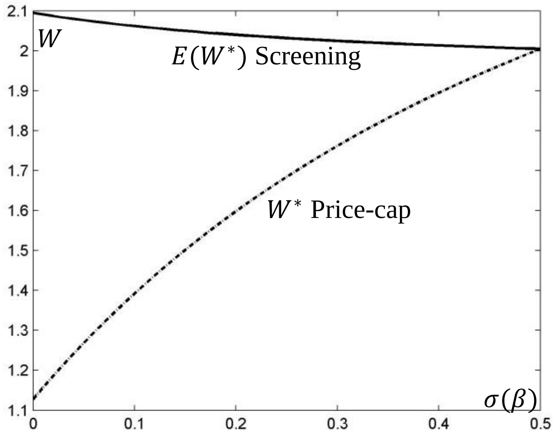


Figure 4.18 China Case: W against $\sigma(\beta)$

Figure 4.18 illustrates that screening yields a higher value of social welfare than price-cap, especially if the information asymmetry gets stronger.

Figures 4.19 to 4.24 draw the curves of optimal decisions and values of UK Case, changing the standard deviation $\sigma(c_I)$ of $\tilde{c}_l$ and $\tilde{c}_h$. Figures 4.21 and 4.22 show that, output q and market equilibrium price p have a similar trend as the screening scenario of China Case. The transfer payments T have monotonic trends with regard to the information asymmetry, showing that with information asymmetry, the low-cost Infrastructure has stronger bargaining power.

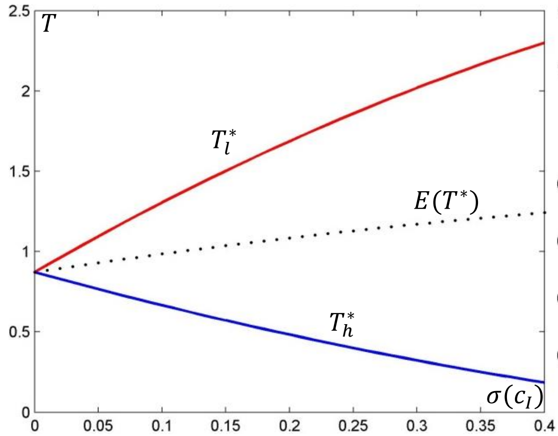


Figure 4.19 UK Case: T against $\sigma(c_I)$

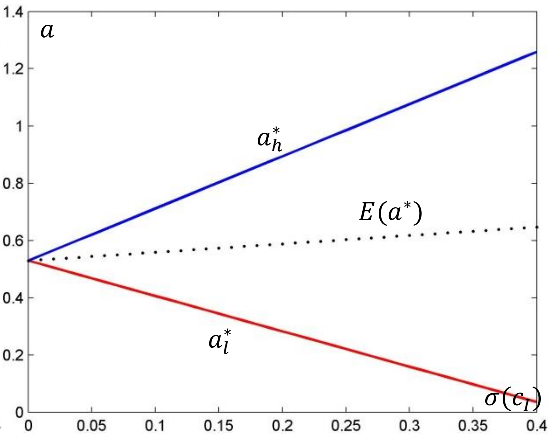


Figure 4.20 UK Case: a against $\sigma(c_I)$

Figure 4.20 shows that the expected access charge $E(a^*)$ is increasing in the standard deviation $\sigma(c_I)$, showing that with information asymmetry, the Infrastructure has stronger pricing power.

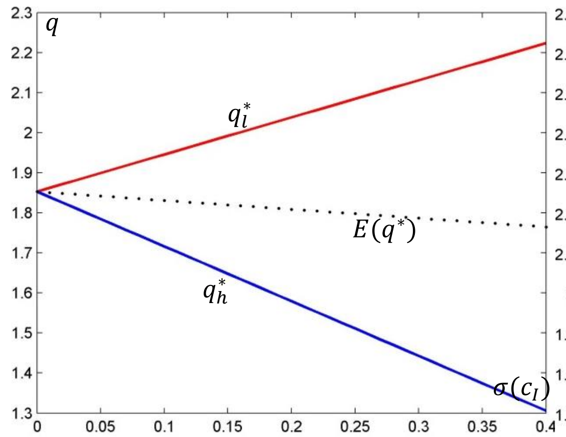


Figure 4.21 UK Case: q against $\sigma(c_I)$

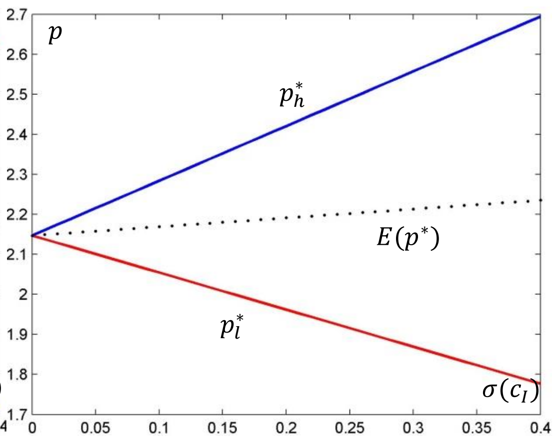


Figure 4.22 UK Case: p against $\sigma(c_I)$

Figure 4.23 shows the trends due to similar reason as output q and market equilibrium price p. In Figure 4.24, the expected social welfare $E(W)$ firstly decreases and then increases, because the Regulator's expense on information rent firstly increases and then decreases.

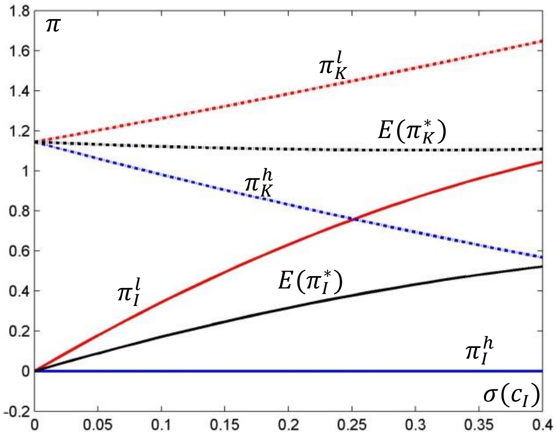


Figure 4.23 UK Case: π against $\sigma(c_I)$

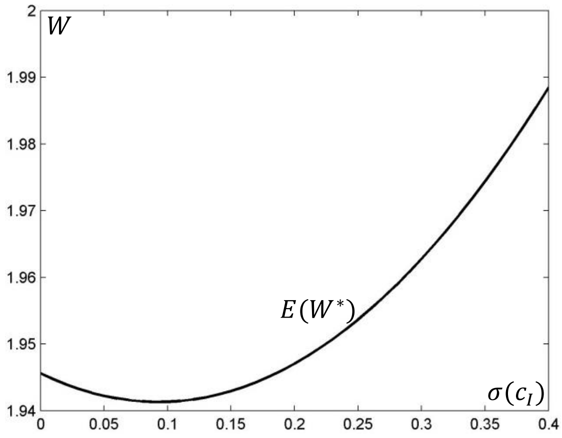


Figure 4.24 UK Case: W against $\sigma(c_I)$

Figures 4.25 to 4.30 draw the curves of optimal decisions and values of UK Case, changing the standard deviation $\sigma(\beta)$ of β. Figure 4.26 shows that the expected access charge $E(a^*)$ is decreasing in the standard deviation $\sigma(\beta)$, showing that with information asymmetry, the Infrastructure has stronger pricing power.

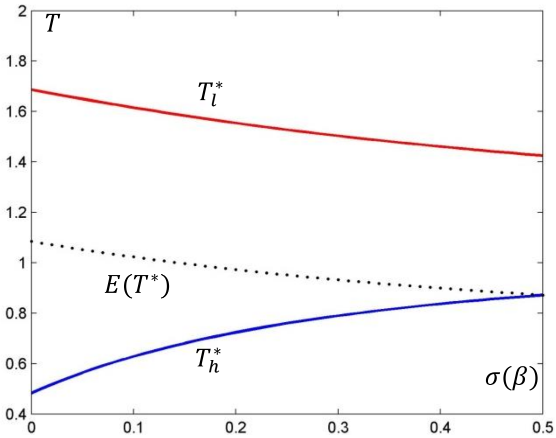


Figure 4.25 UK Case: T against $\sigma(\beta)$

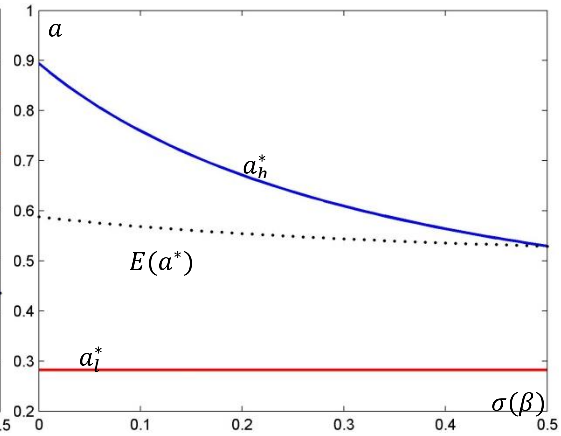
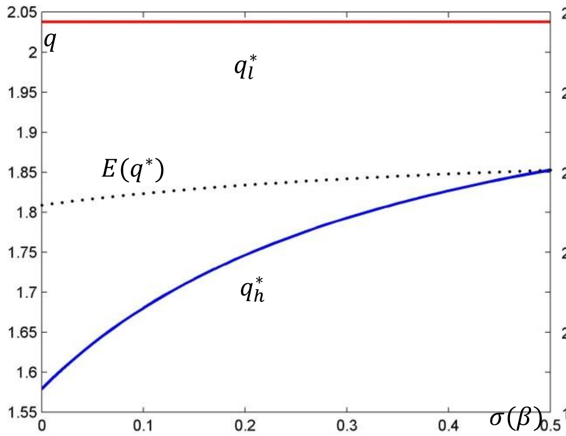


Figure 4.26 UK Case: a against $\sigma(\beta)$

Figures 4.25, 4.27 and 4.28 show that the transfer payment T, output q and market equilibrium price p have a similar trend as the screening scenario of China Case.



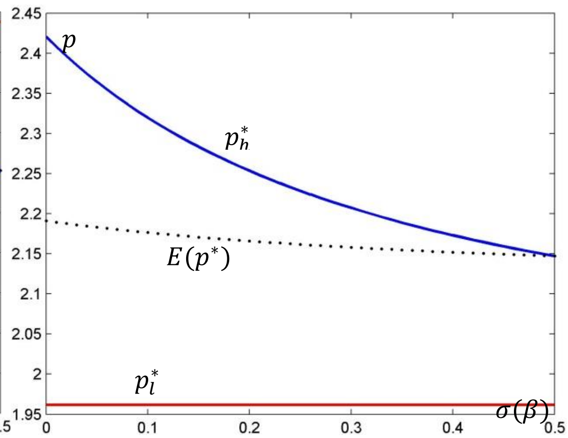
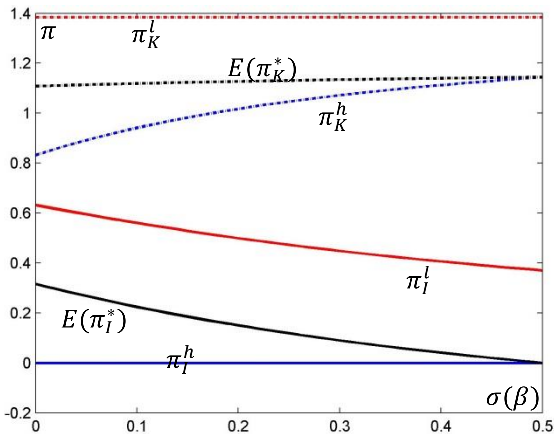


Figure 4.27 UK Case: q against $\sigma(\beta)$ Figure 4.28 UK Case: p against $\sigma(\beta)$

Figure 4.29 shows that as the information asymmetry reduces, the expected profit $E(\pi_I^*)$ of Infrastructure reduces, while the expected profit $E(\pi_K^*)$ of the Carriers remains almost the same. This is because the Infrastructure is losing advantages on the private information. In Figure 4.30, the expected social welfare $E(W^*)$ is increasing in the standard deviation of β, because of the reduction of information asymmetry.



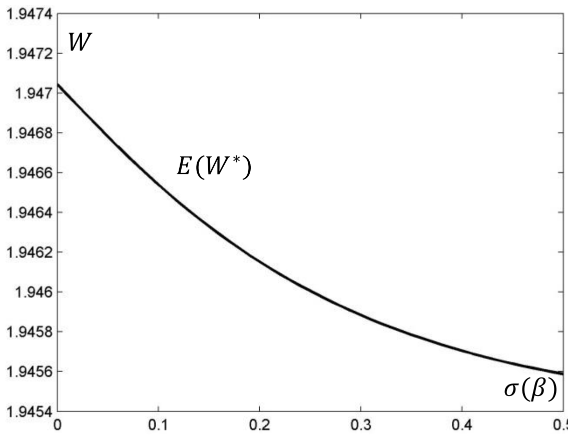


Figure 4.29 UK Case: π against $\sigma(\beta)$ Figure 4.30 UK Case: W against $\sigma(\beta)$

To summarize, we have the following observations regarding the above numerical study:

- With neither vertical nor horizontal separation, the regulator could still do better in terms of social welfare by applying screening strategy, so as to increase social welfare under a more obvious information asymmetric circumstance.
- Between the two aspects describing information asymmetry, $\sigma(\beta)$, represents the information revealed to the Regulator, which has a monotonic effect on the social

welfare, while $\sigma(c)$, however, has a double-sided effect on the social welfare since it also affects the operational decision of firms.

4.6 Concluding Remarks and Implications

In this chapter, we study the structure reform issue of the railway industry through presenting an economic model primarily characterized by three features: vertical / horizontal separation, cost information asymmetry and strategies to eliminate the asymmetry. Within this context, we enumerate all potential structures of the railway industry, exhibit analytical models, derive the optimal solutions of typical structures, and conduct a numerical study and parametric analysis. Through this work, this chapter sheds light on the railway structural choices of a country, especially China, where a reform of the railway sector in undergoing.

Our analysis starts with a model formulation and an enumeration of all potential structures of the railway industry. Among seven structures, three are dominated by the other four. Therefore, in the rest of the chapter, we focus on the analytical model of the four cases. First of all we study the case where the cost information of Infrastructure and Carrier is symmetric for the Regulator. Three issues are addressed. **1)** *Which one is better, separation or integration of government and firms (i.e. Partial Regulation or Full Regulation)?* The model shows that Full Regulation dominates Partial Regulation. **2)** *Which one is better, separation or integration of Infrastructure and Carrier without information asymmetry?* The model proves that vertical integration of Infrastructure and Carrier dominates vertical separation of them in both Full Regulation and Partial Regulation Scenarios. Only if the loss of economies of scales of vertical separation can be eliminated and Carrier's number n tends to infinity can the total social welfare of the vertical separation scenario approaches that of vertical integration scenario. **3)** *Is there a dominant case if information is symmetric?* Our model shows that vertical integration of Infrastructure and Carrier in the Full Regulation Scenario is the first-best of railway industry. In addition, we also give monotonicity analysis on the optimal solutions with regard to the public fund raising parameter, the number of Carriers, and the costs of Infrastructure and Carrier.

As the analysis extends to the case with information asymmetry, we show that if there's neither vertical nor horizontal separation, i.e. China Case, the Regulator is able to improve the social welfare by applying screening strategy towards the integrated Infrastructure and Carrier, which can improve the social welfare under a more obvious information asymmetric circumstance. The model show that the profit for the Infrastructure and Carrier with high cost is zero, while that for the Infrastructure and Carrier with low cost is positive as the information rent. We also demonstrate that screening with a menu of take-it-or-leave-it contracts has a higher social welfare than just employing a single price-cap.

The modeling analysis further explores vertical separation of Infrastructure and Carrier and an introduction of competition among Carriers, i.e. UK Case. We address the issue where the information asymmetry is involved and screening strategy is employed, and solve the optimal solutions explicitly. We show that the UK Case has negative effects (double marginalization, information asymmetry, loss of vertical economic scale) and positive effects (competition of carriers resulting in increasing of total output).

As the last step of the modeling, we model the horizontal separation of Infrastructure and Carrier into regions, i.e. Japan Case, and prove that this kind of yardstick competition succeeds in driving the regional Infrastructures and Carriers to unveil their own private information of cost. Our modeling and numerical results further show that, however, even though the total costs are just a little bit higher than integration, the social welfare of Japan Case is still smaller than UK Case. The reason is that Japan Case incurs a double marginalization with a deregulation between the Regulator and the Infrastructure, which in the UK Case the Regulator reinforces its relationship with the Infrastructure by offering a menu of take-it-or-leave-it contracts.

Based on the analytical results in the models, we step forward with numerical study and parametric analysis. We show that the UK Case is not as good as China case with screening, because a vertical separation between the Infrastructure and Carrier causes double marginalization and loses economies of scale, though it indeed introduces competition among Carriers. To sum, facing asymmetric information, it is better to adopt soft policies to force the asymmetric information holder, i.e. the Infrastructure and Carrier to tell the truth, rather than taking either vertical or horizontal separation. Besides, if one has to choose between vertical and horizontal separation for the railway industry, picks vertical and matching up with screening strategy would be the best policy.

Parametric analysis shows that between the two aspects describing information asymmetry, the standard deviation of the probability represents the information revealed to the Regulator, which has a monotonic effect on the social welfare, while the standard deviation of cost, however, has a double-sided effect on the social welfare since it also affects the operational decision of firms.

In sum, compared with the existing research, this chapter has shed light on the exploration on the choice of main railway industry structures with modeling analysis, and draws an evolution map of the railway reform in China. Though UK and Japan are two cases attracting many discussions in the empirical study, we setup a model showing that UK Case with a screening strategy outperforms Japan Case.

Based on the basic model in this chapter, there are many possible directions that deserve future research. Firstly, this chapter assumes that the costs of the Infrastructure and Carrier are exogenesis parameter, which leads to adverse selection analysis. This assumption can be further eliminated so that a study of moral hazard, i.e. the Infrastructure and Carrier make decision on optimizing their costs, is one potential research direction. Secondly, we may consider that the Infrastructures and Carriers have different costs after vertical or horizontal separation. We may also consider the difference between passenger and cargo transport in the railway, and the competition and coordination among difference levels of railway network. Besides, a competition on service quality rather than quantity (output) is also an interesting issue to be addressed, i.e. we shall apply Bertrand model rather than Cournot model. Finally, we may also describe both setup cost and operational cost for the Infrastructure and the Carrier.

Chapter 5 Competition between Primary and Secondary Airports in Trans-European Transport Network

In this chapter, we explore the competition behavior of airport and carrier in multi-airport regions using European air transport market as an example.

5.1 Introduction

European Union planned a Trans-European Transport Networks (TEN-T) with set of road, rail, air and water transport networks based on trans-European networks in 1990. Besides the developed rail networks between European countries, air transport network is an important component of the Trans-European transport networks. The growth of low-cost carriers (LCCs) has changed the landscape of airline competition within Europe and stimulated the emergence of Europe’s secondary airports. With the fast increasing passenger travel demand, the carriers found it increasingly difficult to get time-slot at the congested hub airports. Some regional airports or secondary airports near the primary airports became attractive for LCCs.

LCCs like to use secondary airports for a few reasons. First, LCCs appreciate low terminal charges at secondary airports in comparison with hub airports. Second, seldom congestion happened in the secondary airport making it possible to follow the flight schedules and thus avoid costs of delay. Third, some LCCs enjoy the advantage of dominated terminals in secondary airports. Nevertheless, secondary airports are usually farther from the city center than primary airports. That means longer surface access time and cost to the majority of passengers. Also, the cost of switching airports is intensely high.

The use of primary airports or secondary airports forms two different market strategies between LCCs. Take the two largest LCCs in Europe Ryanair and easyJet for example. easyJet flies mainly to primary airports in the cities that it serves, while Ryanair often chooses secondary airports to reduce costs. For example, easyJet flies to Paris Charles de Gaulle Airport and Paris Orly, the primary airports in Paris, while Ryanair flies to the smaller Beauvais Airport.

Besides the competition with full-service carrier (FSC) serving the same route, LCC which operates from a secondary airport also compete with that serving a primary airport in adjacent areas. It raises a question which alternative is more attracting to passengers. The entry of LCCs had a stimulating effect in the emergence process which was identified through the observations and study of the regional airport systems.

This chapter explores the issue of the competition between low-cost airlines serving primary and secondary airports in the intra-European market by using econometric estimation of airport choice structure. It contributes to the existing literature on airport choice by focusing competition between primary and secondary airports and studying the impact of LCCs.

The rest of this chapter is organized as follows: Section 5.2 reviews the literature. Section 5.3 provides a discussion on the models applied for estimation. Section 5.4 describes the markets and data. Section 5.5 present coefficient estimates and marginal effects. The last Section provides summary and concluding remarks.

5.2 Literature Review

Barrett (2004) elaborated Ryanair's product and market strategy, such as its low cost base and its use of secondary airports. The emergence of the corporation between LCCs and secondary airports is because of Europe's large supply of underused secondary airports. Passengers are attracted by secondary airports for the benefits of short distances, less congestion and less time waiting for baggage. Bonnefoy et al. (2010) further analyzed the factors influencing the rise of secondary airports and the dynamics of multi-airport systems. The congestion of primary airports, the population distribution at the regional level and the proximity of a secondary basin of population close to secondary airports were identified as major factors. Ground access, airport infrastructure and low proportion of transfer passengers at the primary airport were also found as contributing factors.

Warnock-Smith and Potter (2005) explored the factors affecting airport choice of LCC through survey to eight European LCCs. They showed that airport choice factors contain low airport charges, simple terminals, quick turnarounds, convenient check-in facilities, easy passenger facilities and accessibility. De Neufville (2008) offered a flexible design strategy for secondary airport to adapt to LCCs. He demonstrated that the rise of low-cost airlines stimulates the development of secondary airports and cheaper airport terminals.

From the perspective of passengers, they have to tradeoff between the low fares offered by LCCs and the loss of many of the bundled services provided by FSCs. Humphreys and Francis (2002) found that passengers were willing to travel further to access cheaper flights because they placed more emphasis on accessibility than the airport's current catchment area. Tierney and Kuby (2008) showed that passengers choose smaller, less convenient airport because of cheaper fares, fewer delays, and easier ground transport. The use of less convenient airport often happen with leisure travel, traveling with family, and frequent flyer of LCC.

Dresner (2006) discussed the differences between leisure and business passengers, and their impact on air carriers' choice. The results unexpectedly showed that the two groups of passengers are similar in terms of the reasons for choosing to the departure airport, the parking requirements and the number of bags they checked. These similarities indicated that airline and airport may not be forced to make significant changes of operations to the changing passenger mix.

Loo (2008) analyzed the airport choice of passengers departing from Hong Kong International Airport (HKIA) to 15 destinations in different parts of the world based on stated preference data. The results showed that ticket fare, access time, flight frequency and the number of airlines were the critical airport service attributes. By contrast, access cost, the number of airport access modes, airport shopping area and waiting time at check-in counters were not statistically significant.

As far as we know, there is not yet research on passengers' choice behavior on secondary and primary airport. However, there are many papers dealing with the issue of airport and airline choice model, which we may apply the method in our paper.

Hess and Polak (2005) analyzed airport choice in multi-airport regions. They put focus on comparing different models allowing for random preference variation affects. They found that allowing for random preference variation affects the results of mixed multinomial logit specification. But they did not take the effect of LCC into consideration. Pels et al. (2009) addressed the issue of the competition between full-service and low-cost airlines, and explore three key dimensions of passenger choice: air fare, surface-access costs and frequency. They use the data from adjacent airports in the Greater London. By using a nested logit model with econometric estimation of demand structure, they concluded that low-cost airlines are more competitive.

Ishii et al. (2009) studied how airport and airline supply characteristics affect the customer travel choices. They employed a weighted conditional logit model using survey data of airports in the San Francisco Bay area. They found that non-price characteristics such as access time, frequency, arrival times, delays and airport–airline combinations strongly affect choice of airports. They found that passengers do not separately choose an airline and an airport but rather choose among airline–airport together. They also addressed the competitive effect of entry by low cost carriers, namely "Southwest Effect". Southwest Airline is a LCC which did not provide flight services at the hub airport, which is not as the case of LCC in Europe.

5.3 Model

To measure the effect of LCC on passengers' airport choice, we treat each traveler's air travel options as products that are combined choice of airline and airport, and investigate the driving factors for a particular airport-airline bundle. Passenger p decides a choice of portfolio, $m\{$departure airport i, arrival airport j, airline $k\}$, from a set of alternatives M. According to random utility theory, the probability of individual p choose airport-airline portfolio m can be expressed as

$$P\left(y_p = m\right) = Prob(U_m^p > U_n^p) \quad \text{for } m, n \in (1, M),\ n \neq m$$

$$U_m^p = V_m^p + \varepsilon_m^p$$

where U_m^p is the utility that passenger p is associating with alternative m; V_m^p is the deterministic part of the utility, and ε_m^p is the stochastic part, following Gamble distribution (McFadden).

5.3.1 Conditional logit model

We first estimate a conditional logit model defined over travel choices that are a combination of departure airport, arrival airport and airline. For the conditional logit model, the utility functions are conditioned on observed individual, alternative-invariant characteristics, Z^p, as well as the attributes of the alternatives X^p. The random term ε_m^p are assumed to be independently distributed across the utilities. The deterministic utility of individual p choosing airport-airline portfolio m can be expressed as

$$V_m^p = \beta' X_m^p + \gamma_m' Z^p$$

where V_m^p is the deterministic part of the utility, X_m^p contains attributes of the alternative-specific variables for portfolio m and passenger p, and β contains the coefficients of the alternative-specific variables. Z^p is made up of individual-specific variables for passenger p, and γ_m are coefficients for the effects on portfolio m. Thus the selection probability of airport-airline portfolio m is

$$P(y_p = m) = \frac{exp(\beta' X_m^p + \gamma_m' Z^p)}{\sum_{n=1}^{M} exp(\beta' X_n^p + \gamma_n' Z^p)}$$

In this model, the alternative attributes are characterized by dummy variables for airports and airlines, and air travel cost and flight frequency. The individual-specific variables are selected as trip purpose, age group and income group.

$$\begin{aligned} V_{i,j,k}^p &= \beta' X_m^p + \gamma_m' Z^p \\ &= \sum_{i=I-1} \beta_i D_i + \sum_{j=J-1} \beta_j D_j + \sum_{K=K-1} \beta_k D_k + \beta_1 freq_{i,j,k} \\ &\quad + \beta_2 fare_{i,j,k}^p + \gamma_{1m} purp^p + \gamma_{2m} agegroup^p + \gamma_{3m} incgroup^p \end{aligned} \tag{5.1}$$

where $fare_{i,j,k}^p$ is passenger's air ticket price by airline k from airport i to airport j, $freq_{i,j,k}$ is the flight frequency of k^{th} airline from airport i to airport j using a log transformation; $purp^p$ demonstrates the type of passenger in terms of travel purpose; $agegroup^p$ and $incgroup^p$ are respectively the age group and income group of household that the passenger belongs to.

Flight frequency is measured as the average number of flights per week per airline–airport combination. Flight frequency can be considered a desirable service quality. Higher frequency provides travelers more departure time options.

The departure airport dummies reflect residual preferences for a given airport. The arrival airport dummies are included to account for different end destinations. We include airline dummies to capture residual preferences for a given airline, beyond its fare and frequency. We expect airline dummies to matter more for airlines with desirable frequent flyer rewards.

5.3.2 Nested logit model

We may assume passenger choose airport-airline portfolio with order consideration. The decision order can either be choosing airlines at a given airport or choosing destination airports at a given airline. While heightened correlation is generally expected between the different airline options at a given airport (Hess and Polak, 2006), there is potentially a need to nest by origin airport, destination airport or airline.

The nested logit model is based on the assumption that some of the alternatives share common components in their random error terms. Thus, the random term of the nested alternatives can be decomposed into a portion associated with each alternative and a portion associated with groups of alternatives. The deterministic utility of individual p is made up of alternative-specific attributes X^p, which can be expressed as

$$V_m^p = V_{j,k}^p = \beta' X_{j,k}^p + \alpha' W_j$$

where V_m^p is the utility of combined choice of airport and airline, $X_{j,k}$ contain attributes of the alternative-specific variables (bottom level), and W_j are covariates that are attributes of the choice sets (top level).

The choice probability under the assumption of the nested logit model is defined to be the conditional probability of alternative in branch. In our model, $P(k|j)$ denotes the conditional probability that a passenger chooses airline k under airport branch j, and is a function of alternative-specific variables as

$$P(k|j) = \frac{exp\left(\beta' X_{j,k}\right)}{\Sigma_{n=1}^{N_j} exp\left[\mu\left(\beta' X_{j,n}\right)\right]}$$

Thus, the choice probability of a certain airport-airline portfolio m is

$$P\left(y_p = m\right) = P(j,k) = P(k|j) \cdot P(j)$$

where the probability of branch j is

$$P(j) = \frac{exp\left(\alpha' W_j + \tau_j IV_j\right)}{\Sigma_{l=1}^{L} exp\left(\alpha' W_j + \tau_j IV_l\right)}$$

where IV_j referred as inclusive value equals

$$IV_j = log\left(\sum\nolimits_{n=1}^{N_j} exp\left(\beta' X_{j,n}\right)\right)$$

A three-level structure can be used, discarding one of the three possible nesting levels. This leads to six possible tree structures, when one notes that a tree structure with airport above airline is not equivalent to a tree structure with airline above airport. The use of each of these six three-level structures was attempted, however, none of them led to satisfactory results. This suggests that a multi-level structure is not applicable with the current data and specification of alternatives. Thus, we are restricted to two-level structures, where the interest now lies in a comparison of the performance of two possible structures, i.e., nesting either by original airport, or destination airport. We specify the two cases as (Figure 5.1 and 5.2): (1) first choosing departure airport, and then choosing a combination of arrival airport and carrier; (2) first choosing arrival airport, and then choosing a combination of departure airport and carrier. The more specified nesting structures with respect to each market are shown in Appendix A.5.1.

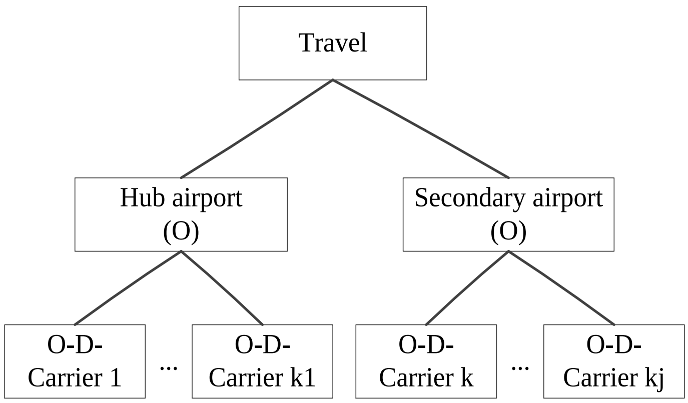


Figure 5.1 Nesting structure: case 1

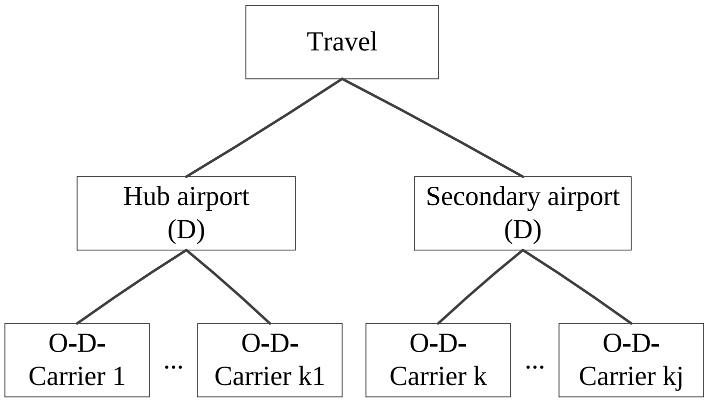


Figure 5.2 Nesting structure: case 2

5.4 Data

We select four European service routes from the airports of London for analysis, namely London-Paris, London-Rome, London-Barcelona and London-Frankfurt. Each destination city is served by both hub airport and competing secondary airport. The four pairs of hub airport and secondary airport, respectively, are Paris Charles de Gaulle (CDG) and Paris Orly (ORY), Rome Fiumicino (FCO) and Rome Ciampino (CIA), Barcelona-El Prat (BCN) and Reus (REU), Frankfurt am Main (FRA) and Frankfurt Hahn (HHN).

London is served by five airports, respectively are London Heathrow airport (LHR), London Gatwick airport (LGW), London City airport (LCY), London Luton airport (LTN) and London Stansted airport (STN).

The data used for analysis were collected from the International Passenger Survey (IPS) by Office for National Statistics of United Kingdom (UK) in 2011. Survey data were collected via face to face interviews with passengers passing through ports and on routes into and out of the UK. The sample period runs from January 2011 up to December 2011. The strength of IPS data lies in the rigorous sampling and weighting methodology. Respondents are systematically chosen for interview at fixed intervals on a given day and within a given period of the day (referred to as a ‘shift’). Passengers indicate information of journey including the carrier and the fare paid. The IPS data also contains individual characteristics, such as gender, age group, travel purpose, county of residence or stay and income group of household.

Information on flight frequencies and number of seats offered by airlines was obtained from OAG Schedules Analyser. The frequency used is the average monthly frequency of the airline on each O-D pair.

Tables 5.1 to 5.4 summarize passengers' choice of Origin airport-Destination airport-Carrier (O-D-C) in the London-Paris, London-Rome, London-Barcelona and London-Frankfurt market during 2011. In the London-Paris market, the top three airlines are easyJet (U2), Air France (AF) and British Airways (BA). Facing competition from Eurostar, however, airlines are continuing to lose market share on routes from London to Paris. Ryanair (FR) dropped the flight schedule to Paris Beauvais airport. London-Rome and London-Barcelona are two service routes that operated by Ryanair (FR), easyJet (U2) and British Airways (BA) in 2011.

Table 5.1 Passengers per alternative by trip purpose (London-Paris)

O-D-C Alternative	All	Leisure	Business
LHR-CDG-BA	521 (22.71%)	431 (18.79%)	90 (3.92%)
LHR-CDG-AF	909 (39.63%)	757 (33.00%)	152 (6.63%)
LHR-ORY-BA	69 (3.01%)	58 (2.53%)	11 (0.48%)
LTN-CDG-U2	690 (30.08%)	626 (27.29%)	64 (2.79%)
LCY-ORY-AF	105 (4.58%)	87 (3.79%)	18 (0.78%)
Total	2294 (100.00%)	1,959 (85.40%)	335 (14.60%)

Notes: percentages in brackets
BA= British Airways, AF=Air France, U2=easyJet;
CDG=Paris Charles de Gaulle airport, ORY= Paris Orly airport;
LHR=London Heathrow airport, LCY= London City airport, LTN= London Luton airport.

Table 5.2 Passengers per alternative by trip purpose (London-Frankfurt)

O-D-C Alternative	All	Leisure	Business
LHR-FRA-BA	464 (23.02%)	345 (17.11%)	119 (5.90%)
LHR-FRA-LH	1093 (54.22%)	833 (41.32%)	260 (12.90%)
LGW-FRA-LH	15 (0.74%)	12 (0.60%)	3 (0.15%)
LCY-FRA-BA	63 (3.13%)	51 (2.53%)	12 (0.60%)
LCY-FRA-LH	96 (4.76%)	80 (3.97%)	16 (0.79%)
STN-HHN-FR	285 (14.14%)	275 (13.64%)	10 (0.50%)
Total	2016 (100.00%)	1,596 (79.17%)	420 (20.83%)

Notes: percentages in brackets
BA= British Airways, LH=Lufthansa, FR=Ryanair;
FRA= Frankfurt am Main airport, HHN= Frankfurt Hahn airport;
LHR= London Heathrow airport, LGW= London Gatwick airport, LCY= London City airport, STN= London Stansted airport.

Table 5.3 Passengers per alternative by trip purpose (London-Rome)

O-D-C Alternative	All	Leisure	Business
LHR-FCO-BA	442 (23.25%)	399 (20.99%)	43 (2.26%)
LHR-FCO-AZ	656 (34.51%)	586 (30.83%)	70 (3.68%)
LGW-FCO-BA	91 (4.79%)	90 (4.73%)	1 (0.05%)
LGW-FCO-U2	205 (10.78%)	199 (10.47%)	6 (0.32%)
LGW-CIA-FR	76 (4.00%)	76 (4.00%)	0 (0.00%)
STN-CIA-FR	431 (22.67%)	422 (22.20%)	9 (0.47%)
Total	1901 (100.00%)	1,772 (93.21%)	129 (6.79%)

Notes: percentages in brackets
BA= British Airways, AZ= Alitalia, U2= easyJet, FR=Ryanair;
FCO= Rome Fiumicino airport, CIA= Rome Ciampino airport;
LHR= London Heathrow airport, LGW= London Gatwick airport, STN= London Stansted airport.

Table 5.4 Passengers per alternative by trip purpose (London-Barcelona)

O-D-C Alternative	All	Leisure	Business
LHR -BCN-BA	1,154 (46.99%)	1,032 (42.02%)	122 (4.97%)
LGW-BCN-U2	420 (17.10%)	398 (16.21%)	22 (0.90%)
LCY -BCN-FR	32 (1.30%)	27 (1.10%)	5 (0.20%)
LTN -BCN-U2	488 (19.87%)	448 (18.24%)	40 (1.63%)
STN -BCN-U2	230 (9.36%)	217 (8.84%)	13 (0.53%)
STN -BCN-FR	16 (0.65%)	16 (0.65%)	(0.00%)
LTN -REU -FR	68 (2.77%)	67 (2.73%)	1 (0.04%)
STN -REU -FR	48 (1.95%)	46 (1.87%)	2 (0.08%)
Total	2,456 (100.00%)	2,251 (91.65%)	205 (8.35%)

Notes: percentages in brackets
BA= British Airways, U2=easyJet, FR=Ryanair;
BCN= Barcelona-El Prat airport, REU= Reus airport;
LHR= London Heathrow airport, LGW= London Gatwick airport, LCY= London City airport, LTN= London Luton airport, STN= London Stansted airport.

Tables 5.5 to 5.8 provide definitions and summary statistics for the explanatory variables, separately for business and leisure travelers.

Table 5.5 Descriptive statistics by trip purpose (London-Paris)

Variable	Description	Leisure					Business				
		Obs.	Mean	Std. dev.	Min	Max	Obs.	Mean	Std. dev.	Min	Max
$D_k, k=BA$	1 if airline is BA	1959	0.250	0.433	0	1	335	0.301	0.460	0	1
$D_k, k=AF$	1 if airline is AF	1959	0.431	0.495	0	1	335	0.507	0.501	0	1
$D_k, k=U2$	1 if airline is U2	1959	0.320	0.466	0	1	335	0.191	0.394	0	1
$D_j, j=CDG$	1 if departure airport is CDG	1959	0.926	0.262	0	1	335	0.913	0.282	0	1
$D_i, i=LHR$	1 if arrival airport is LHR	1959	0.636	0.481	0	1	335	0.755	0.431	0	1
$D_i, i=LCY$	1 if arrival airport is LCY	1959	0.044	0.206	0	1	335	0.054	0.226	0	1
$D_i, i=LTN$	1 if arrival airport is LTN	1959	0.320	0.466	0	1	335	0.191	0.394	0	1
freq	Number of flights per month	1959	177.826	74.529	38	258	335	198.194	66.875	71	258
fare	Average air ticket price per month	1959	121.726	151.762	13	4500	335	204.788	272.163	30	2250
agegroup	Age group in category	571	4.368	1.805	1	8	335	5.158	1.229	1	8
incgroup	Income group in category	99	4.141	1.959	1	7	88	5.307	1.564	1	7

Notes: BA= British Airways, AF= Air France, U2= easyJet; CDG=Paris Charles de Gaulle airport;
LHR= London Heathrow airport, LCY= London City airport, LTN= London Luton airport.

Table 5.6 Descriptive statistics by trip purpose (London-Frankfurt)

Variable	Description	Leisure					Business				
		Obs.	Mean	Std. dev.	Min	Max	Obs.	Mean	Std. dev.	Min	Max
D_k,k=*BA*	1 if airline is BA	1596	0.248	0.432	0	1	420	0.312	0.464	0	1
D_k,k=*LH*	1 if airline is LH	1596	0.580	0.494	0	1	420	0.664	0.473	0	1
D_k,k=*FR*	1 if airline is FR	1596	0.172	0.378	0	1	420	0.024	0.153	0	1
D_j,j=*FRA*	1 if departure airport is FRA	1596	0.828	0.378	0	1	420	0.976	0.153	0	1
D_i,i=*LHR*	1 if arrival airport is LHR	1596	0.738	0.440	0	1	420	0.902	0.297	0	1
D_i,i=*LGW*	1 if arrival airport is LGW	1596	0.008	0.086	0	1	420	0.007	0.084	0	1
D_i,i=*LCY*	1 if arrival airport is LCY	1596	0.082	0.275	0	1	420	0.067	0.250	0	1
D_i,i=*STN*	1 if arrival airport is STN	1596	0.172	0.378	0	1	420	0.024	0.153	0	1
freq	Number of flights per month	1596	233.046	108.262	4	351	420	264.607	83.606	54	351
fare	Average air ticket price per month	1596	114.507	100.384	8	708	420	213.933	261.269	11	2500
agegroup	Age group in category	409	4.377	1.834	1	8	418	5.091	0.992	1	8
incgroup	Income group in category	128	4.344	1.614	1	7	117	5.205	1.557	1	7

Notes: BA= British Airways, LH=Lufthansa, FR=Ryanair; FRA= Frankfurt am Main airport;
LHR= London Heathrow airport, LGW= London Gatwick airport, LCY= London City airport, STN= London Stansted airport.

Table 5.7 Descriptive statistics by trip purpose (London-Rome)

Variable	Description	Leisure					Business				
		Obs.	Mean	Std. dev.	Min	Max	Obs.	Mean	Std. dev.	Min	Max
$D_k, k=BA$	1 if airline is BA	1772	0.276	0.447	0	1	129	0.341	0.476	0	1
$D_k, k=AZ$	1 if airline is AZ	1772	0.331	0.471	0	1	129	0.543	0.500	0	1
$D_k, k=U2$	1 if airline is U2	1772	0.112	0.316	0	1	129	0.047	0.211	0	1
$D_k, k=FR$	1 if airline is FR	1772	0.281	0.450	0	1	129	0.070	0.256	0	1
$D_j, j=FCO$	1 if departure airport is FCO	1772	0.719	0.450	0	1	129	0.930	0.256	0	1
$D_i, i=LHR$	1 if arrival airport is LHR	1772	0.556	0.497	0	1	129	0.876	0.331	0	1
$D_i, i=LGW$	1 if arrival airport is LGW	1772	0.206	0.405	0	1	129	0.054	0.227	0	1
$D_i, i=STN$	1 if arrival airport is STN	1772	0.238	0.426	0	1	129	0.070	0.256	0	1
freq	Number of flights per month	1772	127.382	44.095	28	186	129	150.798	26.630	60	186
fare	Average air ticket price per month	1772	89.391	43.840	23	500	129	165.566	115.491	32	1250
agegroup	Age group in category	547	4.907	1.859	1	8	129	4.915	1.541	1	8
incgroup	Income group in category	112	3.938	1.699	1	7	41	4.585	1.673	1	7

Notes: BA= British Airways, AZ= Alitalia, U2= easyJet, FR=Ryanair; FCO= Rome Fiumicino airport;
LHR= London Heathrow airport, LGW= London Gatwick airport, STN= London Stansted airport.

Table 5.8 Descriptive statistics by trip purpose (London-Barcelona)

Variable	Description	Leisure					Business				
		Obs.	Mean	Std. dev.	Min	Max	Obs.	Mean	Std. dev.	Min	Max
$D_k, k=BA$	1 if airline is BA	2251	0.470	0.499	0	1	205	0.620	0.487	0	1
$D_k, k=U2$	1 if airline is U2	2251	0.472	0.499	0	1	205	0.366	0.483	0	1
$D_k, k=FR$	1 if airline is FR	2251	0.057	0.232	0	1	205	0.015	0.120	0	1
$D_j, j=BCN$	1 if departure airport is BCN	2251	0.950	0.218	0	1	205	0.985	0.120	0	1
$D_i, i=LHR$	1 if arrival airport is LHR	2251	0.458	0.498	0	1	205	0.595	0.492	0	1
$D_i, i=LGW$	1 if arrival airport is LGW	2251	0.177	0.382	0	1	205	0.107	0.310	0	1
$D_i, i=LCY$	1 if arrival airport is LCY	2251	0.012	0.109	0	1	205	0.024	0.155	0	1
$D_i, i=LTN$	1 if arrival airport is LTN	2251	0.229	0.420	0	1	205	0.200	0.401	0	1
$D_i, i=STN$	1 if arrival airport is STN	2251	0.124	0.330	0	1	205	0.073	0.261	0	1
freq	Number of flights per month	2251	152.527	84.814	3	248	205	169.005	82.578	17	248
fare	Average air ticket price per month	2251	81.191	36.796	9	682	205	127.683	47.107	34	340
agegroup	Age group in category	714	4.896	1.765	1	8	205	5.015	1.135	1	7
incgroup	Income group in category	107	4.402	1.758	1	7	57	5.018	1.506	2	7

Notes: BA= British Airways, U2=easyJet, FR=Ryanair; BCN= Barcelona-El Prat airport;
LHR= London Heathrow airport, LGW= London Gatwick airport, LCY= London City airport, LTN= London Luton airport, STN= London Stansted airport.

5.5 Results

The results of Nested Logit model are presented in Appendix A.5.2. The dissimilarity parameters in the results reject the nesting structure, which implies passengers make a combined decision of airport and airline. Here we only discuss the estimation results of conditional logit models.

5.5.1 Basic model

Tables 5.9 to 5.12 show the coefficient estimates and t-statistics of the conditional logit models, as specified in Eq.(5.1), for business and leisure passengers separately. The choice set is more likely to be common among travelers of similar trip type, as leisure travelers are more likely to buy their tickets in advance and business on short notice.

The estimation results of choice between CDG and Orly airport are shown in Table 5.9, separately for business and leisure passengers. The coefficients of fare are statistically significant for both trip purposes in conditional logit model. But frequency is not significant in the London-Paris market.

Table 5.9 Estimates of influencing factors on choice of Paris airports

	All	Leisure	Business
$freq$	0.001	-0.001	0.005
	(0.57)	(-0.19)	(1.16)
$fare$	0.001	-0.002***	0.003***
	(0.89)	(-3.41)	(4.21)
(Base=AF)			
$D_k, k=BA$	-0.508***	-0.680***	-0.108
	(-8.31)	(-9.24)	(-0.71)
$D_k, k=U2$	-0.057	-0.490	0.618
	(-0.18)	(-1.38)	(0.79)
$D_j, j=CDG$	1.955***	2.276***	1.116
	(7.97)	(8.38)	(1.84)
observation	1959	2294	335
log-likelihood	-3008.081	-2555.355	-418.396
LR chi2(X)	1367.94	1195.07	241.53
pseudo R2	0.185	0.190	0.224

Note: t-statistics in parentheses.

∗∗∗ Significant at the 1% level, ∗∗at the 5% level, ∗ at the 10% level.

The qualitative interpretation of the estimation results is the same for both models. Our findings in terms of the signs of fare, and frequency are both in line with intuition and results of previous transport mode choice studies.

The estimation results of choice between Frankfurt airports are shown in the Table 5.10. The coefficients of frequency and fare are significant for both trip purposes passenger. The estimates also suggest that business travelers prefer BA more than leisure travelers.

Table 5.10 Estimates of influencing factors on choice of Frankfurt airports

	All	Leisure	Business
$freq$	0.012***	0.013***	0.010***
	(30.79)	(29.16)	(8.97)
$fare$	0.0002	-0.005***	0.011***
	(0.77)	(-7.82)	(5.77)
(Base=LH)			
D_k,k=BA	0.497***	0.446***	0.759***
	(7.22)	(5.78)	(4.74)
D_j,j=$Dapt$	1.604***	1.642***	0.498
	(14.99)	(14.43)	(1.25)
observation	2016	1596	420
log-likelihood	-2498.809	-1994.172	-387.291
LR chi2(X)	2226.76	1730.95	730.50
pseudo R2	0.308	0.303	0.485

Note: t-statistics in parentheses.
∗∗∗ Significant at the 1% level, ∗∗at the 5% level, ∗ at the 10% level.

Table 5.11 shows the estimation results of choice between Rome airports. The estimated airport dummies indicate that, the surveyed travelers have particular airport preferences. FCO is the preferred arrival airport. Passenger has no significant preference on departure airport. The estimates of the airline dummies show different patterns between FSC and LCC. The results shows that business and leisure travelers disagree on the degree to the choice of LCC. The dummy for U2 is statistically significant for leisure passengers.

Table 5.11 Estimates of influencing factors on choice of Rome airports

	All	Leisure	Business
$freq$	0.023^{***}	0.029^{***}	0.023^{**}
	(5.28)	(6.52)	(2.91)
$fare$	-0.0005	-0.010^{***}	0.049^{***}
	(-0.49)	(-6.96)	(6.90)
(Base=AZ)			
$D_k, k=BA$	-1.031^{***}	-1.216^{***}	-1.575^{***}
	(-7.56)	(-8.31)	(-4.51)
$D_k, k=U2$	-1.401^{***}	-2.248^{***}	0.881
	(-3.74)	(-5.54)	(1.29)
$D_j, j=FCO$	0.710^{***}	1.099^{***}	1.703^{*}
	(4.10)	(6.04)	(2.29)
$D_i, i=LGW$	1.288^{*}	2.109^{***}	
	(2.33)	(3.60)	
$D_i, i=STN$	1.553^{***}	1.903^{***}	
	(4.92)	(5.78)	
observation	1901	1772	129
log-likelihood	-2944.984	-2746.997	-81.202
LR chi2(X)	922.30	856.00	299.87
pseudo R2	0.135	0.135	0.649

Note: t-statistics in parentheses.

∗∗∗ Significant at the 1% level, ∗∗at the 5% level, ∗ at the 10% level.

The estimation results of choice between Barcelona airports are shown in Table 5.12. Frequency is positive and statistically significant to both leisure and business passenger. Fare is negative to leisure passenger but positive to business passenger. This indicates business passengers would like to pay more for the service of a FSC. The estimated airport dummies indicate that the surveyed passengers have residual airport preferences. LTN is the preferred departure airport and BCN the preferred arrival airport, controlling for included airport characteristics. Besides, easyJet Airline (U2) has a competition advantage compared with Ryanair (FR).

Table 5.12 Estimates of influencing factors on choice of Barcelona airports

	All	Leisure	Business
$freq$	0.012***	0.013***	0.008***
	(25.37)	(25.31)	(3.38)
$fare$	0.003**	-0.004**	0.071***
	(3.00)	(-2.92)	(10.04)
(Base=FR)			
D_k,k=$U2$	2.139***	2.459***	0.778
	(8.21)	(9.30)	(1.17)
D_i,i=LTN	1.015***	0.949***	2.199***
	(15.70)	(14.16)	(6.53)
observation	2456	2251	205
log-likelihood	-3637.770	-3372.361	-133.086
LR chi2(X)	2938.68	2616.92	586.40
pseudo R2	0.288	0.280	0.688

Note: t-statistics in parentheses.

$***$ Significant at the 1% level, $**$at the 5% level, $*$ at the 10% level.

5.5.2 Individual-specific model

We further analyze the effects of income group, age group on airport-airline choice through individual-specific model. The magnitude of the individual-specific model is different from the basic model. The sample size is reduced because that a relatively large number of passengers did not indicate their personal information such as age and income group, and these observations are therefore excluded from the analysis.

Tables 5.13-5.16 show the estimation results of individual factors for a specification identical to the one estimated with the conditional logit model. Table 5.13 illustrates the effect of individual attributes in London-Paris aviation market. Airline easyJet is undesirable to passengers aged 35 or more and leisure passenger with income larger than £24,000.

Table 5.13 Estimates of individual factors on choice of Paris airports

	Age group		Income group	
(Base=AF)	Leisure	Business	Leisure	Business
$freq$	-0.008	0.006	-0.019	0.008
	(-1.92)	(1.18)	(-1.42)	(0.80)
$fare$	-0.00004	0.00352***	-0.030***	0.0003
	(-0.10)	(4.26)	(-5.17)	(0.11)
D_k: k=BA	-0.987***	-0.101	-1.778***	-0.639*
	(-7.21)	(-0.66)	(-4.69)	(-2.32)
D_k: k=U2	-1.022	1.320	-3.001	1.294
	(-1.47)	(1.62)	(-1.38)	(0.63)
D_j: j=CDG	3.195***	1.095	7.269***	1.692
	(5.84)	(1.80)	(3.57)	(1.40)
U2_agegroup (35-54)	-0.844***	-0.916**		
	(-4.15)	(-3.03)		
U2_agegroup (55+)	-0.906**	-1.339*		
	(-3.19)	(-2.30)		
fare_inc			364.900***	37.370
			(4.31)	(0.52)
U2_incgroup (£24,000-£71,999)			-2.607**	-1.176
			(-3.05)	(-0.81)
U2_incgroup (£72,000+)			-3.899***	-2.143
			(-3.75)	(-1.39)
observation	571	335	99	88
log-likelihood	-695.246	-412.864	-88.982	-96.554
LR chi2(X)	447.49	252.60	140.71	90.15
pseudo R2	0.2435	0.234	0.442	0.318

Note: t-statistics in parentheses.

∗∗∗ Significant at the 1% level, ∗∗at the 5% level, ∗ at the 10% level.

Table 5.14 illustrates the effect of individual attributes in London-Frankfurt aviation market. Ryanair is favorable to young leisure passengers under 35. BA is the favorable choice for leisure passenger with income small than £24,000.

Table 5.14 Estimates of individual factors on choice of Frankfurt airports

	Age group		Income group	
(Base=LH)	Leisure	Business	Leisure	Business
$freq$	0.018***	0.009***	0.021***	0.015***
	(12.17)	(8.86)	(6.23)	(4.74)
$fare$	-0.003**	0.011***	-0.006*	0.010*
	(-2.80)	(5.84)	(-2.47)	(2.05)
$D_k, k=BA$	0.911***	0.751***	0.838	0.521
	(3.96)	(4.68)	(1.64)	(1.14)
$D_k, k=FR$	3.034***	0.688	3.776***	1.249
	(7.40)	(1.66)	(4.35)	(1.17)
FR_ agegroup (0-34)	0.724**	-1.092		
	(3.02)	(-1.03)		
BA_incgroup (£0- £23,999)			1.470**	-13.28
			(2.66)	(-0.01)
observation	409	418	128	117
log-likelihood	-437.552	-384.180	-119.674	-69.259
LR chi2(X)	590.56	729.55	219.34	280.75
pseudo R2	0.403	0.487	0.478	0.670

Note: t-statistics in parentheses.

$***$ Significant at the 1% level, $**$at the 5% level, $*$ at the 10% level.

Table 5.15 illustrates the effect of individual attributes in London-Rome aviation market. For passengers aged between 35 and 54, BA is the favorable choice to business passenger while Ryanair is undesirable to leisure passenger.

Table 5.15 Estimates of individual factors on choice of Rome airports

	Age group		Income group	
(Base=LH)	Leisure	Business	Leisure	Business
$freq$	0.0311***	-0.0130	0.0466***	0.0577
	(3.66)	(-0.66)	(4.19)	(1.70)
$fare$	-0.0108***	0.0497***	-0.0221**	0.0601***
	(-4.46)	(6.81)	(-3.08)	(3.30)
(Base=AZ)				
D_k,k=BA	-1.409***	-1.516*	-2.652***	-2.006
	(-5.07)	(-2.13)	(-5.82)	(-1.69)
D_k,k=$U2$	-2.513**	3.250*	-1.248	3.080
	(-3.28)	(2.03)	(-1.59)	(1.57)
D_j,j=FCO	1.285***	0.302	2.254**	4.474
	(3.47)	(0.25)	(2.41)	(0.00)
D_i,i=LGW	2.271*	-4.188		
	(2.04)	(-1.79)		
D_i,i=STN	2.441***			
	(3.80)			
FR_agegroup (35-54)	-0.601**			
	(-3.02)			
BA_agegroup (35-54)		1.542**		
		(2.67)		
BA_incgroup (£24,000-£71,999)			-1.085**	-4.393
			(-2.32)	(-1.12)
observation	547	129	672	246
log-likelihood	-808.990	-75.351	-124.685	-20.921
LR chi2(X)	342.21	311.57	151.98	105.08
pseudo R2	0.175	0.674	0.379	0.715

Note: t-statistics in parentheses.

∗∗∗ Significant at the 1% level, ∗∗at the 5% level, ∗ at the 10% level.

The estimation results of choice between Barcelona airports are shown in Table 5.16. BA is shown less attractive in the young passenger market.

Table 5.16 Estimates of influencing factors on choice of Barcelona airports

	Age group		Income group	
(Base=FR)	Leisure	Business	Leisure	Business
$freq$	0.012***	0.008***	0.017***	0.005
	(14.10)	(3.43)	(5.50)	(0.83)
$fare$	-0.009***	0.072***	-0.007	0.141**
	(-3.96)	(9.88)	(-0.98)	(3.08)
D_k,k=BA	1.980***	-0.676	-0.238	-4.899
	(4.46)	(-0.80)	(-0.26)	(-1.85)
D_k,k=$U2$	2.033***	0.643	-0.362	-2.069
	(4.90)	(0.96)	(-0.49)	(-1.35)
D_j,j=BCN	-0.960*	-	2.177*	-
	(-2.28)		(2.33)	
D_i,i=LTN	0.859***	2.230***	1.451***	2.562
	(7.62)	(6.55)	(4.02)	(1.96)
BA_agegroup	-0.474**	-1.057*		
(0-34)	(-3.04)	(-2.28)		
BA_incgroup			-1.457*	-2.705
(£0- £23,999)			(-2.53)	(-0.82)
observation	714	205	107	57
log-likelihood	-1128.260	-130.410	-135.295	-15.801
LR chi2(X)	712.92	591.75	174.41	205.45
pseudo R2	0.240	0.694	0.392	0.867

Note: t-statistics in parentheses.

∗∗∗ Significant at the 1% level, ∗∗at the 5% level, ∗ at the 10% level.

5.5.3 Discussions and implications

This subsection uses disaggregate elasticity to represent the responsiveness of an individual's choice probability to a change in the value of some attributes. The simplest case is the elasticity of the probability of an individual choosing alternative i with respect to a change in some attribute that is an independent variable in the model, namely one of the x_{ink}'s. In this case the direct elasticity of logit is given by

$$E_{x_{ink}}^{P_n(i)} = \frac{\partial\, ln\, P_n(i)}{ln\, x_{ink}} = [1 - P_n(i)] \cdot x_{ink} \cdot \beta_k$$

The elasticities of fare and frequency are shown as follows.

Table 5.17 Elasticities of frequency and fare (London-Paris)

	elasticity of frequency		elasticity of fare	
Alternative	Leisure	Business	Leisure	Business
LHR-CDG-BA	-0.071	0.945	-0.145	0.308
LHR-CDG-AF	-0.058	0.687	-0.207	0.466
LHR-ORY-BA	-0.030	0.406	-0.139	0.284
LTN-CDG-U2	-0.021	0.357	-0.055	0.157
LCY-ORY-AF	-0.051	0.717	-0.153	0.315

Table 5.18 Elasticities of frequency and fare (London-Frankfurt)

	elasticity of frequency		elasticity of fare	
Alternative	Leisure	Business	Leisure	Business
LHR-FRA-BA	2.068	1.551	-0.450	1.164
LHR-FRA-LH	1.977	0.813	-0.363	0.632
LGW-FRA-LH	0.122	0.078	-0.087	0.156
LCY-FRA-BA	0.796	0.599	-0.371	0.844
LCY-FRA-LH	1.008	0.767	-0.385	0.960
STN-HHN-FR	0.741	0.659	-0.196	0.511

Table 5.19 Elasticities of frequency and fare (London-Rome)

	elasticity of frequency		elasticity of fare	
Alternative	Leisure	Business	Leisure	Business
LHR-FCO-BA	4.051	3.298	-0.893	5.446
LHR-FCO-AZ	2.927	0.810	-0.760	1.674
LGW-FCO-BA	1.369	1.109	-0.904	4.643
LGW-FCO-U2	2.630	2.333	-0.602	3.350
LGW-CIA-FR	0.736	0.570	-0.552	2.643
STN-CIA-FR	2.056	2.119	-0.445	2.905

Table 5.20 Elasticities of frequency and fare (London-Barcelona)

	elasticity of frequency		elasticity of fare	
Alternative	Leisure	Business	Leisure	Business
LHR -BCN-BA	1.507	0.174	-0.311	1.784
LGW-BCN-U2	1.181	0.430	-0.308	4.231
LCY -BCN-FR	0.261	0.076	-0.394	4.300
LTN -BCN-U2	0.593	0.194	-0.304	3.940
STN -BCN-U2	0.505	0.148	-0.353	4.228
STN -BCN-FR	0.035	0.008	-0.011	0.094
LTN -REU -FR	0.123	0.031	-0.208	1.942
STN -REU -FR	0.123	0.031	-0.243	2.354

5.6 Conclusion

We study travelers' choices of airport–airline bundles for trips from London to major European cities, by estimating conditional logit and nested logit model of airport and airline choice. A first key finding is that consumers do not choose an airline and an airport separately but rather choose among airline–airport combination alternatives. This confirms the finding by Ishii et al. (2009). Moreover, the behavior of passengers' trade off the airline and airport attributes depends on whether they travel for business or leisure purposes. Specifically, business and leisure travelers care about frequency associated with an airport, but different at flight fare.

In the market of London to Paris, both AF and BA offers high frequency flights between hub airports (LHR-CDG). Besides, AF offers low fare flights between secondary airports (LCY-ORY) while BA offer flights between LHR-ORY. These services enable travelers to make tradeoff among binding of desirable airline and airport.

LCCs have more attractiveness and market share in London-Rome and London-Barcelona market. Particularly, in the market of London to Barcelona, both types of travelers appreciate flight frequency and business travelers are not fare elastic, this enables easyJet to charge higher fares than Ryanair.

This chapter studies the joint choice of airline and airport in the multi-airport region. The basic finding is that choice of airline and airport cannot be separated when analyzing the air transport behavior in the European markets. Our empirical results indicate hub airport dominance is highly affected by the entry of low cost carriers.

Chapter 6 Conclusions

This dissertation is motivated from the developments of comprehensive transport networks in China. After years of rapid growth in the transport sectors, transport network has formed a considerable scale in spatial layout. We have addressed four topics on transport network structure regarding this research background with a multi-disciplinary approach.

Chapter 2, for the first topic, presents the PRD port system development and identifies the underlying forces driving the port system evolution. In particular, this research examines the unique process by which the PRD port system went from one gateway port to two and the undergoing regionalization with specialization. The network strategy is stressed in shaping the port system structure. With the advantage of hinterland regionalization, Shenzhen, among gateway ports in PRD, has acquired the market share from Hong Kong. Shenzhen and Guangzhou ports tend from the hinterland-dominated regionalization to a more balanced regionalization on the basis of established inland transport network, while Hong Kong undergoes the foreland regionalization. If the hinterland connection remains relatively weak, Hong Kong port's gateway function will further decline while its transshipment role will further dominate.

Chapter 3, for the second topic, aims to analyze the impact of railway improvement on the airport passenger traffic. Panel data models are applied to estimation using the data of passenger traffic of main airports and rail stations during 1998 to 2009 in China. The empirical results show that the speed acceleration of railway has a substitution effect on the growth of air passenger traffic. However, improvement of rail does not reduce the airport passenger traffic as a whole, which is inconsistent with expectation. The increase of passengers at rail stations has a positive effect to the concentration at hub airports but a negative effect to regional airports. These findings fill in the research gap left over by previous empirical studies of air-rail competition which has focused on mode-based competition and show some policy implications for air transport network.

Chapter 4, for the third topic, aims at comparing different industrial structures of the railway sector, in order to provide some guidance for the China Railway reform. We study the structure reform issue of the railway industry though presenting an economic model primarily characterized by three features: vertical / horizontal separation, cost information asymmetry and strategies to eliminate the asymmetry. We explore major industrial structures regarding the railway governance and operation. Some structures are proved to be dominated by the others. For those not dominated, we setup analytical models and derive the explicit form of optimal solutions. Our major findings with analytical model and numerical study show that: (1) If cost information is symmetric for the regulator, full regulation dominates partial, and vertical integration dominates separation; (2) Facing information asymmetry, though without structural reform, the regulator can apply screening strategy to yield a higher level of social welfare than price-cap; (3) Facing asymmetric information, it is better to adopt soft policies to force the asymmetric information holder, i.e. the Infrastructure and Carrier to tell the truth, rather than taking either vertical or horizontal separation. Besides, if one has to choose between vertical and horizontal separation for the railway industry, picks vertical and matching up with screening strategy would be the best policy.

The last topic, Chapter 5 studies explores the market competition behavior of airport and carrier in multi-airport regions within Europe. It focuses on the effect of growth of LCC on airline competition within Europe and on the emergence of Europe’s secondary airports by using econometric estimation of airport and carrier choice. Recent passenger survey data from UK are used to estimate logit models to capture the key determinants of passenger’s choice. Frequency and flight fare are found to be the main factors affecting passenger’s choice. One basic finding is that airline and airport is a combined choice and neither can be ignored when analyzing the market for air travel in the European markets. LCCs have more attractiveness and market share in London-Rome and London-Barcelona market. It contributes to the existing literature on airport choice by focusing competition between primary and secondary airports and studying the impact of LCCs.

Under the master plan of an integrated transport system, China will further concentrate on developing integrated transport networks with upgraded transport service. This dissertation sheds light on some primary issues and basis study during the development process. Much promising and valuable research can be done in the future based on the study provided in this dissertation, such as competition and development coordination in regional multi-port or multi-airport system, competition and cooperation between rail and air transport network regarding the route level, reforms and regulatory policies in rail /air transport industry, etc., These topics are our next-step research direction.

APPENDIX

A.4 Proof of Chapter 4

A.4.1 Proof of Proposition 4.1

We model the four scenarios in Section 4.4.1 under information symmetric as below.

Scenario 1: Full Regulation with Infrastructure and Carrier integrated

The demand function is given by $q(p) = \theta - p$, where θ is the maximum price that consumer is willing to pay, p is the market price and q is the total demand. Here we adopt the simplified form as Lang et al. (2013). Thus the consumer surplus is

$$CS = \int_{p}^{\theta} (\theta - x)dx = \frac{(\theta - p)^2}{2} = \frac{q^2}{2}$$

It can be observed that the consumer surplus is affected by the market price p, while the market price is influenced by output q.

The profit function of the integrated Infrastructure and Carrier is:

$$\pi_{IK} = (p - c_{IK})q(p) + T = -q^2 + (\theta - c_{IK})q + T$$

Observing the actual costs of the Infrastructure and Carrier, the Regulator has an objective function as:

$$\underset{T,q}{\text{Max}}\ W = CS + \pi_{IK} - (1 + \lambda)T$$

$$s.t. \pi_{IK} \geq 0$$

It means that the Regulator will require the integrated Infrastructure and Carrier to make output adapt to the transfer payments. Regulator, in order to maximize the total social welfare, will try to maximize $CS + \pi_{IK}$, which is a quadratic function of q, and reduce T until $\pi_{IK} = 0$. Hence, the expression of social welfare can be simplified as:

$$W = -\left(\frac{1}{2} + \lambda\right) q^2 + (1 + \lambda)(\theta - c_{IK})q$$

We obtain the optimal output from the first order condition $q^* = \frac{1+\lambda}{1+2\lambda}(\theta - c_{IK})$. Thus, the optimal price is $p^* = \frac{(1+\lambda)c_{IK}+\lambda\theta}{1+2\lambda}$. The optimal transfer payment is $T^* = -\frac{\lambda(1+\lambda)}{(1+2\lambda)^2}(\theta - c_{IK})^2$. This negative value of transfer payment means that the Regulator squeezes profit from the Infrastructure and Carrier. The total social welfare is $W^* = \frac{(1+\lambda)^2}{2(1+2\lambda)}(\theta - c_{IK})^2$.

Scenario 2: Partial Regulation with Infrastructure and Carrier integrated

The objective function of integrated Infrastructure and Carrier is

$$\underset{q}{Max}\,\pi_{IK} = (\theta - q - c_{IK})q + T$$

As q is decided when T is given, we shall firstly optimize q. Then the optimal output is $q^* = \frac{\theta - c_{IK}}{2}$. The corresponding optimal market price is $p^* = \frac{\theta + c_{IK}}{2}$. The objective function of Regulator is

$$\underset{T}{Max}\,W = CS + \pi_{IK}(q^*) - (1+\lambda)T$$

$$s.t. \pi_{IK} \geq 0$$

Since CS and π_{IK} is constant, to maximize the social welfare, the Regulator will choose a minimum T while satisfying the constraint. Substituting the optimal decision $q^* = \frac{\theta - c_{IK}}{2}$ into the constraint we have $\pi_{IK} = (\theta - q^* - c_{IK})q^* + T$. The Regulator has incentive to let π_{IK} equal 0. Then we have $T^* = -\frac{(\theta - c_{IK})^2}{4}$. And therefore, the social welfare is $W^* = \frac{3+2\lambda}{8}(\theta - c_{IK})^2$.

Compared with Scenario 1, the optimal output q^* here is roughly half of that in Scenario 1. The Regulator successfully squeezes profit from the Infrastructure and Carrier. Regarding the social welfare, it is easy to prove that Scenario 1 dominates Scenario 2.

Scenario 3: Full Regulation with Infrastructure and Carrier separated

In this scenario, the Regulator will also arrange the Infrastructure's access charge a, and the i^{th} Carrier decides the output q_i. With separating, assume that the number of Carriers is n, then the i^{th} Carrier's profit function is $\underset{q_i}{\text{Max}}\, \pi_{Ki} = (p - a - c_K)q_i$, where c_K is the operating cost of the Carrier, which is assumed to be the same among different Carriers. The inverse demand function is: $p = \theta - q = \theta - \sum_{i=1}^{n} q_i$. Then the objective function of the i^{th} Carrier is:

$$\pi_{Ki} = \left(\theta - \sum_{i=1}^{n} q_i - a - c_K\right) q_i = -q_i^2 + \left(\theta - \sum_{j=1, j\neq i}^{n} q_j - a - c_K\right) q_i$$

By taking derivative of π_{Ki} w.r.t. q_i, we have the first order condition (FOC) as:

$$-2q_i + \theta - \sum_{j=1, j\neq i}^{n} q_j - a - c_K = 0$$

From the symmetry structure of cost of the Carriers, we have $q_i = q_j$. Therefore, the FOC function can be simplified as $q_i = \frac{\theta - a - c_K}{n+1}$. Then the total output is $q = \frac{n}{n+1}(\theta - a - c_K)$. The total profits of the Carriers are $\sum_{i=1}^{n} \pi_{Ki} = \frac{n}{(n+1)^2}(\theta - a - c_K)^2$.

The profit of the Infrastructure is:

$$\pi_I = (a - c_I)q(p) + T = \frac{n}{n+1}(a - c_I)(\theta - a - c_K) + T$$

where c_I is the operating cost of infrastructure.

The objective function of Regulator is:

$$\underset{T,a}{\text{Max}}\, W = CS + \pi_I + \pi_K - (1 + \lambda)T$$

$$s.t. \pi_I \geq 0$$

Note that $(a - c_I)(\theta - a - c_K)$ is a negative quadratic function of a, with the central axis $a = \frac{\theta - c_I - c_K}{2}$. It happens to be the optimal access charge the infrastructure would choose if there is no regulatory. Then the Regulator will inevitably reduce infrastructure requirements on the basis of this value, then $(a - c_I)(\theta - a - c_K)$ will decrease. Similarly, to maximize the social welfare W, π_I finally will be 0. Then we have $T = -\frac{n}{n+1}(a - c_I)(\theta - a - c_K)$. Substitute T to the welfare function W, we obtain:

$$W = \frac{n(n+2)}{2(n+1)^2}(\theta - a - c_K)^2 + (1+\lambda)\frac{n}{n+1}(a - c_I)(\theta - a - c_K)$$

By taking derivative with respect to a, we have the first order condition, and the second order condition is negative, and then we obtain the optimal access charge $a^* = \frac{[\lambda(n+1)-1](\theta-c_K)+(1+\lambda)(n+1)c_I}{n+2\lambda(n+1)}$. The output for each Carrier is $q_i^* = \frac{(1+\lambda)(\theta-c_K-c_I)}{n+2\lambda(n+1)}$. The optimal total output is $q^* = \frac{n(1+\lambda)(\theta-c_K-c_I)}{n+2\lambda(n+1)}$. The optimal market price is $p^* = \frac{\lambda(n+2)\theta+n(1+\lambda)(c_I+c_K)}{n+2\lambda(n+1)}$. The optimal transfer payment is $T^* = -\frac{n(1+\lambda)[\lambda(n+1)-1]}{[n+2\lambda(n+1)]^2}(\theta - c_K - c_I)^2$. The optimal total profits for the Carriers are $\sum_{i=1}^{n}\pi_{Ki} = \frac{n(1+\lambda)^2(\theta-c_K-c_I)^2}{[n+2\lambda(n+1)]^2}$. The corresponding social welfare is $W^* = \frac{n(1+\lambda)^2}{2[n+2\lambda(n+1)]}(\theta - c_K - c_I)^2$.

Since the vertical integration structure enjoys the economies of scale than the vertical separation, according to the assumption on costs in the model formulation sub-section, we have $c_{IK} \leq c_I + c_K$. Obviously, even if $c_{IK} = c_I + c_K$ the total output q under separation is still lower than the case of integration. It results in a higher market price p, and thus total welfare decreases. Only if $c_{IK} = c_I + c_K$ and Carrier's number n tends to infinity can the total social welfare of the separation case approaches that of integration case.

Scenario 4: Partial Regulation with Infrastructure and Carrier separated

Assume that there are n Carriers after vertical separation. The profit function of the Carrier i is $\underset{q_i}{\text{Max}}\,\pi_{Ki} = (p - a - c_K)q_i$, where c_K is the operating cost of i^{th} Carrier, which is assumed to be the same among different Carriers. The inverse demand function is $p = \theta - q = \theta - \sum_{i=1}^{n} q_i$. Thus the objective function of Carrier i can be written as:

$$\pi_{Ki} = \left(\theta - \sum_{i=1}^{n} q_i - a - c_K\right)q_i = -q_i^2 + \left(\theta - \sum_{j=1, j\neq i}^{n} q_j - a - c_K\right)q_i$$

Taking derivative of π_{Ki} w.r.t. q_i, the FOC is:

$$-2q_i + \theta - \sum_{j=1, j\neq i}^{n} q_j - a - c_K = 0$$

From the symmetry structure of cost of the Carriers, we have $q_i = q_j$. Therefore, the above FOC function can be simplified as $q_i = \frac{\theta - a - c_K}{n+1}$. Thus, the total output is $q = \frac{n}{n+1}(\theta - a - c_K)$. The objective function of the Infrastructure is

$$\underset{a}{\text{Max}}\, \pi_I = (a - c_I)q(p) + T$$

where c_I is the operating cost of the Infrastructure. Substituting with q, we obtain

$$\pi_I = \frac{n}{n+1}(\theta - a - c_K)(a - c_I) + T$$

By first order condition, we have the optimal access charge $a^* = \frac{\theta + c_I - c_K}{2}$. We can see the optimal access charge by the Infrastructure is independent of the number of Carriers n. The access charge only change in accordance to the operating costs of the Carriers and the Infrastructure as well as the Consumer's value of service. If the Consumer has a higher willingness to pay, then the Infrastructure will increase the access charge. If the Carrier has a higher operating cost, in order to induce its supply, the Infrastructure will reduce the access charge to share some of the Carrier's cost burden.

Substituting a^* into the expression of q, we obtain the optimal total output of the Carriers $q^* = \frac{n}{2(n+1)}(\theta - c_I - c_K)$. The optimal market price is $p^* = \frac{(n+2)\theta + n(c_I + c_K)}{2(n+1)}$. The optimal transfer payment decision for the Regulator is $T^* = -\frac{n}{n+1}\left(\frac{\theta - c_I - c_K}{2}\right)^2$. Note that the transfer payment is a negative value. The optimal total profits of the Carriers are $\sum_{i=1}^{n} \pi_{Ki} = \frac{n(\theta - c_I - c_K)^2}{4(1+n)^2}$. And the optimal social welfare is $W^* = \frac{n[3n + 2\lambda(n+1) + 4]}{8(n+1)^2}(\theta - c_I - c_K)^2$.

Since the vertical integration structure enjoys economies of scale compared with vertical separation, according to the assumptions on costs we have $c_{IK} \leq c_I + c_K$. Thus, even if $c_{IK} = c_I + c_K$, the total output q under vertical separation is lower than that in the scenario of vertical integration. This results in a higher market price p and higher transfer payment T. It can be proved that the social welfare in Scenario 4 (vertical separation) is smaller than in Case 3 (vertical integration). Only if $c_{IK} = c_I + c_K$ and Carrier's number n tends to infinity can the total social welfare of the separation scenario approaches that of integration scenario. □

A.4.2 Proof of Proposition 4.2

In Scenario 1, we have

$$\frac{dT}{d\lambda} = -\frac{1}{(1+2\lambda)^3}(\theta - c_{IK})^2 \leq 0,\ \frac{dq}{d\lambda} = -\frac{1}{(1+2\lambda)^2}(\theta - c_{IK}) \leq 0,$$

$$\frac{dp}{d\lambda} = \frac{1}{(1+2\lambda)^2}(\theta - c_{IK}) \geq 0,\ \ \frac{dW}{d\lambda} = \frac{\lambda(1+\lambda)}{(1+2\lambda)^2}(\theta - c_{IK})^2 \geq 0.$$

In Scenario 3, we have

$$\frac{dT}{d\lambda} = -\frac{n(n+2)^2}{[n+2\lambda(n+1)]^3}(\theta - c_K - c_I)^2 \leq 0, \frac{da}{d\lambda} = \frac{(n+1)(n+2)(\theta - c_K - c_I)}{[n+2\lambda(n+1)]^2} \geq 0,$$

$$\frac{dq}{d\lambda} = -\frac{n(n+2)}{[n+2\lambda(n+1)]^2}(\theta - c_K - c_I) \leq 0, \frac{dp}{d\lambda} = \frac{n(n+2)}{[n+2\lambda(n+1)]^2}(\theta - c_K - c_I) \geq 0,$$

$$\frac{d\pi_K^*}{d\lambda} = -\frac{2n(n+2)(1+\lambda)}{[n+2\lambda(n+1)]^3}(\theta - c_K - c_I)^2 \leq 0,$$

$$\frac{dW}{d\lambda} = \frac{n(1+\lambda)[\lambda(n+1)-1]}{[n+2\lambda(n+1)]^2}(\theta - c_K - c_I)^2 \geq 0 \ if\ \lambda \geq \frac{1}{n+1},$$

$$\frac{da}{dc_K} = -\frac{(1+n)\lambda - 1}{n+2(1+n)\lambda} \leq 0, \frac{dT}{dn} = -\frac{(1+\lambda)[n+(n-2)\lambda+2(n+1)\lambda^2]}{[n+2\lambda(n+1)]^3}(\theta - c_K - c_I)^2 \leq 0,$$

$$\frac{da}{dn} = \frac{(1+\lambda)(\theta - c_K - c_I)}{[n+2\lambda(n+1)]^2} \geq 0,\ \frac{dq}{dn} = \frac{2\lambda(1+\lambda)}{[n+2\lambda(n+1)]^2}(\theta - c_K - c_I) \geq 0,$$

$$\frac{d\pi_K^*}{dn} = -\frac{(1+\lambda)^2[n-2\lambda(n+1)]}{[n+2\lambda(n+1)]^3}(\theta - c_K - c_I)^2 \leq 0 \ if\ \lambda \leq \frac{n}{2(n+1)},$$

$$\frac{dW}{dn} = \frac{\lambda(1+\lambda)^2}{[n+2\lambda(n+1)]^2}(\theta - c_K - c_I)^2 \geq 0.$$

In Scenario 4, we have $\frac{dW}{dn} = \frac{2+n+\lambda(n+1)}{4(1+n)^3} \geq 0.$ □

A.4.3 Proof of Proposition 4.3

The Regulator's objective function is:

$$\operatorname*{Max}_{q_i,T_i} W = \sum_{i=l,h} \beta_i\left[CS + \pi_{IK}^i - (1+\lambda)T_i\right]$$

where the consumer surplus is $CS = \frac{q_i^2}{2}$. The profit function of the integrated

Infrastructure and Carrier is $\pi_{IK}^{i} = (\theta - q_i - c_l)q_i + T_i$. Hence,

$$\underset{q_i, T_i}{\text{Max}} = \sum_{i=l,h} \beta_i \left[-\frac{q_i^2}{2} + (\theta - c_i)q_i - \lambda T_i \right]$$

Regulators need to meet certain constraints. First need to meet individual rationality constraints, which are to make profit of the integrated Infrastructure and Carrier not less than zero, i.e. $(\theta - q_l - c_l)q_l + T_l \geq 0$ and $(\theta - q_h - c_h)q_h + T_h \geq 0$.

Moreover, it should meet the incentive constraint constraints, which is to ensure that each type of integrated Infrastructure and Carrier chooses according to their own cost type, reported their true cost information, i.e.:

$$(\theta - q_l - c_l)q_l + T_l \geq (\theta - q_h - c_l)q_h + T_h$$

$$(\theta - q_h - c_h)q_h + T_h \geq (\theta - q_l - c_h)q_l + T_l$$

Therefore, the objective function for the Regulator with constraints is:

$$\underset{q_i, T_i}{\text{Max}}\, W = \sum_{i=l,h} \beta_i \left[-\frac{q_i^2}{2} + (\theta - c_i)q_i - \lambda T_i \right] \tag{A.1}$$

$$s.t. \begin{cases} (\theta - q_l - c_l)q_l + T_l \geq 0 & (IR - l) \\ (\theta - q_h - c_h)q_h + T_h \geq 0 & (IR - h) \\ (\theta - q_l - c_l)q_l + T_l \geq (\theta - q_h - c_l)q_h + T_h & (IC - l) \\ (\theta - q_h - c_h)q_h + T_h \geq (\theta - q_l - c_h)q_l + T_l & (IC - h) \end{cases}$$

Next, consider how to simplify the constraints.

(1) Since

$$(\theta - q_l - c_l)q_l + T_l \geq (\theta - q_h - c_l)q_h + T_h \geq (\theta - q_h - c_h)q_h + T_h \geq 0$$

Thus, constraint $(IC - l)$ and $(IR - h)$ ensures $(IR - l)$.

(2) According to the objective function, the Regulator will make T_h as small as possible, q_h as large as possible. In terms of constraint $(IR - h)$, since $(\theta - q_h - c_h)q_h = -q_h^2 + (\theta - c_h)q_h$ is a negative quadratic function of q_h with the central axis is $\frac{\theta - c_h}{2}$, which is the optimal output when integrated Infrastructure and Carrier makes single decision.

Because the Regulator has an incentive to increase the output of the integrated Infrastructure and Carrier, it will set a higher q_h than the optimal output by decision of integrated Infrastructure and Carrier. That means $q_h \geq \frac{\theta-c_h}{2}$, thus the increase of q_h will result to the decrease of $-q_h^2+(\theta-c_h)q_h$. Therefore, constraint $(IR-h)$ will eventually have the equal sign.

(3) We will demonstrate that constraint $(IC-l)$ also eventually take the equal sign. From the discussion of (1) and (2), we can easily observe,

$$(\theta-q_l-c_l)q_l+T_l \geq (\theta-q_h-c_l)q_h+T_h \ \geq (\theta-q_h-c_h)q_h+T_h=0$$

For the left part, regulators will eventually make it as small as possible, regardless of how changes in the middle part, and ultimately must be greater than 0, so the first inequality will eventually become equal sign. Therefore constraint $(IC-l)$ eventually takes the equal sign.

(4) The $(IC-h)$ can be introduced from the other conditions.

$$\begin{aligned}(\theta-q_h-c_h)q_h+T_h-[(\theta-q_l-c_h)q_l+T_l]\\ &=(q_l-q_h)(q_l+q_h-\theta+c_h)+T_h-T_l\\ &\geq (q_l-q_h)(q_l+q_h-\theta+c_l)+T_h-T_l\\ &=(\theta-q_h-c_l)q_h+T_h-[(\theta-q_l-c_l)q_l+T_l]=0\end{aligned}$$

To sum up, the objective function (A.1) and constraints of the Regulator can be simplified as:

$$\underset{q_i,T_i}{\text{Max}}\, W=\sum_{i=l,h}\beta_i\left[-\frac{q_i^2}{2}+(\theta-c_i)q_i-\lambda T_i\right] \tag{A.2}$$

$$s.t.\begin{cases}(\theta-q_h-c_h)q_h+T_h=0 & (IR-h)\\ (\theta-q_l-c_l)q_l+T_l=(\theta-q_h-c_l)q_h+T_h & (IC-l)\end{cases}$$

Then we can obtain

$T_h=-(\theta-q_h-c_h)q_h$, $T_l=-(\theta-q_l-c_l)q_l+(c_h-c_l)q_h$

Substitute into the objective function Eq.(A.2), and then obtain the optimal outputs

$q_l^* = \frac{1+\lambda}{1+2\lambda}(\theta - c_l)$, $q_h^* = \frac{1+\lambda}{1+2\lambda}\left[\theta - c_h - \frac{\beta_l}{\beta_h}\frac{\lambda}{1+\lambda}(c_h - c_l)\right]$

The market equilibrium prices are

$p_l^* = \frac{\lambda\theta+(1+\lambda)c_l}{1+2\lambda}$, $p_h^* = \frac{\lambda\theta+(1+\lambda)c_h+\frac{\beta_l}{\beta_h}\lambda(c_h-c_l)}{1+2\lambda}$

And the optimal transfer payments are

$T_l^* = -\frac{\lambda(1+\lambda)}{(1+2\lambda)^2}\left[(\theta - c_h)^2 + (c_h - c_l)^2 - \frac{1}{\lambda}(\theta - c_h)(c_h - c_l) + \frac{\beta_l}{\beta_h}\frac{1+2\lambda}{1+\lambda}(c_h - c_l)^2\right]$,

$T_h^* = -\frac{\lambda(1+\lambda)}{(1+2\lambda)^2}\left[\theta - c_h + \frac{\beta_l}{\beta_h}(c_h - c_l)\right]\left[\theta - c_h - \frac{\beta_l}{\beta_h}\frac{\lambda}{1+\lambda}(c_h - c_l)\right]$ □

A.4.4 Proof of Proposition 4.4

After separation, assume the number of the Carriers is n, the profit function of the Carrier i is $\max\limits_{q_i} \pi_{Ki} = (p - a - c_K)q_i$, where c_K is the operating cost of the Carrier. We assume the Carriers have a same cost c_K. The inverse demand function is $p = \theta - q = \theta - \sum_{i=1}^{n} q_i$. Then the objective function of the Carrier i becomes:

$$\pi_{Ki} = \left(\theta - \sum_{i=1}^{n} q_i - a - c_K\right)q_i = -q_i^2 + \left(\theta - \sum_{j=1, j\neq i}^{n} q_j - a - c_K\right)q_i$$

By taking derivative w.r.t. q_i, the first order condition is obtained as follows:

$$-2q_i + \theta - \sum_{j=1, j\neq i}^{n} q_j - a - c_K = 0$$

As $q_i = q_j$, thus the above equation can be simplified as $q_i = \frac{\theta-a-c_K}{n+1}$. Thus the total output is $q = \frac{n}{n+1}(\theta - a - c_K)$.

Next we consider the Regulator optimize the contract menu (a, T) through Screening. Assume that the Infrastructure's cost has two possible value: high cost $\tilde{c}_h$ with probability β_h, and low cost $\tilde{c}_l$ with probability β_l, with $\beta_h + \beta_l = 1$. If the Regulator does nothing, then the Infrastructure with high cost will announce his own cost c_h, while the Infrastructure with low cost will cheat and also announce cost c_h, in order to get a higher transfer payment, but resulting in a loss of the social welfare. The Regulator will offer contract menu (a_l, T_l) and (a_h, T_h) for the Infrastructure firm. This is a take-it-or-leave-it offer. It means that the transfer payment will be binding with the access charge. In this way, the Infrastructure does not have the right to optimize access charge a, but only can make a take-it-or-leave-it choice. The Regulator is more powerful in deciding the access charge. The objective function of the Regulator is:

$$\underset{a_i,T_i}{\text{Max}}\, W = \sum_{j=l,h} \beta_j \left[CS + \sum_{i=1}^{n} \pi_{Ki}^{j} + \pi_I^j - (1+\lambda)T_j \right]$$

where the consumer surplus is $CS = \frac{(q^j)^2}{2}$. The profit function of the integrated Infrastructure and Carrier is $\sum_{i=1}^{n} \pi_{Ki} = \frac{n}{(n+1)^2}(\theta - a^j - c_K)^2$. And the output is $q^j = \frac{n}{n+1}(\theta - a^j - c_K)$. The profit function of the Infrastructure is:

$$\pi_I^j = \left(a^j - c_I^j\right) q^j + T^j = \left(a^j - c_I^j\right) \frac{n}{n+1} (\theta - a^j - c_K) + T^j$$

The Regulator has to be confined with the individual rationality Conditions, i.e. Infrastructure's profit non-negative:

$$(a_l - \tilde{c}_l) \frac{n}{n+1} (\theta - a_l - c_K) + T_l \geq 0$$

$$(a_h - \tilde{c}_h) \frac{n}{n+1} (\theta - a_h - c_K) + T_h \geq 0$$

In addition, the regulator will have to satisfy the incentive constraint conditions to induct the Infrastructure provider to reveal his private information, i.e.:

$$(a_l - \tilde{c}_l) \frac{n}{n+1} (\theta - a_l - c_K) + T_l \geq (a_h - \tilde{c}_l) \frac{n}{n+1} (\theta - a_h - c_K) + T_h$$

$$(a_h - \tilde{c}_h) \frac{n}{n+1} (\theta - a_h - c_K) + T_h \geq (a_l - \tilde{c}_h) \frac{n}{n+1} (\theta - a_l - c_K) + T_l$$

Then we have the objective function of the Regulator with constraints as:

$$\underset{a_i,T_i}{\text{Max}}\, W = \sum_{j=l,h} \beta_j \left[CS + \sum_{i=1}^{n} \pi_{Ki}^{j} + \pi_I^j - (1+\lambda)T_j \right] \tag{A.3}$$

$$s.t.\begin{cases} (a_l - \tilde{c}_l)\dfrac{n}{n+1}(\theta - a_l - c_K) + T_l \geq 0 & (IR-l) \\ (a_h - \tilde{c}_h)\dfrac{n}{n+1}(\theta - a_h - c_K) + T_h \geq 0 & (IR-h) \\ (a_l - \tilde{c}_l)\dfrac{n}{n+1}(\theta - a_l - c_K) + T_l \geq (a_h - \tilde{c}_l)\dfrac{n}{n+1}(\theta - a_h - c_K) + T_h & (IC-l) \\ (a_h - \tilde{c}_h)\dfrac{n}{n+1}(\theta - a_h - c_K) + T_h \geq (a_l - \tilde{c}_h)\dfrac{n}{n+1}(\theta - a_l - c_K) + T_l & (IC-h) \end{cases}$$

According to the proof similar in China Case, the objective function Eq.(A.3) can be simplified with reduction in the number of constraints as:

$$\underset{a_i,T_i}{\text{Max}}\, W = \sum_{i=l,h} \beta_i \left[CS + \sum_{i=1}^{n} \pi_{Ki}^{j} + \pi_I^j - (1+\lambda)T_j \right] \tag{A.4}$$

$$s.t.\begin{cases} (a_h - \tilde{c}_h)\dfrac{n}{n+1}(\theta - a_h - c_K) + T_h = 0 & (IR-h) \\ (a_l - \tilde{c}_l)\dfrac{n}{n+1}(\theta - a_l - c_K) + T_l = (a_h - \tilde{c}_l)\dfrac{n}{n+1}(\theta - a_h - c_K) + T_l & (IC-l) \end{cases}$$

After eliminating T_l and T_h with the two constraints $(IR-h)$ and $(IC-l)$, we have

$$T_l = -\frac{n}{n+1}[(\tilde{c}_h - \tilde{c}_l)a_h - (a_l - \tilde{c}_l)a_l + (\theta - c_K)(a_l - \tilde{c}_h)]$$

$$T_h = -\frac{n}{n+1}(a_h - \tilde{c}_h)(\theta - a_h - c_K)$$

There are only a_l and a_h decision variables. Take derivative on a_l and a_h respectively, and then we have:

$$a_l^* = \frac{[\lambda(n+1)-1](\theta - c_K) + (1+\lambda)(n+1)\tilde{c}_l}{n+2\lambda(n+1)},\ a_h^* = \frac{[\lambda(n+1)-1](\theta - c_K) + (1+\lambda)(n+1)\tilde{c}_h + \frac{\beta_l}{\beta_h}(\tilde{c}_h - \tilde{c}_l)}{n+2\lambda(n+1)}$$

The optimal outputs for each type of Carriers is

$$q_{il}^* = \frac{(1+\lambda)(\theta - \tilde{c}_l - c_K)}{n+2\lambda(n+1)},\ q_{ih}^* = \frac{(1+\lambda)(\theta - \tilde{c}_h - c_K) - \frac{\beta_l}{\beta_h}\frac{\tilde{c}_h - \tilde{c}_l}{n+1}}{n+2\lambda(n+1)}$$

Then we have the optimal total outputs

$q_l^* = \frac{n(1+\lambda)(\theta-\tilde{c}_l-c_K)}{n+2\lambda(n+1)}$, $q_h^* = \frac{n}{n+2\lambda(n+1)}\left[(1+\lambda)(\theta-\tilde{c}_h-c_K)-\frac{\beta_l}{\beta_h}\frac{\tilde{c}_h-\tilde{c}_l}{n+1}\right]$

The transfer payments are respectively as

$$
\begin{aligned}
T_l^* == -\frac{n}{(n+1)[n+2\lambda(n+1)]^2}\Bigg\{\Bigg[&(1+\lambda)(n+1)(\theta-\tilde{c}_h-c_K) \\
&-\frac{\beta_l}{\beta_h}(\tilde{c}_h-\tilde{c}_l)\Bigg]\left([\lambda(n+1)-1](\theta-\tilde{c}_h-c_K)+\frac{\beta_l}{\beta_h}(\tilde{c}_h-\tilde{c}_l)\right) \\
&+(1+\lambda)(n+1)[\lambda(n+1)-1](\theta-c_K-\tilde{c}_l)^2 \\
&-\Big\{(1+\lambda)(n+1)(\theta-\tilde{c}_h-c_K) \\
&-\frac{\beta_l}{\beta_h}(\tilde{c}_h-\tilde{c}_l)\Big\}\Big\{[\lambda(n+1)-1](\theta-\tilde{c}_l-c_K) \\
&+\left[\frac{\beta_l}{\beta_h}+(1+\lambda)(n+1)\right](\tilde{c}_h-\tilde{c}_l)\Big\}\Bigg\}
\end{aligned}
$$

$$
\begin{aligned}
T_h^* = -\frac{n}{(n+1)[n+2\lambda(n+1)]^2}\Big\{&(1+\lambda)(n+1)(\theta-\tilde{c}_h-c_K) \\
&-\frac{\beta_l}{\beta_h}(\tilde{c}_h-\tilde{c}_l)\Big\}\Big\{[\lambda(n+1)-1](\theta-\tilde{c}_h-c_K)+\frac{\beta_l}{\beta_h}(\tilde{c}_h-\tilde{c}_l)\Big\}
\end{aligned}
$$

The corresponding market equilibrium prices are

$p_l^* = \frac{\lambda(n+2)\theta+(1+\lambda)n(\tilde{c}_l+c_K)}{n+2\lambda(n+1)}$, $p_h^* = \frac{\lambda(n+2)\theta+(1+\lambda)n(\tilde{c}_h+c_K)+\frac{n}{n+1}\frac{\beta_l}{\beta_h}(\tilde{c}_h-\tilde{c}_l)}{n+2\lambda(n+1)}$ □

A.4.5 Proof of Proposition 4.5

If yardstick competition is adopted, then the profit function of i^{th} regional Infrastructure and Carrier is:

$$\pi_{IK} = -q^2 + (\theta - \tilde{c}_{IK})q + T(\overline{c}_i)$$

If the Regulator determines the output q, then similar to the proof of Scenario 1, the optimal output is $q = \frac{1+\lambda}{1+2\lambda}(\theta - \overline{c}_i)$. In order to maximize its profit, the i^{th} regional Infrastructure and Carrier will set $\frac{1+\lambda}{1+2\lambda}(\theta - \overline{c}_i) = \frac{\theta-\tilde{c}_{IK}}{2}$, which is the peak point of the quadratic function $-q^2 + (\theta - \tilde{c}_{IK})q$. It means that the optimal output is $q = \frac{\theta - \tilde{c}_{IK}}{2}$, which is the optimal output when the Regulator does not make output decision. Therefore, the Regulator's full regulation scenario will ultimately reduce to a partial regulation scenario.

Note that the transfer payment of the i^{th} the regional Infrastructure and Carrier is irrelevant with the cost c_i, while the output $q(c_i)$ is a function of the regional Infrastructure and Carrier's decision variable c_i. Taking derivative of the profit function with respect to c_i, the FOC is

$$-2q(c_i)q'(c_i) + (\theta - \tilde{c}_{IK})q'(c_i) = 0$$

Further we have $-2q(c_i) + (\theta - \tilde{c}_{IK}) = 0$. The output is $q(c_i) = \frac{\theta - \tilde{c}_{IK}}{2}$. It means that for every regional Infrastructure and Carrier to choose to report $c_i = \tilde{c}_{IK}$ is a symmetric Nash Equilibrium. Next we shall prove by contradiction that there does not exist an asymmetric equilibrium. First suppose that $c_i > \tilde{c}_{IK}$, and now the regional Infrastructure and Carrier lowers c_i by Δc. It gains $(\theta - \tilde{c}_{IK})\Delta c$ at the cost of $-2q(c_i)\Delta c$.

Since $-2q(c_i)q'(c_i) + (\theta - \tilde{c}_{IK})q'(c_i) \leq 0$ and $q'(c_i) = -\frac{1}{2}$, then we have $2q(c_i) \leq \theta - c_i$. Further we have $\theta - c_i < \theta - \tilde{c}_{IK}$. Hence $2q(c_i)\Delta c < (\theta - \tilde{c}_{IK})\Delta c$, and then the regional Infrastructure and Carrier clearly prefers to lower its cost until $c_i = \tilde{c}_{IK}$. This shows that there is no equilibrium with $c_i > \tilde{c}_{IK}$. Similarly, if $c_i < \tilde{c}_{IK}$, it can be shown the regional Infrastructure and Carrier wants to raise its cost, and again there can be no equilibrium. This contradiction establishes that the equilibrium of the regional Infrastructure and Carrier is unique. □

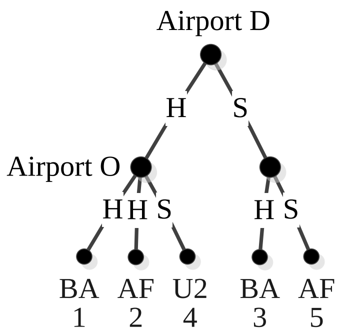
A.5 Additional Results of Chapter 5

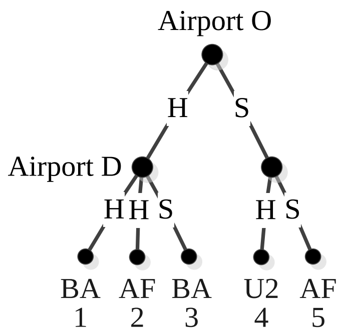
Results are referred to the nested logit model discussed in Chapter 5.3.2.

A.5.1 Nested Logit model structure

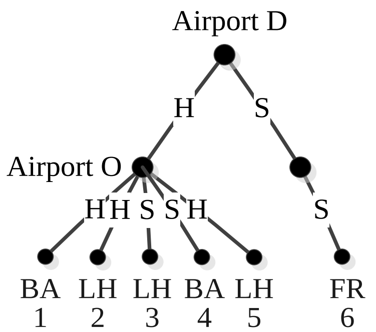
We specify the two-level nesting structure in two cases: (1) first choosing departure airport (O), and then choosing a combination of arrival airport and carrier (D-C); (2) first choosing arrival airport (D), and then choosing a combination of departure airport and carrier (O-C). Specified nesting structures with respect to each market are shown as follows.

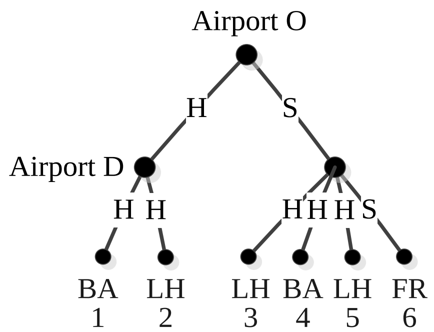
London-Paris



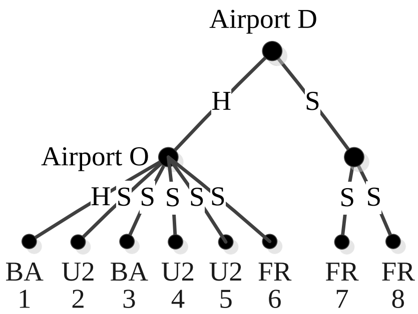


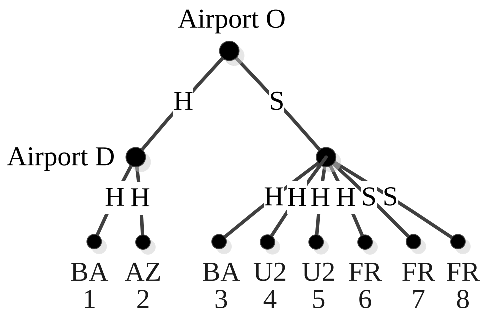
London – Frankfurt



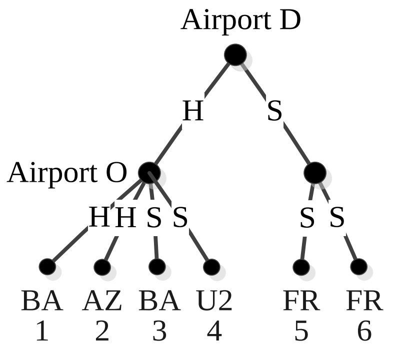


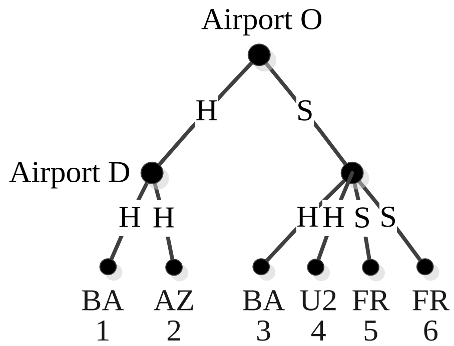
London-Barcelona





London-Rome





A.5.2 Nested Logit model results

Based on the nesting structure represented in A.5.1, we estimate the nested logit model discussed in Chapter 5.3.2. Since the results show the model is inconsistent with RUM, the nesting structure is rejected. Thus only a very limited part of the results is presented here. The estimation results of choice between CDG and Orly airport in London-Paris market are shown below.

London – Paris

Case1: Departure airport (O) - Arrival airport & carrier (D-C)

London-Paris	Leisure	Business
Alternative		
$Infreq$	0.606	0.945
	(0.66)	(1.22)
$fare$	0.0001000	-0.00495***
	(0.36)	(-4.88)
Hub brunch		
$freq\_Dapt$	0.00588	0.0176**
	(1.02)	(2.87)
Secondary brunch		
$freq\_Dapt$	0.00721	0.0192**
	(1.19)	(2.79)
Alternative constant		
LHR-CDG-AF	0.577	1.826***
	(0.89)	(4.82)
LHR-ORY-BA	4.264	12.93*
	(1.02)	(2.42)
LTN-CDG-U2	-1.438	-0.587
	(-0.50)	(-0.19)
LCY-ORY-AF	0.0917	4.650
	(0.02)	(0.59)
Dissimilarity parameters		
τ_{hub}	1.084	2.652***
	(0.90)	(4.36)
τ_{sec}	2.839	7.017
	(1.07)	(1.63)
N	11470	9795

Note: t-statistics in parentheses.

$***$ Significant at the 1% level, $**$at the 5% level, $*$ at the 10% level.

Case2: Arrival airport (D) - Departure airport & carrier (O-C)

London-Paris	Leisure	Business
Alternative		
$Infreq$	1.608	2.697
	(1.45)	(0.86)
$fare$	-0.00608**	0.0182**
	(-2.74)	(2.62)
Hub brunch		
$freq\_Dapt$	0.00298	0.00915
	(1.30)	(1.44)
Secondary brunch		
$freq\_Dapt$	0.00379	-0.00231
	(1.82)	(-0.56)
Alternative constant		
LHR-CDG-AF	2.162**	0.543
	(2.77)	(0.52)
LHR-ORY-BA	4.840	23.91*
	(1.04)	(1.97)
LTN-CDG-U2	2.460	1.935
	(1.78)	(0.57)
LCY-ORY-AF	4.471	22.86
	(0.98)	(1.94)
Dissimilarity parameters		
τ_{hub}	3.019**	6.329*
	(2.67)	(2.23)
τ_{sec}	1.003	0.551*
	(1.59)	(2.05)
N	9795	1675

Note: t-statistics in parentheses.

$***$ Significant at the 1% level, $**$at the 5% level, $*$ at the 10% level.

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