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Why Chinese airlines haven't become leading cargo carriers - analyzing air freight network and international trade drivers for mainland China

By
Qiang Gong[1], Kun Wang[2], Xingli Fan[3] and Xiaowen Fu

[1]Southwestern University of Finance and Economics, P.R. China
[2] The Hong Kong Polytechnic University, Hong Kong
[3] Academy of Civil Aviation Science and Technology, P.R. China

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ABSTRACT:

In contrast to the tremendous growth in the passenger sector, Chinese airlines and logistics operators still play relatively minor roles in the world's air cargo market. This study investigates the air freight network within mainland China using complex network analysis, and identifies the key drivers for international trade delivered by air with an augmented gravity model. Our network analysis suggests that domestic air freights flow through a relatively small point-to-point network. Demands are concentrated in the catchments of metropolitan regions, where passenger hubs have not served as cargo gateways. International air cargo flow is more balanced than China's overall merchandise trade. As a result, foreign carriers can cherry-pick the most lucrative markets and link them to their global networks. Gravity model estimation suggests that for China's international trade by air, the composition of the economy is a more important driver than the simple size of the economy. Therefore, air freight demand in China was not as high as past GDP numbers suggested, but is likely to outpace overall economic growth in the years to come. This should help Chinese airlines to achieve their cargo ambitions in the long term.

KEY WORDS: ***air freight, network, Chinese airlines, international cargo flow***

AUTHORS: **Gong, Wang, Fan and Fu**

CONTACT:

INSTITUTE OF TRANSPORT AND LOGISTICS STUDIES (C13)

The Australian Key Centre in Transport and Logistics Management

The University of Sydney NSW 2006 Australia

Telephone:	+612 9114 1824
E-mail:	business.itlsinfo@sydney.edu.au
Internet:	http://sydney.edu.au/business/itls

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1. Introduction

For the past three decades, it seems that everything has been on the side of Chinese airlines. From 1978 to 2011, real gross domestic product (GDP) in China grew nearly 10% annually. As a result, air passenger traffic grew more than 15% a year during the same period. Chinese airlines enjoy much lower input prices than their international peers (Fu et al. 2012); work unions are, in reality, subordinates of airline management; capital costs have been effectively decreasing thanks to currency appreciation; and there have been continual investments in transport infrastructure, airports, fleets and human resources. In terms of scheduled traffic, China ranked only seventy-eighth in the world in 1978, but since 2005 the country has become the second largest aviation market, only behind the United States. In terms of passenger traffic volume, airlines such as China Southern, China Eastern and Air China have become world leading carriers. In 2010, Chinese airlines earned RMB 35.1 billion (about US$ 5.3 billion), more than the rest of the world's airlines combined.

However, Chinese airlines have been unable to grow their cargo business in the same way as passenger traffic, and they still lag behind established cargo carriers in neighboring economies such as Korean Air, Singapore Air, Cathay Pacific and China Air. This is remarkable as there are no large integrated carriers competing in the domestic market, whereas the presence of UPS and FedEx partly explains the limited cargo operations of North American commercial airlines. This is rather puzzling, in view of China's leadership in global merchandise trade. Growth of the economy and trade calls for efficient and timely cargo movement, making air freight an indispensable means of logistics in today's global supply chains. Chinese airlines' limited exposure to cargo operations under such favorable circumstances is therefore quite unexpected, especially considering that many studies have confirmed that cargo operations are likely to improve commercial airlines' productivity and efficiency (Oum and Yu 1995, 1998, Oum et al. 2005, Homsombat et al. 2010). Therefore, this study aims to review the development status of the air cargo sector in mainland China, and empirically investigate why Chinese airlines have failed to grow into world leading cargo carriers. We use two complementary research components: we first evaluate the air freight network configuration in the Chinese domestic market using complex network analysis, and then identify the key drivers for international air trade with an augmented gravity model. Such an approach allows us to bypass some data restrictions, but nevertheless obtain an overall picture of the industry.

Research on air cargo is less developed compared to what has been achieved in relation to passenger traffic, mainly due to constraints in data availability. Comprehensive data on price and traffic volume at route or airline level are usually not accessible. Some researchers thus choose to investigate the airline network pattern, which can be identified from schedule information. Complex network theory has been developed as a powerful tool for studying the topological features of real-life networks including the Internet and social networks (Albert and Barabasi, 2002). Airport networks can also be analyzed using such an approach (Guimera and Amaral, 2004). Li and Cai (2004) investigated the aviation network in China and concluded that it has some scale-free features, which suggests the existence of hub airports connecting different airport clusters. Zhang et al. (2010) drew the same conclusions when studying the evolution of Chinese aviation network over the past decade. Network studies in these two articles did not discriminate between passenger and cargo operation. Dang and Peng (2012) conducted a dedicated study on the air freight network in China. They found topological features consistent with those in Li and Cai

(2004) and Zhang et al. (2010), and concluded that there was a significant overlap between passenger and cargo networks. The authors also demonstrated that air freight distribution in China is very imbalanced and airports can be classified into a four-level hierarchical system. Hui et al. (2004) reviewed the Chinese air freight market development in both domestic and international cargo sectors. The authors illustrated that Beijing, Shanghai and Guangzhou are the dominant airports forming a tripod in Chinese domestic air cargo traffic, whereas Hong Kong replaces the role of Guangzhou in international air cargo. Pan et al. (2007), Wei (2011) and Zhang et al. (2010) grouped Chinese airports into various hierarchies by calculating alternative indices. For example, Pan et al. (2007) constructed the Airport Organizational Indexes (AOI) and classified Beijing, Shanghai, Guangzhou and Shenzhen as international air cargo gateways, whereas airports such as Chengdu, Kunming, Xiamen, Hangzhou and Urumqi were classified as domestic air cargo hubs.

Although these studies provided valuable insights into the air cargo industry, they either investigated combined passenger-cargo networks, or focused on hierarchical classification of airports. No study has identified the network pattern of freight networks, e.g. whether the freight network is characterized as a hub-and-spoke network or a point-to-point network. Hub-and-spoke networks are primarily used by integrated carriers such as FedEx and UPS, which distribute a large number of shipments over an extended network. Point-to-point networks have been used by carriers focusing on airport-to-airport carriage, or commercial airlines with limited capacities. Therefore, the network configuration pattern may provide valuable insights into airlines' market development strategies. In addition, due to increases in labor and operational costs along the coastal region, many manufacturing firms in China are relocating their plants to inland provinces (Homsombat et al. 2013). More than 50 new airports have been built in China in the past couple of years. Therefore, there is a need for an updated analysis.

Due to data limitations, however, it is generally difficult to conduct network analyses for global networks. A few studies have estimated gravity models for international cargo flow. Matsumoto (2004, 2007) adopted a simple gravity model to identify airport hubs for major intra- and inter-continental air traffic. His gravity model controlled for GDP, population, distance and several airport dummy variables. As an extension, Yamaguchi (2008) investigated the effects of transport cost on US air cargo export by including this variable in his gravity model, although it was based on export data only. Hwang et al. (2011) analyzed air cargo flow in Taiwan Taoyuan Airport. More geo-economic variables that might affect international air cargo flow were incorporated into a gravity model, including flight frequency, freight rate, Open Skies Agreement and trading blocs. If the results obtained in these studies were applicable to the air cargo market in China, one would expect much faster growth of air cargo operations for Chinese carriers than has been observed. Despite being one of the most important cargo markets in the world, few empirical investigations have been carried out on China's air-borne merchandise trade. Therefore, there is a need to examine the Chinese air cargo market directly.

To fill these research gaps, this study investigates the air freight network within mainland China using complex network analysis, and identifies the key drivers for international trade delivered by air with an augmented gravity model. We hope such an analysis will, at least partly, explain why Chinese airlines have not been able to achieve the same status in cargo logistics as in passenger operations. The quantitative investigations carried out also complement qualitative reviews such as that carried out by

Zhang (2003) on Hong Kong's hub status, the investigation by Fung et al. (2005) on the effects of China's WTO entry in 2001, and Zheng and Chen's (2012) comparison between export and import cargo flows.

The paper is organized as follows. After a brief overview of the Chinese air cargo industry in recent years, Section 2 investigates the domestic air freight network using complex network analysis, Section 3 identifies the key drivers for international trade delivered by air with an augmented gravity model, and the summary and conclusions are reported in the last section.

2. Air Freight Network Analysis and Implications to Chinese Airlines

Overall, the air cargo sector in China has experienced tremendous growth over the past decades. However, the performance of Chinese airlines clearly lags behind that of their international competitors. From 2002 to 2012, air cargo traffic volume in China increased from 4 million tons to 12 million tons at an average annual growth rate of 11.5%. This growth rate was faster than the world average as evidenced in Figure 1, and was mostly led by international air cargo as shown in Figure 2. The domestic air cargo growth pattern has been consistent with international traffic, albeit less volatile. The volatility of international cargo is largely due to demand shocks overseas. In 2008 and 2009, international air cargo was badly hit due to the global financial crisis. In comparison, domestic cargo volume continued to record decent growth. This is consistent with China's overall economy, which maintained growth momentum thanks to large stimulus investments launched by the government. By 2010, the Chinese air cargo market made a full rebound, which did not last long due to the debt crisis in Europe, and the tapering of government stimulation.

<Figure 1 Here> <Figure 2 Here>

Despite the short-term uncertainty and fluctuation, most industry players are positive about the long-term prospects. Boeing (2011) predicted that China will continue to lead world air cargo growth for the next twenty years, as strong international trade and economic growth will continue to boost air cargo demand. According to China Customs' statistics, in 2011 international trade by air reached US$ 551,714 million, accounting for 12.9% of exports and 17.5% of imports. Air freight service is of critical importance for merchandise trades in precision equipment, electronics and machineries.

Air Cargo operations are clearly concentrated in metropolitan areas. Table 1 summarizes cargo volume and market share for top Chinese airports in selected years. The Shanghai Pudong airport alone controls around 25% of the national market. The top three airports in the cities of Beijing, Shanghai and Guangzhou handle more than 50% of cargo throughput. At the route level, out of 1,495 domestic routes, the top 50 airport pairs made up about 50% of total traffic as of 2011. To examine airport traffic inequality, we construct the Herfindahl-Hirschman index (HHI) and the Gini index[1] as reported in Table 2. We first consider the network containing all of the airports, and denote the corresponding Gini index as

[1] The formula for the index calculation is attached in Appendix 1.

"Gini1". Because many airports have negligible cargo volumes, including them may lead to an exaggerated inequality index. Therefore, an index denoted as "Gini2" is created by including only airports whose cargo volume exceeds 10,000 tons per year. Overall, the HHI indices are above 1,000 whereas the Gini indices are over 0.70, indicating significant traffic concentration. Such imbalance has a decreasing trend, as evidenced by the HHI and Gini2 indices. The Gini1 index is somewhat stable, probably because many newly-built airports have been added, which tend to have low cargo volume in the first couple of years.

<Table 1 Here> <Table 2 Here >

To better identify the network configuration pattern, a detailed topology study on the air freight network is carried out. First, we examine the whole domestic network including all of the airports. This includes very small airports with negligible cargo throughput that may distort topological features. Therefore, different from previous studies, we also construct another network by considering only airports with over 10,000 tons of annual throughput. These airports accounted for over 98% of total cargo volume in 2011, and routes linked to them added up to 96% of the total cargo market.

As of 2011, the domestic freight network in China consisted of 163 airports and 1,495 routes. Among them, only 49 airports had cargo volumes over 10,000 tons. The airport degree[2] distribution is investigated as depicted in Figure 3, which reports degree distributions for both networks consisting of all airports (Network 1) and the top 49 airports only (Network 2). Network 1 has a degree distribution $P(K > k)$ following a two-regime power-law distribution. For small degrees, $P(k) \propto k^{\lambda_1}$ where $\lambda_1 = -0.41$; whereas for large degrees, $P(k) \propto k^{\lambda_2}$ where $\lambda_2 = -3.5$. This is similar to the degree distribution in Li and Cai (2004) and Zhang et al. (2010), which studied a combined network for both passenger and cargo operations. This suggests that there is a significant overlap between passenger and cargo traffic in China, mostly due to Chinese airlines' reliance on belly space for cargo operations. The two-regime power law degree distribution also suggests that the network has a scale-free feature. That is, there are a few extensively connected hubs in the network, with other poorly connected airports linked to those hubs. Preferential attachment theory (Li and Cai, 2004) would predict that newly built airports prefer to connecting to airports with the highest degrees in the network. This is consistent with our observation that small or newly-built airports in China almost always establish direct flights to mega hubs such as Beijing, Guangzhou, and Shanghai first.

<Figure 3 Here>

Clustering coefficients and average shortest path lengths are also important topological properties (definition provided in Appendix 2). Summary statistics for some of the most connected airports are reported in Table 3. Figure 4 provides the correlation between airport degree and clustering coefficients. It is clear that for Network 1, airport clustering coefficients decrease with airport degree. For example, high degree airports such as Beijing, Guangzhou and Shanghai have low clustering coefficients. As mentioned earlier, small airports with poor connections prefer to be linked to these high degree airports,

[2] The degree of an airport (vertex) is the number of undirected routes (edges) incident to the airport (vertex).

thus lowering the clustering coefficients of the large airports. This observation confirms the validity of preferential attachment theory, and suggests that high degree airports serve as hubs that link to small spoke airports in the network.

<Table 3 Here> <Figure 4>

For Network 2, composed of large airports only, airport degrees fit an exponential distribution better than a power-law, as tested by the ordinary least squares estimation proposed in Tranos (2011). This network exhibits clear small-world features instead of scale-free features. The hub status of large airports is less obvious. Airport clustering coefficients are high, and the average shortest path length of the network is only 1.294, with 70.3% of airport pairs directly linked. This suggests point-to-point traffic flow prevails in the network. In summary, different patterns are identified for Network 1 and Network 2. The overall air cargo network in China demonstrates some hub-and-spoke features in the sense that small airports tend to prioritize links to high degree airports which serve as hubs. This allows high network accessibility with a relatively simple network, a well-known benefit of hub-and-spoke networks. Nevertheless, such a hub-and-spoke system is in a very early stage. The majority of air freight is carried by direct flights linking a small number of large airports.

Several factors have contributed to the observed pattern. First, cargo operations in China, especially in the domestic market, have largely been an add-on service using aircraft belly space. This implies that the overall freight network, and the overall aviation network, is mostly determined by passenger demand rather than cargo demand. Table 4 compares the freighter fleets of major Chinese and foreign carriers. Large freighters such as B747s are mostly deployed in international routes, leaving a small freighter fleet to serve the domestic market.

<Table 4 Here>

The limitation of belly space utilization is well known to the aviation industry. Belly space provides rather limited capacity, not capable of handling shipments of large size or weight. Increasing security requirements[3] also increase the operational costs of cargo delivery via passenger aircrafts. It also offers less flexibility compared to freighter operation, as schedule and capacity allocation are determined by passenger service rather than cargo demand. When there is sufficient demand, cargo operations usually need to be carried by freighter via a dedicated network. In the United States, after the domestic deregulation in 1978, an increasing number of all-cargo operators emerged. Many started with point-to-point operation but later switched to hub-and-spoke systems to serve a large number of destinations. Commercial airlines, mostly so-called full service airlines or network carriers, also established hub-and-spoke systems (Reynolds-Feighan, AJ 1994). Chinese airlines are also creating their own cargo subsidiaries. Air China formed Air China Cargo in 2003. China Eastern founded its cargo subsidiary China Cargo airlines in 1998. In 2011, China Cargo airlines merged with Shanghai Airlines' cargo operation, while Great Wall airlines grew into one of the largest cargo carriers in China. China Southern and Hainan airlines also created their own cargo subsidiaries. However, these cargo subsidiaries have

[3] For example, in the United States (since the 9/11 incident) it is required that cargo shipments carried with passenger traffic need to be 100% screened. This is another reason that North American airlines have not developed strong cargo operations.

rather small freight fleets. The true cargo network (i.e. Network 2) is still a point-to-point network instead of a hub-and-spoke system.

The second contributing factor is that effective hub-and-spoke cargo operations need efficient airport support services. Cargo operations on the ground, such as packing and unpacking, cargo build up, warehousing, apron and ground services, billing, security check and quarantine, and balancing and loading, must be quick and efficient for ground-to-aircraft and aircraft-to-aircraft operations. Although cargo terminals in major hubs have achieved substantial improvements in recent years, it will take a bit more time for them to match the service level provided by their peers, the neighboring cargo hubs of Hong Kong, Seoul and Singapore. In addition, despite aggressive expansions, these hub airports still face some constraints in capacity, mostly during peak hours. The priority of passenger service will limit the flexibility offered to cargo operations.

Finally, much of the air freight demand in China has been concentrated in the catchment region of metropolitan areas. Unlike passenger travel, which usually involves less than 2 hours of ground transportation, air cargo ground delivery can easily reach up to 5-8 hours. This allows a hub airport to serve a large catchment area (e.g. Beijing Capital airport may serve the areas near Beijing, Tianjing or the Bohai Bay area; Shanghai Pudong can serve Shanghai and much of the Yangzi River Delta (YRD); the Hong Kong International Airport, together with the closely situated Guangzhou Baiyun and Shenzhen Baoan airports, can effectively serve virtually the whole Pearl River Delta (PRD)). This allows a few hub airports to cover the economically most developed regions in mainland China.

In the long term, with increasing demand, larger freighter fleets and more efficient airport operations, the air cargo network is likely to evolve towards a true hub-and-spoke network. Specialized integrated carriers, such as SF Express, will emerge and grow. These carriers are likely to adopt hub-and-spoke networks so that a large number of shipments can be distributed to many destinations via a relatively simple network. In the short term, the current network configuration will persist; but a few regional hubs, such as Zhengzhou, Chengdu, Xi'an, Chongqing, and Urumqi, will be of growing importance. These airports are located in central and western China, which are less developed but have populations in the catchment areas. With a substantial increase in labor and operational costs in the coastal regions, many firms in China have started to relocate their production plants to inland provinces over recent years. For example, Foxconn, the iPhone and iPad OEM manufacturer, recently set up two manufacturing factories in Zhengzhou and Chengdu, bringing considerable air freight growth for their airports. As evidenced in Figure 5, the market shares of these inland airports have been increasing. In 2011, Chengdu saw a 10% increase in total cargo volume, with international air cargo increased by 118%. For Zhengzhou airport, its air cargo throughput increased by 48% and is now served by 9 foreign cargo carriers with 62 weekly freighter services. Zhengzhou municipal government is determined to develop its airport into an air cargo hub in central China. A dedicated cargo runway is planned, and cargo handling facilities are being upgraded.

<Figure 5>

3. Chinese international air cargo flow

China serves as an important manufacturing base in the global supply chain. Table 5 reports the major trading items of total trade and air-delivered trade in 2011. Clearly, air freight has facilitated international trade by moving high-value items such as electronics, precision instruments, machinery parts and medicines in a timely manner. The key air cargo destination countries are developed countries such as the United States, Japan, Hong Kong, and South Korea. This is understandable because China imports production equipment and materials from developed economies. Taiwan and South Korea are key suppliers of electronic boards and LED screens. Japan, the United States and Germany provided much of the precision equipment and semi-conductors. This is evidenced in Table 6, which summarizes country pair-wise air cargo shares by value.

<Table 5 here><Table 6 here>

Hong Kong ranks third in total trade, but seventh in air cargo. This is because much of the cargo flow between Hong Kong and mainland China is delivered via road and waterway. Brazil and Australia are important trading partners with China, but in terms of air cargo they rank below the top ten because most of the imports are iron ore and coal carried by bulk shipping. Overall, there is an apparent imbalance of cargo flow, as reported in Figure 6. China has a large surplus with the United States, Hong Kong and the Netherlands, but has deficits with Japan, Taiwan, Germany and South Korea. Imbalance indices [4] are calculated for the top-10 destinations and are reported in Table 7. There is a significant imbalance at the country-pair level. However, it tends to be more balanced than total trade. For China's overall trades delivered by air, such imbalances are even smaller (Table 7).

<Figure 6 Here> <Table 7 Here>

To better identify the key determining factors for China's international air cargo flow, a gravity model is estimated by extending the models developed in Matsumoto (2004, 2007), Yamaguchi (2008) and Hwang et al. (2011). An augmented gravity model is specified as

$$\ln V_j = \alpha_0 + \alpha_1 \ln gdp_j + \alpha_2 \ln pop_j + \alpha_3 lndist_j + \alpha_4 \ln tertiary_j + \alpha_5 border + \alpha_6 culture + \alpha_7 lib + \eta_j \quad (1)$$

The dependent variable V_j is specified as the total trade by air, air cargo export or import, between China and its trading partner j, respectively in alternate tests. For comparison, total international trade and share of air cargo in total trade are also used in the gravity model. Data on the value of Chinese trade for 2011 are retrieved from the General Administration of Customs of China. Due to data limitation, a cross sectional data set for China's top 100 air trade destinations are compiled for 2011.

Our gravity model includes seven dependent variables. GDP and population represent economic and demographic characteristics. Country level data from the World Bank are used, because trade data are

[4] The imbalance index is calculated as $\frac{export_i - import_i}{export_i + import_i}$.

also aggregated at country level, and the definition of airport hinterland is ambiguous. We also hypothesize that the "quality" of an economy may be as important as its size. In our study, the GDP share of tertiary industry is used as a proxy. There may be other, better proxy variables, but as far as we know, this is the first attempt to incorporate a quality of economy measure to examine air cargo flow. We hypothesize that tertiary industry is an important indicator for air cargo potential because industries such as information technology, telecommunication, and pharmaceutical sectors usually generate large volumes of high-value and time-sensitive cargoes, and involve a lot of supporting services. GDP composition data are compiled from the Central Intelligence Agency (CIA) website.

A border effect has been observed in international trade and air services (McCallum 1995, Hazledine 2009). In the context of air freight flow, it is expected that a common border negatively affects air cargo volume due to the availability of a land transport alternative. The variable "culture" captures racial ties between mainland China and neighboring regions including Hong Kong, Macao, Taiwan, Singapore and Malaysia. In the literature, Taiwan, Hong Kong and Macao, together with mainland China, are recognized as the "Great China Circle" (Huwang and Shiao 2011). Ethnic Chinese account for about 80% and 30% of the total populations of Singapore and Malaysia, respectively. This close racial tie may promote economic interactions and trade. The variable "lib" captures the effects of air cargo liberalization on trade by air. Micco and Serebrisky (2005) found Open Skies Agreements signed by the US with other countries lowered the cost of air freight by 9%, and increased the share of air-borne imports by 7%. A consistent observation was made by Yamaguchi (2008). China has been gradually liberalizing its air cargo sector. As early as 2003, fifth freedom of air cargo was granted to Singapore airlines in Xiamen. In the following year, China and the US increased their weekly cargo flights from 17 to 128, and eliminated the restrictions on destination airports. In 2007, China announced a complete liberalization of its air cargo sector to US carriers. Therefore, a dummy variable "lib" is used in order to quantify the effects of Sino-US air cargo liberalization. Lastly, flying distance may reduce trading activities. Great circle distances between Beijing and other capital cities are used as a proxy, a similar approach to that used in Khadaroo and Seetanah (2008). Summary statistics for these variables are reported in Table 8.

< Table 8 Here >

The gravity model specified in Equation 1, referred to as Gravity Model 1, is estimated with an Ordinary Least Squares (OLS) regression as summarized in Table 9. As expected, economy size, measured by GDP, has a positive effect on air cargo trade. This effect is more significant for trade by air than the case of total trade (elasticity of air cargo to GDP is 1.1, while it is 0.85 for total trade). The share of air cargo in total trade also increases with GDP. The most important finding for air cargo is that the quality of economy is more important than the size of economy, which does not seem to hold for total trade. The elasticity of trade by air to the quality of economy is 1.47, and is even higher (i.e. 5.1) in the case of imports. The share of air cargo in total trade also increases with the quality of economy. The intuition is that air freight mostly carries high-value items, which involve substantial support services. The large elasticity for imports reflects China's reliance on developed countries to supply high-tech and capital intensive products. In summary, our findings suggest that apart from conventional wisdom looking at the size of the economy, it is also important to consider the composition of the economy for trading countries. As expected, border effect and distance reduce airborne trade. Racial ties promote trade between China and regions that share a common language and culture.

In addition, our estimation indicates that the Sino-US cargo liberalization has promoted bilateral air cargo flow. Liberalization has allowed major US integrators to establish cargo facilities in China: FedEx relocated their Asia Pacific hub from the Philippines to Guangzhou; UPS built cargo centers in Shanghai Pudong and Shenzhen airports; and DHL added cargo handling stations in Shanghai Pudong. By September 2011, there were a total of 22 airlines serving China-US routes, which include 12 US carriers, 7 Chinese airlines and 3 fifth-freedom carriers. In comparison, only eight airlines were allowed as of 2001.

Despite market growth followed by liberalization, Chinese airlines have been losing market shares to their foreign competitors, as reported in Figure 7. Many factors have contributed to such a market outcome in addition to the network configuration issue analyzed in the previous section. There is substantial imbalance in air cargo flow as summarized in Table 10. This is bad news for Chinese carriers relying more on belly space carriage, as cargo space on return flights is more likely to be wasted. For freighter services, this problem may be more easily alleviated by planning one-way flights with a circular network (for example, Singapore airlines operates directional routes from China to the US and then from the US to other destinations before returning to Singapore). More importantly, leading cargo carriers such as FedEx, UPS and DHL have extensive global networks, which give them more flexibility in flight scheduling and planning.

<Figure 7 Here> < Table 9 Here > <Table 10 Here>

Chinese airlines have made several efforts to enhance their competitiveness. In 2011, Air China cooperated with Cathay Pacific airlines to form the new Air China Cargo. In 2010, Singapore airlines and Evergreen airlines invested in China Cargo airlines. Meanwhile, China Southern joined the SkyTeam Cargo alliance and China Cargo airlines become a formal member in June 2013. These joint-ventures and alliances will enable Chinese airlines to learn from their partners, and to optimize their network configuration.

The Pearl River Delta (PRD), Yangtze River Delta (YRD) and Bohai Economic Rim (BER) are the three largest economic zones in China, and account for a large share of international trade as summarized in Table 11. These three areas contributed 58.24% of China's GDP, 85% of international trade and 88% of airborne trade. These three economic zones, however, have different economy compositions. The Pearl River Delta and Yangtze River Delta have longer histories of development in manufacturing than the Bohai Economic Rim. Consequently, these two areas manifest export-oriented economies, accounting for 70% of China's international exports. With a huge population and high personal income, however, the Bohai Economic Zone is the most important consumption market in China. To explore the different airborne trade patterns for these three zones, we specify a regional gravity Model 2 as follows:

$$\ln T_{ij} = \beta_0 + \beta_1 lnDist_j + \beta_2 Border_j + \beta_2 Culture_3 + \beta_{3,i}\ln agdp_{ij} + \beta_{4,i}\ln apop_{ij} + \beta_{5,i}\ln atertiary_{ij} + \beta_{6,i} lib_{ij} + \varepsilon_{ij} \qquad (2)$$

The dependent variable T_{ij} is the air cargo flow between economic zone i and trading country j. Explanatory variables "Dist", "Border" and "Culture" have the same definitions as in Model 1, whereas GDP, population and tertiary industry proportion in GDP are now the geometric means of economic zone i and trading country j. In this gravity model, the coefficients for $agdp_{ij}$, $apop_{ij}$, $atertiary_{ij}$ are set as random for economic zone i. This allows us to identify possible regional differences. We expect PRD and YRD to benefit more from liberalization because of the cargo handling centers established by FedEx and UPS in Shanghai, Guangzhou and Shenzhen.

<Table 11 here>

The estimation results for the constant coefficients are intuitively correct and consistent with the Model 1 estimation (see Table 12). For those coefficients specific to each economic zone, some variations can be observed. First, Yangtze River Delta and Baohai Economic Rim have higher air trade elasticity to economy size and economy quality, compared to that of the PRD. This is because Hong Kong is still the most important gateway serving PRD, capturing most of the air cargo growth in the region. According to statistics reported by the Hong Kong Airport Authority, in 2011, over 70% of the cargoes handled were sourced from mainland China. The rankings of Hong Kong and Guangzhou are illustrated in Table 13. There is likely to be a sharp competition between these two closely situated airports.

<Table 12 Here> < Table 13 Here >

4. Conclusion

In contrast to the tremendous growth in the passenger sector, Chinese airlines and logistics operators still play relatively minor roles in the global air cargo market. This study investigates the air freight network within mainland China using complex network analysis, and identifies the key drivers for international trade delivered by air with an augmented gravity model. Our network analysis suggests that domestic air freights flow through a relatively small point-to-point network. Several factors have contributed to the pattern observed. First, cargo operations in China, especially in the domestic market, have largely been an add-on service using aircraft belly space/lower-hold. This implies that the overall freight network, and the overall aviation network, is mostly determined by passenger rather than cargo demand. When there is sufficient demand, cargo operations usually need to be carried by freighters via a dedicated network. Chinese carriers have created their own cargo subsidiaries. However, these cargo subsidiaries have rather small freighter fleets. A second contributing factor is that effective hub-and-spoke cargo operations need efficient airport support services. It will take more time for Chinese airports to match the service level provided by neighboring cargo hubs in Hong Kong, Seoul and Singapore. Finally, much of the air freight demand in China has been concentrated in the catchment region of metropolitan areas. This allows a hub airport to serve a large catchment area. In the long-term, with increasing demand, larger freighter fleets and more efficient airport operations, the air cargo network in China is likely to evolve towards true hub-and-spoke networks. Specialized, integrated carriers using hub-and-spoke networks will emerge and grow.

In the short run, the current network configuration will persist, but a few regional hubs will be of growing importance.

Such a network configuration implies that passenger hubs have not served as cargo gateways. As a result, the domestic freight network is not really feeding traffic to major hubs in the cities of Beijing, Shanghai and Guangzhou. In addition, international air cargo flow is more balanced than China's overall merchandise trade. Therefore, foreign carriers can cherry-pick the most lucrative markets and link them to their global networks.

Gravity model estimation suggests that for China's international trade by air, the composition of economy is a more important driver than the size of economy. Therefore, air freight demand in China was not as high as past GDP numbers suggested, but it is likely to outpace overall economic growth in the years to come. This should help Chinese airlines to achieve their cargo ambitions in the long-term. Liberalization has led to cargo volume growth for China, but many of the benefits to the airline industry have been captured by foreign carriers. Joint-venture and airline alliances should help Chinese airlines in the longer term.

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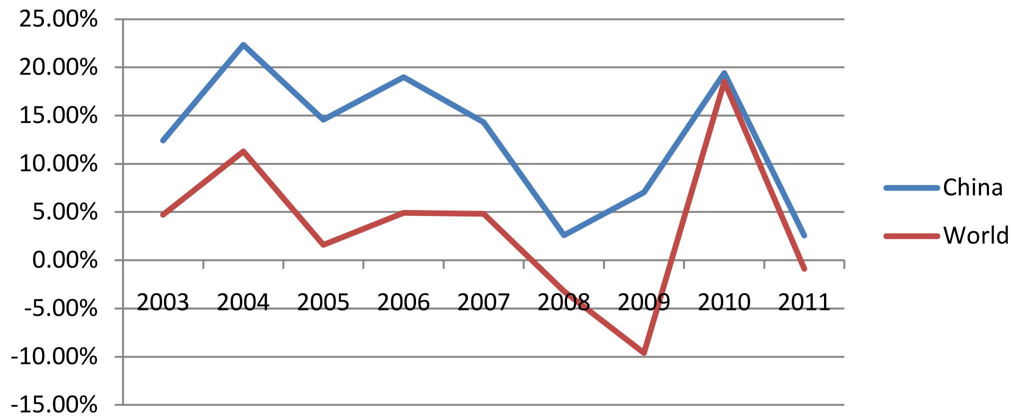

Figure 1. Growth rates for the Chinese and global air cargo markets

Caution: Due to limitations in data availability, Chinese air cargo is measured by weight carried (ton), whereas world air cargo traffic is measured by RTKs.
Source: Boeing World Air Cargo Forecast 2012-2013; Statistical Data on Civil Aviation of China by CAAC.

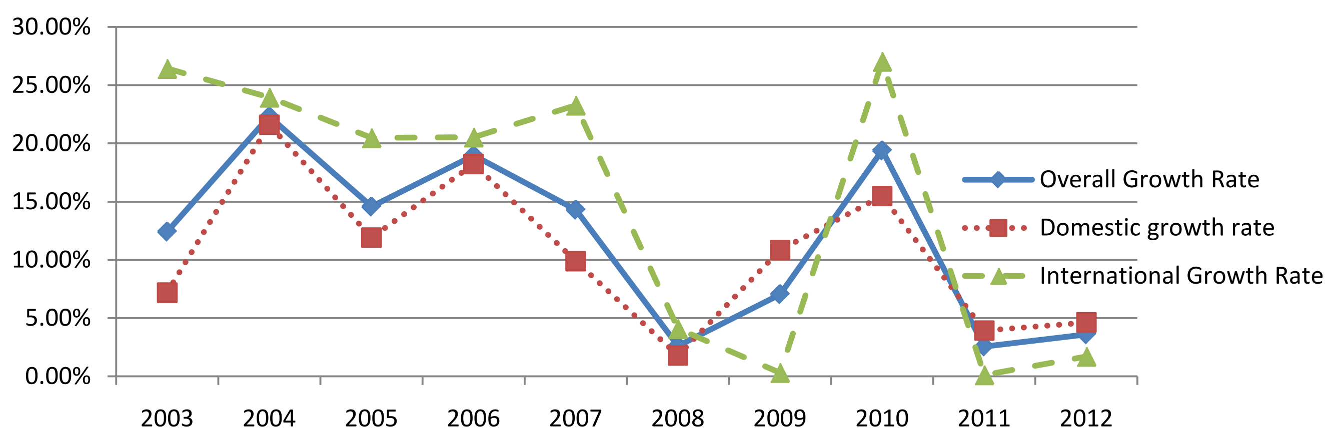

Figure 2. The air cargo growth rate in China over the last decade

Source: Statistical Data on Civil Aviation of China by CAAC.

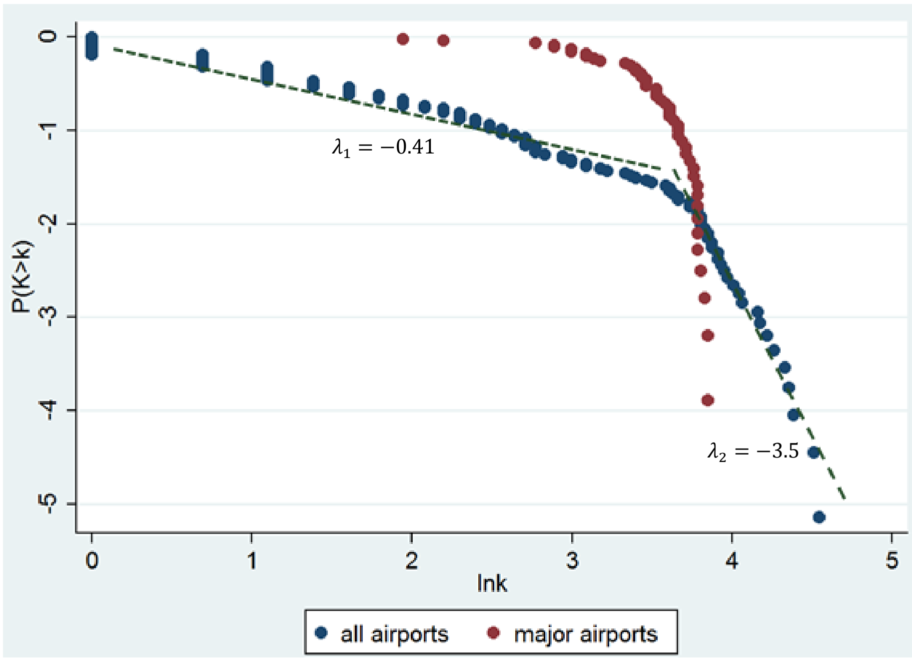

Figure 3. Airport degree distribution

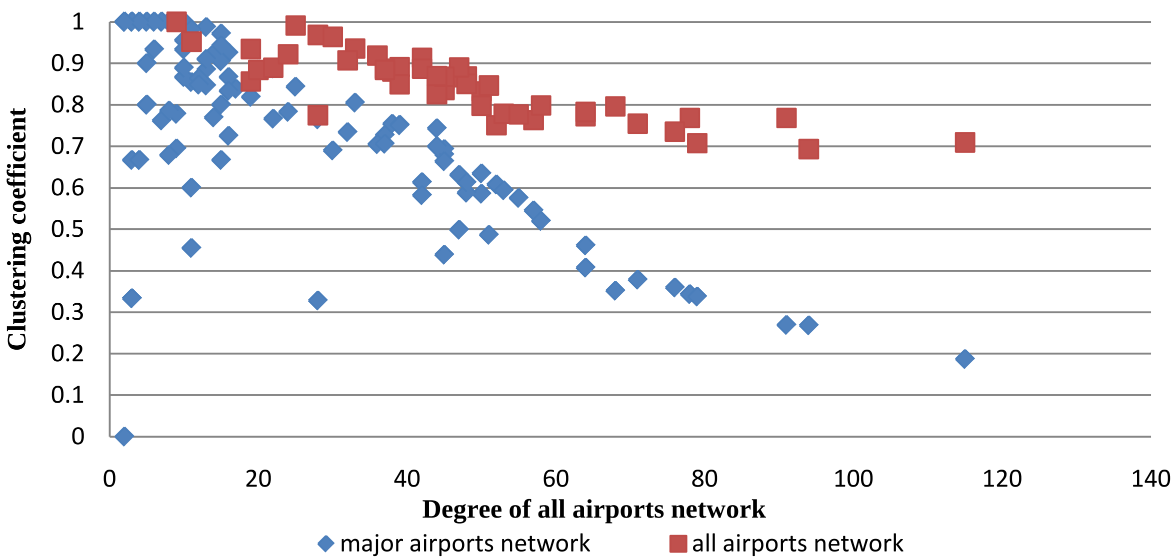

Figure 4. Correlation between airport degree and clustering coefficient

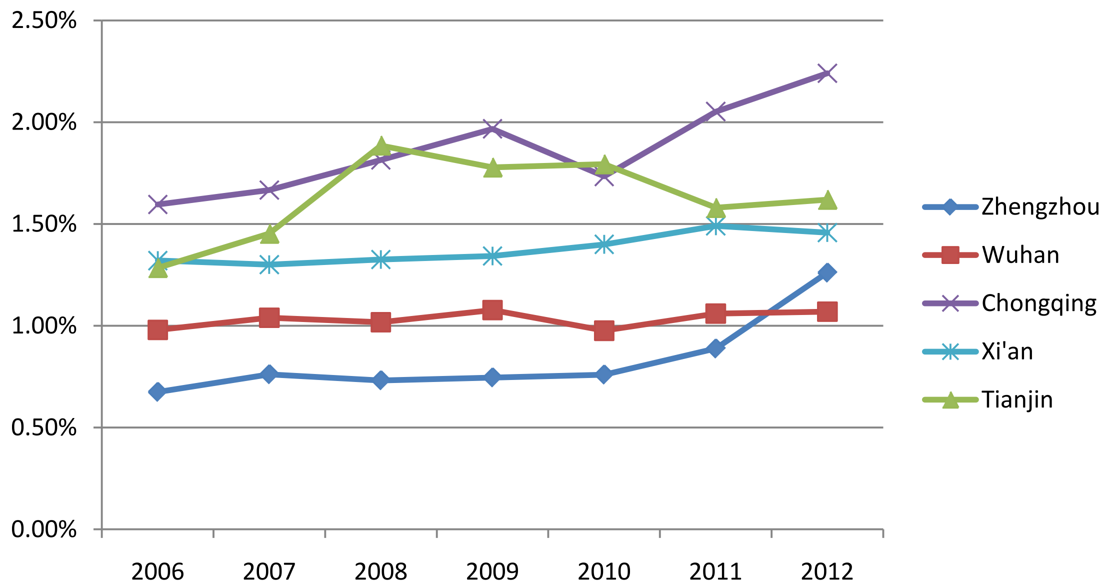

Figure 5. Market share of some regional airports

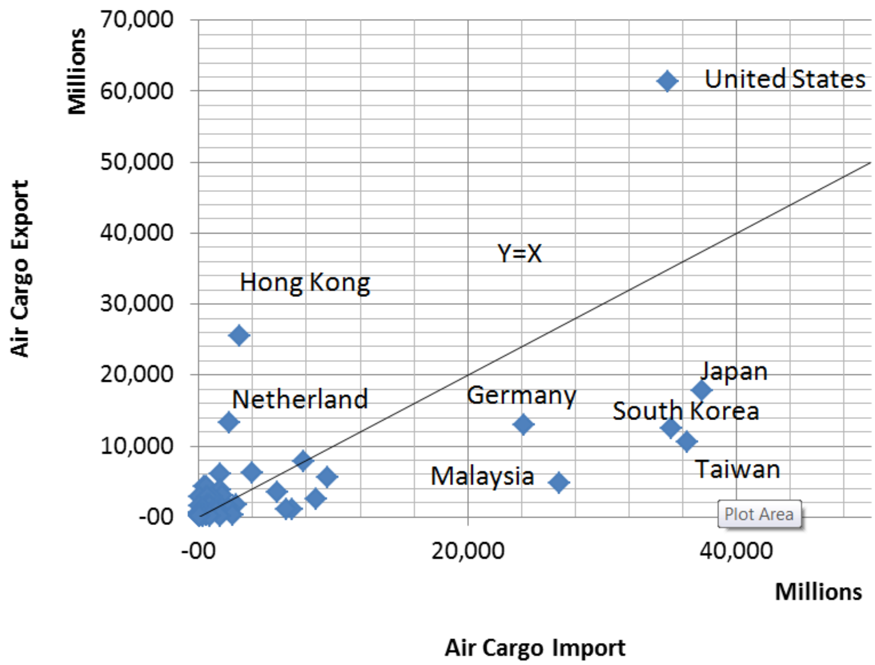

Figure 6. The relation between Chinese bilateral air cargo export and import in ad-valorem for 2011

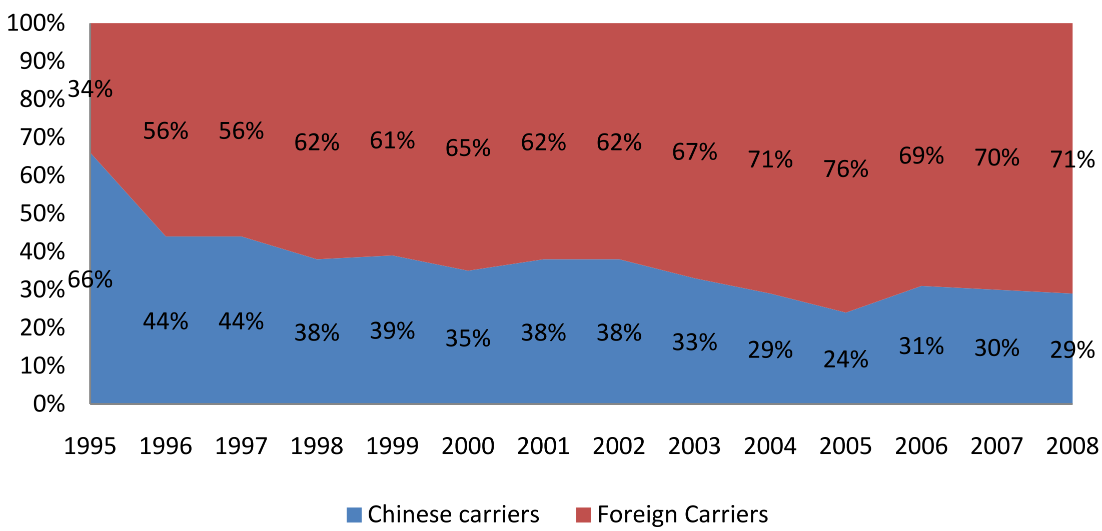

Figure 7. Share comparison between Chinese and foreign carriers

in the Chinese international air cargo market

Source: Report on Chinese air cargo industry development published by Industrial Securities.

Table 1. Summary of airport air cargo volume for major airports in mainland China

	2006			2009			2012	
Airport	**Cargo**	**%**	**Airport**	**Cargo**	**%**	**Airport**	**Cargo**	%
Shanghai Pudong	2,168,072	28.8%	Shanghai Pudong	2,543,394	26.9%	Shanghai Pudong	2,938,157	24.5%
Beijing	1,201,815	16.0%	Beijing	1,475,657	15.6%	Beijing	1,799,864	15.0%
Guangzhou	653,261	8.7%	Guangzhou	955,270	10.1%	Guangzhou	1,248,764	10.4%
Shenzhen	559,244	7.4%	Shenzhen	605,469	6.4%	Shenzhen	854,901	7.1%
Shanghai Hongqiao	363,581	4.8%	Shanghai Hongqiao	439,072	4.6%	Chengdu	508,031	4.2%
Chengdu	295,498	3.9%	Chengdu	373,515	4.0%	Shanghai Hongqiao	429,814	3.6%
Kunming	219,198	2.9%	Kunming	258,755	2.7%	Hangzhou	338,371	2.8%
Hangzhou	185,518	2.5%	Hangzhou	226,308	2.4%	Xiamen	271,466	2.3%
Xiamen	175,011	2.3%	Nanjing	200,099	2.1%	Chongqing	268,642	2.2%
Nanjing	152,063	2.0%	Xiamen	196,025	2.1%	Kunming	262,272	2.2%
Total	**7,531,935**	**100.0%**	**Total**	**9,455,645**	**100.0%**	**Total**	**11,993,971**	**100.0%**

Source: Statistical Data on Civil Aviation of China by the CAAC.

Table 2. HHI and Gini Indices to measure airport cargo volume inequality

	2006	2007	2008	2009	2010	2011	2012
Gini1	0.9056	0.9087	0.9091	0.9072	0.9115	0.9047	0.9023
Gini2	0.7521	0.7524	0.7426	0.7326	0.7316	0.7202	0.7086
HHI	1294	1345	1298	1191	1235	1175	1094
No. of Airports	139	145	151	155	166	163	168

Table 3. Summary of topological features for the Chinese air cargo network and sample airports

	Network 1		Network 2	
Airport	**Degree**	**Clustering Coefficient**	**Degree**	**Clustering Coefficient**
Beijing	115	0.187	44	0.768
Guangzhou	94	0.268	44	0.768
Shanghai Hongqiao	91	0.269	46	0.735
Chengdu	79	0.338	47	0.710
Shanghai Pudong	78	0.343	48	0.693
Shenzhen	76	0.359	47	0.708
Chongqing	71	0.378	44	0.763
Kunming	68	0.352	40	0.796
Changsha	64	0.461	39	0.833
Xi'an	64	0.407	45	0.751
Zhengzhou	58	0.520	44	0.755
Hangzhou	57	0.545	44	0.773
Wuhan	55	0.575	18	0.856
Tianjin	53	0.594	34	0.847
Nanjing	52	0.608	30	0.860
Dalian	51	0.486	41	0.798
Xiamen	50	0.585	42	0.783
Haikou	50	0.634	43	0.779
Shenyang	48	0.588	35	0.869
Qiangdao	48	0.613	44	0.777
Network Clustering Coefficient	0.799		0.843	
Network Shortest Path Length	2.174		1.294	

Note: Network 1 refers to the network containing all airports; Network 2 refers to the network containing only the airports with more than 10,000 ton cargo throughput.

Table 4. Freighter fleet for major Chinese and foreign cargo airlines

	Airlines	**Number of freighters**	**Aircraft type**
China	China Southern	8	B747-400, B777
	Air China Cargo	10	B747-400
	China Cargo Airlines	19	B747-400,B757-200,B777,A300-600,MD11
	China Postal Airlines	16	B737-300, B737-400
	Yangtze River Express	14	B737-300, B747-400
	Jade Cargo	6	B747-400
	SF Express	7	B737-300, B757-200
Foreign	Korean Air	24	B747-400
	Cathay Pacific	21	B747-400, B747-8
	China Airlines	20	B747-400
	Martinair	13	B747-400, MD11
	Nippon Cargo Airlines	8	B747-400
	Cargolux Airlines International	15	B747-400, B747-8
	Singapore Airlines	12	B747-400
	Aerologic	8	B777
	UPS	523	Boeing, Airbus, MD, DC
	FedEx	688	Boeing, Airbus, MD, DC, ATR, Cessna

Source: Report on Chinese air cargo industry development published by Industrial Securities.

Table 5. The major export and import items of Chinese international trade in 2011

(a) China Export

Total Export Items	(000,000 USD) Ad-Valorem	**Air Cargo Export** Items	(000,000 USD) Ad-Valorem
Machineries, electrical apparatus	799,519 (42.12%)	Machineries, electrical apparatus	194,204 (79.02%)
Textile products	240,539 (12.67%)	Precision Instruments and equipment	13,167 (5.36%)
Base metal	144,921 (7.63%)	Textile products	9,950 (4.05%)
Transportation equipment	109,107 (5.75%)	Chemical Products	8,672 (3.53%)
miscellaneous products	103,789 (5.47%)	Precious stones and metal	3,894 (1.58%)
Chemical Products	97,091 (5.11%)	Minerals	2,995 (1.22%)
Rubber and plastic products	66,346 (3.49%)	Base metal	2,264 (0.92%)
Precision Instruments and equipment	65,997 (3.48%)	leather and fur articles	2,231 (0.91%)
Shoe, hat, umbrellas, sticks and their parts	52,464 (2.76%)	miscellaneous products	1,892 (0.77%)
Minerals	36,288 (1.91%)	Specialized unclassified products	1,600 (0.65%)
Others	182,240 (9.6%)	Others	4,915 (2.00%)
Total	1,898,381 (100%)	Total	245,751 (100%)

(b) China Imports

Total Import Items	(000,000 USD) Ad-Valorem	**Air Cargo Import** Items	(000,000 USD) Ad-Valorem
Machineries, electrical apparatus	550,246 (31.56%)	Machineries, electrical apparatus	210,653 (68.85%)
Minerals	432,249 (24.79%)	Precision Instruments and equipment	34,863 (11.39%)
Base metal	118,836 (6.82%)	Chemical Products	18,561 (6.07%)
Chemical Products	117,962 (6.77%)	Transportation equipment	13,275 (4.34%)
Precision Instruments and equipment	102,674 (5.89%)	Precious stones and metal	7,342 (2.40%)
Rubber and plastic products	93,259 (5.35%)	Base metal	5,266 (1.72%)
Transportation equipment	83,030 (4.76%)	Rubber and plastic products	3,997 (1.31%)
Special and unclassified products	49,498 (2.84%)	Textile products	3,068 (1.00%)
Plant products	40,225 (2.31%)	leather and fur articles	1,809 (0.59%)
Textile products	37,588 (2.16%)	Stone, plaster, cement	1,792 (0.59%)
Others	117860 (6.76%)	Others	5,324 (1.74%)
Total	1743484 (100%)		305,963 (100%)

Note: Figures in parentheses are the ad-valorem share of the item in total trade.
Source: China Statistics Year Book, 2012 edition; China Customs

Table 6. China's major trading partners ranked by value for 2011

Total trade		**Air cargo trade**					
Country	**Total trade**	**Country**	**Air trade**	**Country**	**Air export**	**Country**	**Air import**
United States	12.71%	United States	18.26%	United States	24.97%	Japan	13.28%
Japan	9.76%	Japan	10.46%	Hong Kong	10.44%	Taiwan	12.92%
Hong Kong	8.07%	South Korea	9.03%	Japan	7.22%	South Korea	12.48%
South Korea	6.99%	Taiwan	8.91%	Netherlands	5.36%	United States	12.40%
Germany	4.81%	Germany	7.07%	Germany	5.30%	Malaysia	9.52%
Taiwan	4.55%	Malaysia	5.99%	South Korea	5.08%	Germany	8.61%
Australia	3.32%	Hong Kong	5.46%	Taiwan	4.31%	France	3.41%
Malaysia	2.56%	Singapore	2.97%	Singapore	3.20%	Thailand	3.11%
Brazil	2.40%	Netherlands	2.92%	United Kingdom	2.59%	Singapore	2.78%
Russian	2.26%	France	2.88%	India	2.43%	Switzerland	2.45%
Others	42.75%	Others	26.05%	Others	29.10%	Others	19.04%

Source: China statistics year book 2012 edition; China Customs

Table 7. China's trade imbalance indices for air and total trade in 2011

Country Name	**Air trade**	**Total trade**
United States	0.27	0.45
Japan	-0.36	-0.14
South Korea	-0.48	-0.32
Taiwan	-0.55	-0.56
Germany	-0.30	-0.10
Malaysia	-0.70	-0.38
Hong Kong	0.78	0.89
Singapore	0.00	0.12
Netherlands	0.71	0.75
France	-0.27	0.15

Table 8. Data descriptive summary of Model 1

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
trade	100	5.26E+09	1.37E+10	2.90E+07	9.63E+10
export	100	2.45E+09	7.16E+09	1172709	6.14E+10
import	100	2.81E+09	7.87E+09	26520	3.74E+10
airshare	100	0.118	0.140	0.001	0.836
gdp	100	6.16E+11	1.69E+12	8.76E+09	1.50E+13
pop	100	5.02E+07	1.32E+08	415654	1.24E+09
dist	100	7950.86	3991.391	956	19274
tertiary	100	0.60333	0.148296	0.221	0.936
border	100	0.100	0.302	0.000	1.000
culture	100	0.060	0.239	0.000	1.000
lib	100	0.020	0.141	0.000	1.000

Table 9. Gravity model estimation results for Model 1

Dependent Variable	lnAirtrade	*lnAirexport*	*lnAirimport*	lnTotaltrade	lnAirshare
constant	1.88	*0.77*	*1.82*	3.46	-1.19
	(2.54)	*(1.96)*	*(5.90)*	(2.19)	(2.68)
lngdp	1.10**	*1.05***	*1.19***	0.85**	0.26**
	(0.09)	*(0.07)*	*(0.21)*	(0.08)	(0.09)
lnpop	-0.04	*0.02*	*0.17*	0.06	-0.09
	(0.12)	*(0.10)*	*(0.24)*	(0.08)	(0.12)
lndist	-1.00**	*-0.90***	*-1.68***	-0.41**	-0.66**
	(0.20)	*(0.16)*	*(0.44)*	(0.18)	(0.22)
lntertiary	1.47**	*1.19***	*5.10***	-0.39	1.89**
	(0.46)	*(0.36)*	*(0.97)*	(0.38)	(0.54)
border	-0.82*	*-0.41*	*-1.84**	-0.06	-0.84**
	(0.50)	*(0.40)*	*(1.16)*	(0.41)	(0.48)
culture	1.46*	*1.04**	*1.76*	1.50**	-0.10
	(0.76)	*(0.58)*	*(1.41)*	(0.43)	(0.73)
lib	0.55	*0.88***	*0.41*		0.34
	(0.39)	*(0.37)*	*(0.85)*		(0.43)
No. of Obs.	100	100	100.0	100.0	100
Prob. > F	0.00	0.00	0.0	0.0	0.00
R-squared	0.77	0.81	0.6	0.8	0.32
Root MSE	1.11	0.93	2.5	0.8	1.18

Note: Figures in parentheses are standard errors adjusted for heteroscedasticity
* Significant at the 10% level, ** Significant at the 5% level, *** Significant at the 1% level

Table 10. Outbound and return flights' air cargo comparison between China and major trading partners

	Export/Import	2002	2003	2004	2005	2006	2007	2008	2009
Korea	weight	1.27	1.23	1.34	1.49	1.75	1.64	1.36	1.06
	value	0.54	0.47	0.45	0.46	0.50	0.54	0.66	0.52
Australia	weight	2.30	3.45	6.20	4.46	4.27	3.43	2.78	2.61
	value	0.78	0.86	0.77	0.68	0.64	0.70	0.59	0.52
Japan	weight	1.77	1.72	1.82	1.89	1.75	1.66	1.89	1.84
	value	0.91	0.80	0.78	0.84	0.79	0.76	0.77	0.75
ASEAN	weight	1.17	1.34	1.48	1.43	1.52	1.53	1.46	1.55
	value	0.76	0.65	0.68	0.74	0.80	0.87	0.98	1.00
Canada	weight	1.96	1.73	2.49	2.15	2.03	1.95	1.81	1.83
	value	1.18	1.29	1.00	1.55	2.02	1.77	1.72	1.47
European Union	weight	1.09	1.30	1.58	1.80	1.71	1.63	2.36	1.89
	value	1.25	1.36	1.53	1.95	2.01	2.21	2.17	1.85
US	weight	2.38	2.37	2.80	3.17	3.30	3.36	3.09	3.60
	value	2.57	2.73	2.80	3.34	3.44	3.35	3.10	2.85

Source: Zheng and Chen (2012)

Table 11. Trade statistics summary for China's three economic zones in 2011

Economic Zones	Total trade	*Export*	*Import*	Air trade	*Air export*	*Air import*
Pearl River Delta	10,067,940 (27.6%)	*5,632,160 (29.7%)*	*4,435,780 (25.4%)*	19,006 (3.4%)	*7,698 (3.1%)*	*11,308 (3.7%)*
Yangtze River Delta	13,658,002 (37.5%)	*7,619,755 (40.1%)*	*6,038,247 (34.6%)*	358,146 (64.9%)	*167,920 (68.3%)*	*190,226 (62.2%)*
Bohai Economic Rim	7,226,379 (19.8%)	*2,981,783 (15.7%)*	*4,244,596 (24.3%)*	111,389 (20.2%)	*45,282 (18.4%)*	*66,107 (21.6%)*
Total	36,418,644 (100%)	*18,983,809 (100%)*	*17,434,836 (100%)*	551,674 (100%)	*245,751 (100%)*	*305,923 (100%)*

Note: 1.) The Pearl River Delta includes Guangdong province. The major airports include Guangzhou and Shenzhen. The Yangtze River Delta includes the city of Shanghai, and Jiangsu and Zhejiang provinces. The major airports include Shanghai Pudong and Hongqiao, Nanjing and Hangzhou. The Bohai Economic Rim includes the city of Beijing and Tianjin, and Hebei, Liaoning and Shandong provinces. The major airports include Beijing, Tianjin, Dalian, Qingdao and Shenyang.
2.) Figures in parentheses are the shares of total international trade categories.
Source: China 2012 Year Book; China Customs

Table 12. Gravity model estimation results for Model 2

Dependent Variable		lnairtrade	*lnairexport*	*lnairimport*
	Constant	-33.42***	*-33.52****	*-38.26****
		(2.99)	*(2.68)*	*(6.45)*
	lndist	-0.95***	*-0.81****	*-1.71****
		(0.14)	*(0.12)*	*(0.28)*
	border	-0.91***	*-0.69***	*-1.94****
		(0.32)	*(0.35)*	*(0.68)*
	culture	1.29**	*0.88*	*1.43*
		(0.54)	*(0.65)*	*(0.94)*
Pearl River Delta	***lnagdp***	*1.99****	*1.60****	*2.29****
		(0.19)	*(0.20)*	*(0.40)*
	lnapop	*0.36*	*0.84****	*0.74*
		(0.27)	*(0.31)*	*(0.57)*
	lnatertiary	*0.57*	*0.41*	*8.38****
		(0.99)	*(0.96)*	*(2.56)*
	lib	*0.65*	*1.10**	*0.56*
		(0.42)	*(0.66)*	*(0.78)*
Yangtze River Delta	***lnagdp***	*2.43****	*2.33****	*2.69****
		(0.17)	*(0.15)*	*(0.34)*
	lnapop	*-0.08*	*-0.04*	*0.31*
		(0.24)	*(0.20)*	*(0.46)*
	lnatertiary	*4.18****	*3.53****	*11.00****
		(0.93)	*(0.80)*	*(1.83)*
	lib	*0.52*	*0.93**	*0.33*
		(0.53)	*(0.55)*	*(1.05)*
Bohai Economic Rim	***lnagdp***	*2.20****	*1.98****	*2.44****
		(0.14)	*(0.14)*	*(0.34)*
	lnapop	*0.16*	*0.37***	*0.68*
		(0.19)	*(0.17)*	*(0.47)*
	lnatertiary	*2.59****	*1.92****	*12.05****
		(0.70)	*(0.67)*	*(1.85)*
	lib	*0.22*	*0.22*	*0.37*
		(0.41)	*(0.49)*	*(0.94)*
	Number of obs.	300	*300*	*298*
	Prob. > F	0.00	*0.00*	*0.00*
	R-squared	0.78	*0.79*	*0.59*
	Root MSE	1.21	*1.15*	*2.68*

Note: Figures in parentheses are standard errors adjusted for heteroscedasticity
* Significant at the 10% level, ** Significant at the 5% level, *** Significant at the 1% level

Table 13. The global ranking of airport cargo throughput (ton) in 2011

2011 Rank	Airport	Total Cargo	2011 vs. 2010	2010 Rank
1	HONG KONG, HK (HKG)*	3,939,000	-4.60%	1
2	MEMPHIS TN, US (MEM)	3,917,207	0.00%	2
3	SHANGHAI, CN (PVG)*	3,085,268	-4.40%	3
4	INCHEON, KR (ICN)	2,539,222	-5.40%	4
5	ANCHORAGE AK, US (ANC)	2,526,815	-4.50%	5
6	PARIS, FR (CDG	2,307,902	-3.80%	6
7	FRANKFURT, DE (FRA)	2,251,618	-2.40%	7
8	DUBAI, AE (DXB)	2,190,000	-0.50%	8
9	LOUISVILLE KY, US (SDF)	2,188,422	1.00%	10
10	TOKYO, JP (NRT)	1,939,473	-10.50%	9
11	SINGAPORE, SG (SIN)	1,893,218	2.80%	11
12	MIAMI FL, US (MIA)	1,842,304	0.30%	12
13	LOS ANGELES CA, US (LAX)	1,681,610	-3.80%	14
14	BEIJING, CN (PEK)*	1,632,994	5.30%	15
15	TAIPEI, TW (TPE)	1,627,462	-7.90%	13
16	LONDON, GB (LHR)	1,563,415	0.80%	16
17	AMSTERDAM, NL (AMS)	1,549,686	0.80%	17
18	GUANGZHOU, CN (CAN)*	1,425,900	24.60%	21
19	CHICAGO IL, US (ORD)	1,365,510	-4.60%	18
20	NEW YORK NY, US (JFK)	1,349,267	0.40%	19

Source: Airports Council International.
Note: the airports with * are Chinese airports and Hong Kong International Airport

Appendix 1. Formula for HHI and Gini Indices

The ***Herfindahl-Hirschman*** index is calculated as

$$HHI = \sum_{i=1}^{N} s_i^2 \times 10000$$

where s_i is the share of airport i in Chinese total air cargo traffic.

The Gini index is calculated as

$$G = \frac{N+1}{N} - \frac{2\sum_1^N (N+1-i)X_i}{N\sum_1^N X_i}$$

where X_i is the cargo volume for airport i.

Appendix 2. Clustering coefficients and average shortest path length.

The clustering coefficient for airport i is calculated with the following formula:

$$C(\Gamma_i) = \frac{E(\Gamma_i)}{C_m^2}$$

where $E(\Gamma_i)$ is the number of real connections in Γ_i consisting of m airports, and C_m^2 is the total number of all possible connections in Γ_i. The average clustering coefficient of the entire air network is defined as

$$C = \frac{1}{N}\sum_{\Gamma_i} C(\Gamma_i)$$

where N is the number of airports in the whole network.