Measuring air connectivity between China and Australia

Abstract: This paper assesses air connectivity between China and Australia for the period 2005–16 using a Connectivity Utility Model. Our direct connectivity measure shows that as a gateway city, Sydney continues to play a key role in facilitating the movements of people and goods between China and Australia. Guangzhou has become the city best connected with Australia since 2011 as measured by direct connectivity. When indirect connections are considered, the largest increases in overall connectivity from 2005 to 2016 can be observed among Australia's major capital cities, particularly Sydney, Melbourne and Brisbane. Chinese carriers are the key drivers behind the increases. There have been rises and falls for airports serving as a hub between China and Australia. Guangzhou has forged its strong status as a transfer hub between Australia and China thanks to the quick expansion of China Southern. The gaps between Guangzhou and other transfer hubs measured by hub connectivity have widened since 2010.

Key words: Direct connectivity; indirect connectivity; hub connectivity; air transport; China; Australia

1. Introduction

Air transport between Australia and China has experienced a phenomenal growth during the past decade. In 2005 only Beijing, Shanghai and Guangzhou in China had direct flights to Sydney and Melbourne in Australia. At that time, many Chinese travellers used Hong Kong, Singapore and even Seoul, Korea as a transfer point to Australia. However, in 2016, there were seven Chinese airlines providing direct flight services between China and Australia – from ten cities in China to Australia's major capital cities, although Sydney and Melbourne remained the most interested destinations.

In December 2016 an open skies arrangement was concluded between China and Australia. It removed all capacity restrictions for each country's airlines. This arrangement arose through an intention to cater for the increasing number of Chinese visitors to Australia. Since 2010 Chinese tourists have been Australia's biggest spenders, and the China market is expected to be the most valuable inbound market for the next decade (Zhang and Peng, 2014). Geographers have identified the expansion of air transport as one of the key drivers of globalisation (Adey et al., 2007). Air transport has not only facilitated tourism between China and Australia, but it has also provided access to new markets for businesses in both countries. China has been Australia's largest trading partner since 2009. Although China and Australia concluded a free trade agreement in 2015, it is understood that trade barriers due to infrastructure and transport services, especially air transport services, cannot be resolved easily in a free trade agreement because most free trade agreements do not address the liberalisation of air transport services. Improving connectivity is increasingly a topic at the top of international trade and transport policy agenda (Calatayud et al., 2016).

Scholarly research into the air transport connections between the two nations is rare. Gao and Koo (2014) might be the only academic paper to discuss the emergence of the 'Canton Route'. A comprehensive assessment of the air connectivity between the two countries is lacking. Huang and Wang (2017) investigated the spatial patterns of indirect connections of the top hub airports in China for 2012 and 2015, but they did not specifically address the connectivity between China and Australia. Considering the strong economic ties between China and Australia, it is necessary to assess the air connectivity between the two nations given its strong relationship to economic development and growth (Basile et al., 2006; Zhang, 2012; Banno and Redondi, 2014; Li and Qi, 2016). It is particularly important for a city or a region to understand the level of its air connectivity in the air transport network in order to attract tourists, business investment and human capital.

In considering both the direct and indirect connections for Chinese and Australian cities for the period 2005–16, we make two contributions. First, this paper extends the Connectivity Utility Model (ConnUM) developed in Zhu et al. (2018) and considers all of the flight schedule information in calculating the air connectivity at the airport/city and national levels, which is of great value to governments at all levels for identifying gaps in air service provisions, detecting weak points in the existing transport network and seeking ways to improve the reliability and accessibility of the network to reduce travel time and costs (Hadas et al., 2017). This research also examines the hub connectivity of the key airports that have served as transfer hubs between China and Australia, which will provide a strong basis for airport managements to develop strategies to boost their hub status. Second, in the airline economics literature there are numerous studies examining the relationship between air service provision and economic activities (see, e.g., Button and Taylor, 2000; Matsumoto, 2004, 2007, Matsumoto et al., 2016). However, few of these studies use a comprehensive and systematic measure of air transport service provision that captures consumers' utility. The comprehensive and consistent measure for air connectivity developed in this research will provide a better proxy of air service provision and can be used in future studies examining the effects of air transport on economic activities.

The next section will review the relevant literature, followed by a description of the ConnUM for measuring air connectivity. Section 4 reports the results and interpretations. The last section provides a summary and a conclusion.

2. Literature review

A safe and well-connected transport network is vital for the efficient functioning of a country's economy. Numerous literature has examined the intertwined relationship between air transport and economic development (see, e.g., Cristea 2011; Banno and Redondi, 2014; Van De Vijver et al., 2014; Matsumoto et al., 2016). Baker et al. (2015) reveal significant bi-directional relationship between regional economic growth and regional air transport services in Australia. Blonigen and Cristea (2015) provide strong evidence that a 50% increase in an average city's air traffic growth could result in an additional 7.4% increase in real GDP in the US. Liu et al. (2013) show that cities with a higher level of air connectivity are appealing to globalised business service firms, which in turn can stimulate the development of aviation connections. However, Ng et al. (2018) argue that transport infrastructures have a strong influence over the patterns of regional and national development, but such influence is greater on the more established cities ad areas. In particular, O'Connor (2010) and O'Connor et al. (2016) pointed out that a large part of the world's sea and air cargoes are handled at a small number of cities and places, which play a significant role in the location decisions of the largest logistics service companies. Therefore, the aviation gateway cities have significant implications to a country's economy (O'Connor and Fuellhart, 2015).

There has been much literature evaluating air services at cities (see, e.g., Derudder and Witlox, 2014). For a long time, Tokyo, Hong Kong and Singapore were the most important international aviation hubs in East Asia (Matsumoto, 2004, 2007). However, Matsumoto et al. (2016) found that Seoul, Guangzhou, Ho Chi Minh City and Hanoi, have been rising rapidly in terms of their aviation hub status since 2000. De Wit et al (2009) reveal that while Tokyo has the best network performance and hub competitive position in the Asia Pacific rim, Chinese airports are experiencing the most striking growth of network development. They also found that the network performance deteriorates at Oceanian airports. O'Connor et al. (2018) examined the distribution of air services among Chinese cities between 2005 and 2015 with a consideration of the number of routes, departures, and the number of seats available. They found that the competitive position of Chinese cities in the nations' air transport market did not changed much during the studied period. Although a small number of regional cities have strengthened their role in the air transport network, the ranks of the seven leading cities remain unchanged. In particular, cities in the three mega-metropolitan regions, Beijing–Tianjin, Shanghai, Hong Kong–Shenzhen–Guangzhou, play a dominant role in China's air transport systems (Zheng et al. 2009, Wu and Dong, 2015).

Air transport deregulation is one of the key factors that drive the changes in airlines' behaviour and the provisions of air services at national, regional and local levels (Goetz and Sutton, 1997; Burghouwt and Hakfoort, 2001; Wei, 2007; Williams, 2009). Wang et al. (2014) analyse the evolution process of the air transport network of China from 1930 to 2012 and report a three-stage evolvement since the 1980s when the deregulation process began: hub formation, a complex network structure and emerging multi-airport systems. Over the last 20 years, Chinese major carriers have developed multiple hubs (bases) through mergers and acquisitions (Zhang and Round, 2008). Such expansion was supported by the local governments--many secondary cities in China provide subsidies to attract airlines to build bases and operate international services out of their local airports (Zhang and Lu, 2013). In the case of Australia, O'Connor (1998) observed a shift of the country's international airline linkages in favour of the Asian countries from 1985 to 1996, reflecting the shifts in trade and immigration. Such shifts strengthened the role of Cairns and Brisbane as gateways for the tourism industry, but the dominance role of the nation's aviation gateways, Sydney and Melbourne, was not weakened, which is still the case today (Fuellhart and O'Connor, 2013; O'Connor and Fuellhart, 2015; O'Connor, 2018).

When assessing the air services at cities and regions, researchers have used different definitions for air connectivity. Traditional approaches to measuring air connectivity include the number of destinations or the number of direct flights from/to an airport. A good review of recently developed connectivity models can be found in Burghouwt and Redondi (2013), Suau-Sanchez et al. (2015), Calatayud et al. (2016) and Zeigler et al. (2017). Calatayud et al. (2016) show that some transport economics literature defines connectivity based on infrastructure availability and capacity (see, e.g., Moreno and Lopez, 2007; Wilmsmeier and Hoffmann, 2008). Márquez-Ramos et al. (2011) referred to this as a narrow concept of connectivity because this definition only focuses on the physical properties of a network. A broader definition for connectivity emphasises the importance of the availability and the capacity of transport services within the framework of complex systems theory (see, e.g., Alderighi et al., 2007; Malighetti et al., 2008; Redondi et al., 2011). Zeigler et al. (2017) note that one stream of air connectivity measures is constructed based on flight schedule date such as the NetScan (Veldhius, 1997) and the accessibility index (Redondi et al., 2013) models. Another stream of measures is demand-based studies which require the use of passenger traffic or booking data (e.g., Wang et al., 2011). The connectivity measure used in this research is the single transport mode version of the model developed in Zhu et al. (2018) that has its origin in the NetScan model. The ConnUM incorporates multiple quality-adjustment factors such as capacity and velocity penalties so as to correct/adjust for the quality of a connection. It can be used to measure the direct and indirect, single- and multi-modal connections of a city, region or country. By revealing the level of air connections of cities in China and Australia using such a comprehensive measure, this research will add knowledge to the understanding of the hierarchy and the specific roles of cities in the two countries.

3. Methodology

2.1 The Connectivity Utility Model

The ConnUM is modified to consider the air transport mode only. By incorporating multiple connection quality factors such as travel time, speed, comfort and convenience, the connectivity calculated in this study captures air passengers' travel utility and reflects both the quantity and quality levels of air transport services provided to passengers. The construction of a modified ConnUM measuring air connectivity is briefly described below.[1] Previous literature such as Vowles (2001), Bowen (2010), and O'Connor and Fuellhart (2012) has shown that airline type, aircraft used and low cost carrier (LCC) operations are significant factors that can shape the air service at a city. In fact, for most travellers the availability of seats (capacity), trip duration (velocity) and the quality of transfer (for indirect connections) are among the most important quality factors. These are considered in our model. Considering that dissatisfaction with any one of those three preferences would lead to 0 utility (Keeney, 1974), a multiplicative utility function is adopted. We use equal weights for all preferences.[2] For convenience, the utility scores of capacity, velocity and transfer quality are named as capacity discount, velocity discount and transfer discount, respectively. The connectivity of flight *k* from airport i to airport j is:[3]

$$\text{Connectivity}_{ijk} = D_{{Cap}_{ijk}} \times D_{{Vel}_{ijk}} \times D_{{Trans}_{ijk}} \tag{1}$$

where $D_{{Cap}_{ijk}}$ denotes the capacity discount for connection *k* between airports *i* and j. $D_{{Vel}_{ijk}}$ represents the velocity discount and $D_{{Trans}_{ijk}}$ is the transfer discount.[4]

As noted in Zhang et al. (2017), capacity is a key indicator measuring connection quality. Larger aircraft are usually preferred by passengers as they tend to carry more passengers, and provide more seats and space (Coldren et al., 2003). A concave function in the form of a

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[1] Readers can refer to Zhu et al. (2018) for the full methodology for constructing the multi-modal connectivity measure based on ConnUM.

[2] We tried different weights and the results were quite consistent.

[3] *k* represents a unique connection (direct or indirect) between origin airport i and destination airport j. Every connection on a route between airport *i* and airport *j* is treated as a different connection, even for the connection with the same flight number on a different date, as the connection might use a different type of aircraft and thus represents a unique level of service quality. This implies that the frequency for every connection is always 1. We understand that in reality, many people would regard a flight as a direct flight if it has an intermediate stop, but there is no change in the flight number.

[4] Transfer discount is always 1 for direct flights.

squared root is used for measuring capacity discount. This is because the marginal benefit of having more seats in a plane diminishes after a certain point, and the extra benefit of having an additional 100-seat flight is greater than that of changing a 100-seat aircraft to a larger aircraft with a capacity of 200 seats for a connection. This reflects the fact that passengers place more value on frequency (Wei and Hansen, 2005). We choose the capacity of the largest aircraft in use in 2005, 434 seats, as a benchmark to calculate the capacity discount,[5] which can be expressed as:

$$D_{Cap_{ijk}} = \sqrt{\frac{Seat_{ijk}}{\mathrm{Seat}_0}} \tag{2}$$

where $Seat_{ijk}$ represents the number of seats on connection k. For an indirect connection it is the number of seats of the flight segment with a smaller seat capacity. Seat_0 is the number of seats of the benchmark aircraft, which is 434 in this study.

Velocity is another important indicator for connection quality. If the passenger takes an indirect connection, the time he/she spends at the transit stop would be more uncomfortable or stressful than the in-flight time. Therefore, both the extra time needed at the airports and the penalty for transfer should be reflected in the velocity discount. The velocity discount is calculated based on the following system of equations:

$$Duration_{Adjusted_{ijk}} = T_{arrive_{ijk}} - T_{depart_{ijk}} + \mathrm{p}_T \times t_{transfer_{ijk}} + t_{airport_{ijk}} \tag{3}$$

$$\mathrm{Velocity}_{ijk} = \frac{Distance_{ij}}{Duration_{Adjusted_{ijk}}} \tag{4}$$

$$\mathrm{D}_{Vel_{ijk}} = \sqrt{\frac{\mathrm{Velocity}_{ijk}}{\mathrm{Velocity}_0}} \tag{5}$$

where $Duration_{Adjusted_{ijk}}$ is the adjusted time length (duration) of $\mathrm{connection}_k$ from $airport_i$ to $airport_j$. The scheduled in-flight time between two airports is the difference between the scheduled arrival time and scheduled departure time,[6] represented by $T_{arrive_{ijk}} - T_{depart_{ijk}}$. Extra time at the airports is represented by $t_{airport_{ijk}}$. For indirect connections the additional penalty for spending time at the transfer airport is a penalty factor

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[5] In effect, we can choose any type of aircraft as our benchmark because it will only affect the scale of the capacity discount and, subsequently, the connectivity scores without hampering the purpose of comparing these scores across airports or over years.

[6] Transfer time is included in indirect connections. We understand that the actual flying time might be shorter than the published estimated flying time as these days longer taxiing time at the busy airports is required and the estimated flying time will have to consider this as well as other infrastructure constraints.

p_T times $t_{transfer_{ijk}}$. The velocity ($\mathrm{Velocity}_{ijk}$) is calculated by dividing the great circle distance between airport *i* and airport *j* by the adjusted time duration. The velocity discount is calculated by comparing the velocity of a connection against the benchmark velocity, $\mathrm{Velocity}_0$, which is assumed to be 850 km/h.[7] In this study we assume that the extra time needed at the airports (both departure and arrival airports) is 100 minutes for domestic flights and 180 minutes for international flights. Also, following previous literature such as De Wit et al. (2009), we assume the extra penalty for transfer time to be 50%.

The quality of indirect connections is largely dependent on the quality of transfer. Two aspects of the transfer quality are considered here: time and service. The time quality for transfer measures the quality of transfer time. When the transfer time is too short, passengers will have to rush to the boarding gate for the next flight, but still have a high chance of missing the connection. Thus, the transfer time quality is very low. However, if the transfer time is too long, the long wait will result in lower transfer quality. The transfer time quality function is thus built by mapping the difference between the transfer time and the minimum connection time (MCT) at an airport, Δt_{ijk}, for each indirect connection.[8] We set the time quality as 0.2 when the transfer time is the same as the MCT, 1 when the transfer time is 30 minutes longer than the MCT and 0.7 when the transfer time is 3 hours or more than the MCT.[9] The time quality function is as follows:

$$q_{ijk}^{T} = \begin{cases} 0, & \Delta t_{ijk} < -10 \\ (\Delta t_{ijk} + 10) \times 0.02, & -10 \le \Delta t_{ijk} < 0 \\ \dfrac{\Delta t_{ijk}}{30} \times 0.8 + 0.2, & 0 \le \Delta t_{ijk} < 30 \\ 1 - \dfrac{\Delta t_{ijk} - 30}{500}, & 30 \le \Delta t_{ijk} \le 180 \\ 0.7, & \Delta t_{ijk} > 180 \end{cases} \tag{6}$$

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[7] Statista (2018) suggests that major commercial jet aircraft cruise at about 420–500 knots or 778–926 km/h. Therefore, we assume that the average speed is 850 km/h.

[8] The MCT standards used here are those published by China Eastern Airline at Shanghai Pudong International Airport and Shanghai Hongqiao International Airport. That is, the MCT is 120 minutes if the transfer is within the same terminal and 160 minutes if the transfer occurs between terminals.

[9] We acknowledge that the assignment of the value of 0.2 is arbitrary and the connectivity values will depend on the values assigned to the time and service qualities. One can always try different values for these parameters, but this would not change the ranking order of the airports considered. However, future studies can consider using survey data to elicit more accurate values for these parameters.

where q_{ijk}^{T} represents the time quality for using indirect connection k from airport i to airport j; Δt_{ijk} represents the difference between the transfer time and the MCT at the transfer airport for indirect connection k.

The service quality for transfer measures the quality of transfer services such as walking distance, waiting lounge comfortableness and the availability of a flexible arrangement when a connection is missed. Service quality is different for different indirect connections. In most instances the service quality is mainly decided by the relationship between the airlines operating the two flight segments. When both flights are operated by the same airline or by airlines in the same alliance, the transfer service quality is generally better than the situation where the two segments are operated by two separate airlines without any cooperation agreement. In the case where one flight is operated by a LCC, the service quality would be relatively less desirable. Therefore, in this research the service quality for a transfer is assumed to be 1 when both flights are operated by the same airline and there is no LCC involved. A value of 0.9 is assigned for the service quality when the two segments are served by two airlines from the same alliance group. The value is 0.3 when two full-service airlines from different alliance groups are involved.[10] If the whole journey is served by the same LCC, the service quality is also assumed to be 0.3. We give a value of 0.1 to service quality for all other situations.[11]

The transfer discount can be expressed as:

$$D_{Trans_{ijk}} = q_{ijk}^{T} \times q_{ijk}^{S} \tag{7}$$

where q_{ijk}^{T} represents the time quality for the transfer of indirect connection k from airport i to airport j, and q_{ijk}^{S} is the service quality of transfer for indirect connection k from airport i to airport j.

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[10] It should be noted that this study does not distinguish the experiences of different travel cabins.

[11] The transfer service quality may also be affected by the transfer airport's facilities and services, which may cause an overestimation of indirect connectivity if the transfer airport's facilities and services are less desirable to passengers.

For simplicity, this research only considers one transfer for an indirect connection.[12] This is a realistic simplification as the vast majority of passengers travelling between Australia and China use direct flights or indirect flights with only one transfer point. Two types of connections, direct and indirect, are shown in Figure 1. De Wit et al. (2009) also identified a third type of connection: hub connection. In the indirect connection shown in Figure 1, airport x acts as a transfer hub, enabling the cooperation between connection k_1 and connection k_2. This type of hub connectivity is known as centrality (Burghouwt and Redondi, 2013). The centrality of airport x is the total connectivity of indirect connections with a transfer at airport x. The centrality of airport x can be defined as:

$$\text{centrality}_x = \sum_{\forall i,j,k\ transfer\ at\ x} \text{connectivity}_{ijk} \tag{8}$$

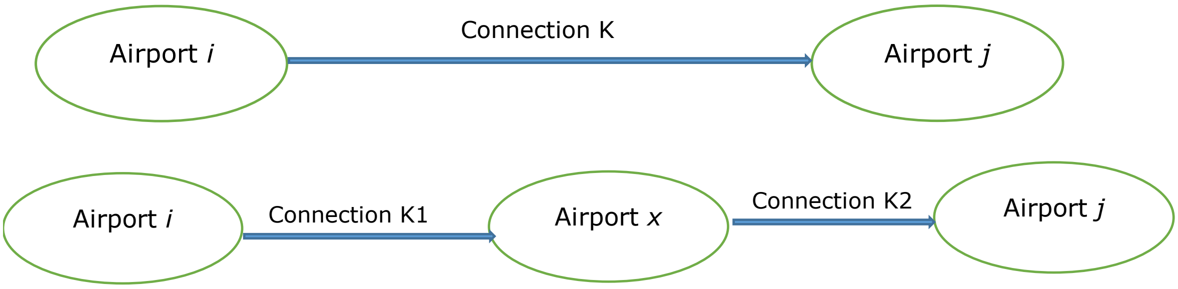

Figure 1: Two types of connections: direct and indirect.

The directional connectivity from airport *i* to airport *j* is the connectivity of route *i*→*j*, which is the aggregate connectivity for all connections (direct and indirect) on the route:

$$\text{connectivity}_{ij} = \sum_k \text{connectivity}_{ijk} \tag{9}$$

The connectivity of airport *i* is the aggregate of the connectivity for all routes starting or ending at airport *i*, which can be expressed as:

$$\text{connectivity}_i = \sum_j \text{connectivity}_{ij} + \sum_j \text{connectivity}_{ji} \tag{10}$$

2.2 The data

Given the restriction of data availability, we consider a period from 2005 to 2016. For each year, two weeks' flight information was collected: 10–16 April and 10–16 November. All the

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[12] We understand that we may underestimate the connectivity when passengers use two or more transfers. However, in 2016, only 1.7% of the passengers travelling from China to Australia involved two or more transfers according the AirportIS database.

direct flight information to and from China and Australia was extracted from IATA AirportIS database.[13] The flight data includes the flight number,[14] the number of seats, the origin airport, the destination airport, and the take-off and landing times. The time zone is then matched to every airport and the airline block time is calculated in minutes. As the connection dataset is a full set of all available air services to and from Chinese and Australian airports, the overall connectivity and centrality are produced for all airports involved.[15] Indirect connections are generated with the direct connection data for all Chinese and Australian airports, following the enumeration methods with programs coded in R language. The produced indirect connection dataset is then filtered with loose constraints in travel distance and transfer time: when taking indirect connections, the total distance of the connection is constrained to be smaller than twice the direct distance between the origin and destination airports; the transfer time at hub airports is limited to between 30 minutes and 24 hours. The distance and transfer time constraint can be expressed as:

$$distance_{ix} + distance_{xj} \leq 2 \times distance_{ij} \tag{11}$$

$$30 \leq t_{transfer_{ijk}} \leq 1440 \tag{12}$$

where $distance_{ix}$ denotes the great circle distance[16] between origin airport *i* and transfer airport *x*; $distance_{xj}$ denotes the great circle distance between transfer airport *x* and destination airport j; $distance_{ij}$ denotes the great circle distance between origin airport *i* and destination airport j; $t_{transit_{ijk}}$ denotes the transfer time at the transfer airport for indirect connection *k* from airport *i* to airport j. Another obvious constraint for indirect flights connecting China and Australia is that the original airport and the destination airport must be in either China or Australia.

4. Results and Analysis

3.1. Direct connectivity

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[13] The AirportIS database is constructed based on the reported information from IATA's Billing and Settlement Plan (BSP). The BSP reported information does not include data from low cost carriers, direct airline sales, scheduled charter or other carriers not using agencies. In areas where the ticket sales are not supported by BSP, there would be no ticket sales information.

[14] For code-sharing flights, only the operating flights are retained.

[15] Flights from mainland China to Hong Kong and Macau are treated as international flights.

[16] All great circle distances in this research are calculated with the Python package 'Geographiclib' using tGPS coordinates of OD.

Figures 2 and 3 show the direct connectivity between Australia and China of selected airports of the two countries for the period 2005–16, respectively. It can be seen that before 2010 only Sydney and Melbourne had direct connections to mainland China and only Shanghai, Guangzhou and Beijing were connected to Australia with direct services. Through China Southern, direct air services became available for Brisbane and Perth from 2010 and 2011, respectively. The direct connectivity score of Sydney almost tripled from 52 in 2005 to 148 in 2016. During the same period, the direct connectivity score for Melbourne increased from 14 to 101. The connectivity difference between Sydney and Melbourne can be considered substantial, given that in 2016 the connectivity sores for Brisbane and Perth were only 19 and 14, respectively. This is consistent with the findings reported in O'Connor (2018) that Sydney accounted for about 50% of passengers on direct services between China and Australia in 2016 and this number was about 30% for Melbourne. It is apparent that Sydney was in a leading position throughout the period in terms of the direct connectivity with China. The 2009 global financial crisis had a strong and negative impact on air connectivity and the direct connectivity almost halved for Sydney in 2009 but it rose quickly in 2010 and continued to grow in the following years. As a gateway and global city (O'Connor, 2018), Sydney continues to play a key role in facilitating the movements of people and goods between China and Australia.

Of the Chinese cities, Shanghai Pudong had the lead in direct connectivity before 2011, followed by Guangzhou and Beijing. However, Guangzhou surpassed Shanghai from 2011 and became the city best connected with Australia. Chengdu, Nanjing and Chongqing established their direct connection with Australia from 2013 and more Chinese secondary cities launched direct services to Australia in 2016, including Hangzhou, Qingdao, Fuzhou, Xiamen and so on. The ongoing deregulation in China's domestic market and the more liberal arrangement between China and Australia is key to this outcome.

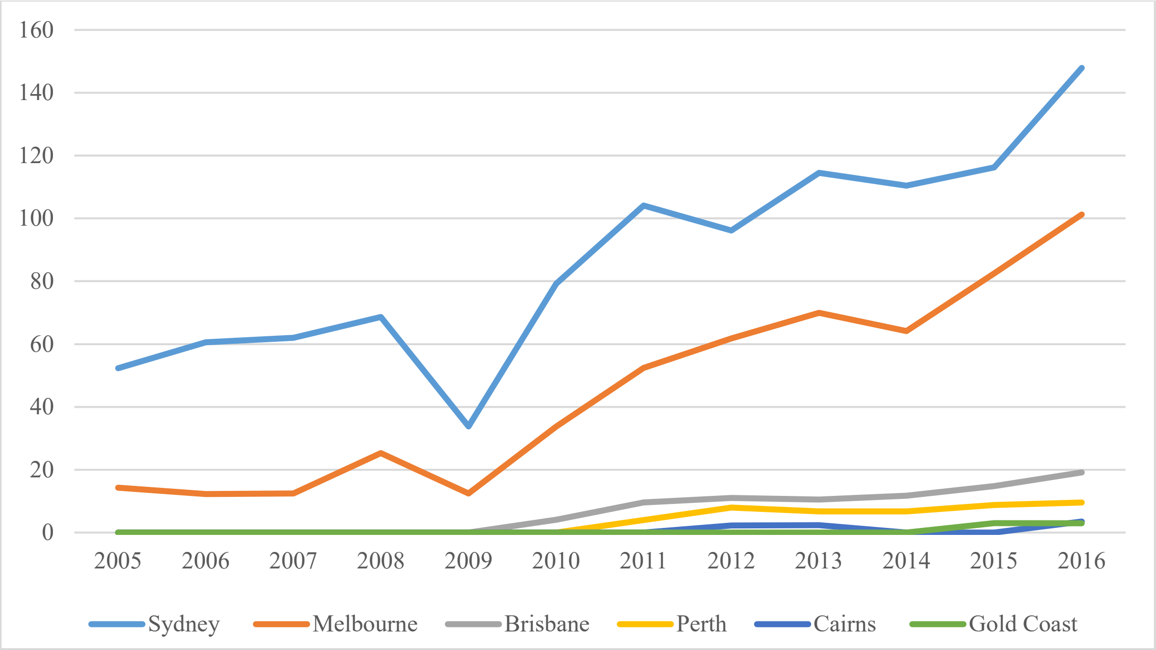

Figure 2: Direct connectivity (vertical axis) between Australia and China at Australian airports, 2005–16.

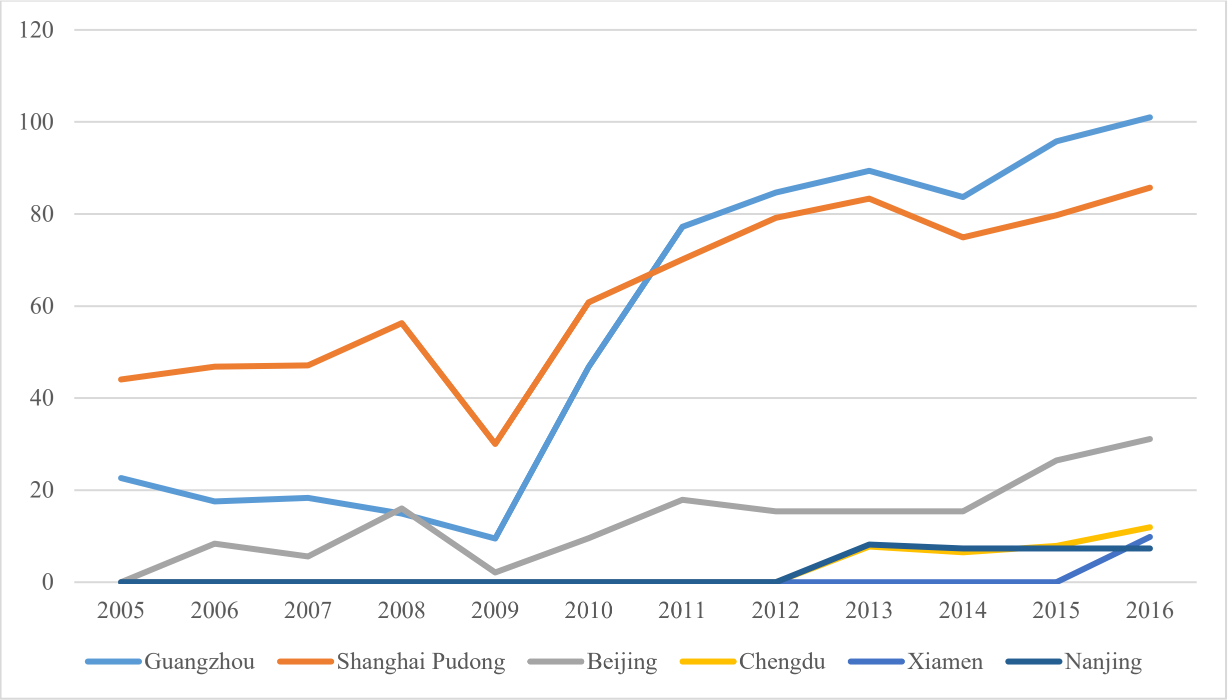

Figure 3: Direct connectivity (vertical axis) between Australia and China at Chinese airports, 2005–16.

As shown in Figure 4, in 2016 China Southern was the largest contributor to the direct connectivity between China and Australia (38%), followed by China Eastern's 21.8% and Air China's 18.6%. Qantas made a contribution of only 6.2%.

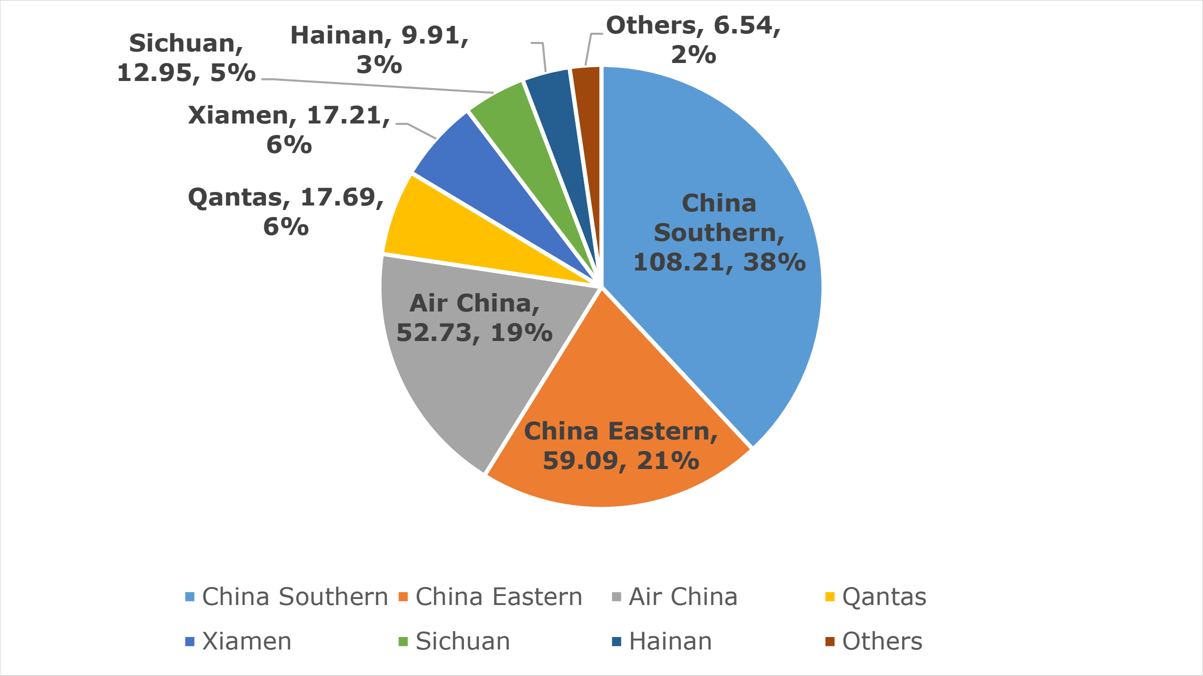

Figure 4: Individual carriers' contribution to direct air connectivity between China and Australia in 2016.

3.2 Overall connectivity (direct and indirect)

The overall connectivity scores of Chinese and Australian airports considering both direct and indirect connections are reported in Appendices 1 and 2. The airports are ranked based on their overall connectivity in 2016. Note that only indirect connections with one transfer point are considered in constructing the overall connectivity indices. Thanks to the contribution of indirect connections, we can see that the values of overall connectivity of the major cities in the two countries are 10–20 times higher than those of direct connectivity, implying that indirect connections give people living in these cities more choices for travelling between China and Australia.

Due to the small number of large cities, in general, Australia's main airports have much higher overall connectivity than their Chinese counterparts as these cities have good connections with major Asian hubs, which gives them a higher level of indirect connectivity. However, for its smaller cities their overall connectivity (purely due to indirect connections) is rather small in value, suggesting limited air services between Australia's regional and remote areas and its capital cities.

Figures 5 and 6 present a comparison of the connectivity between 2005 and 2016 for Australian and Chinese airports, respectively. A substantial increase in overall connectivity can be observed for Sydney, Melbourne, Brisbane and Perth airports in the former. The increases for major Chinese airports were also impressive but were not comparable with the large increases in Sydney and Melbourne. The trend can be seen more clearly in Figures 7 and 8, which show that the growth rate is much higher for Australia's major cities, particularly Sydney and Melbourne. Shanghai remained the best connected city in China throughout the period. However, the connectivity of Beijing and Guangzhou had caught up to it quickly by the end of 2016. Beijing surpassed Guangzhou to be the second best connected city with Australia, and was very close to Shanghai. The connectivity scores of many secondary cities did not differ much and they experienced modest growth (Figure 7).

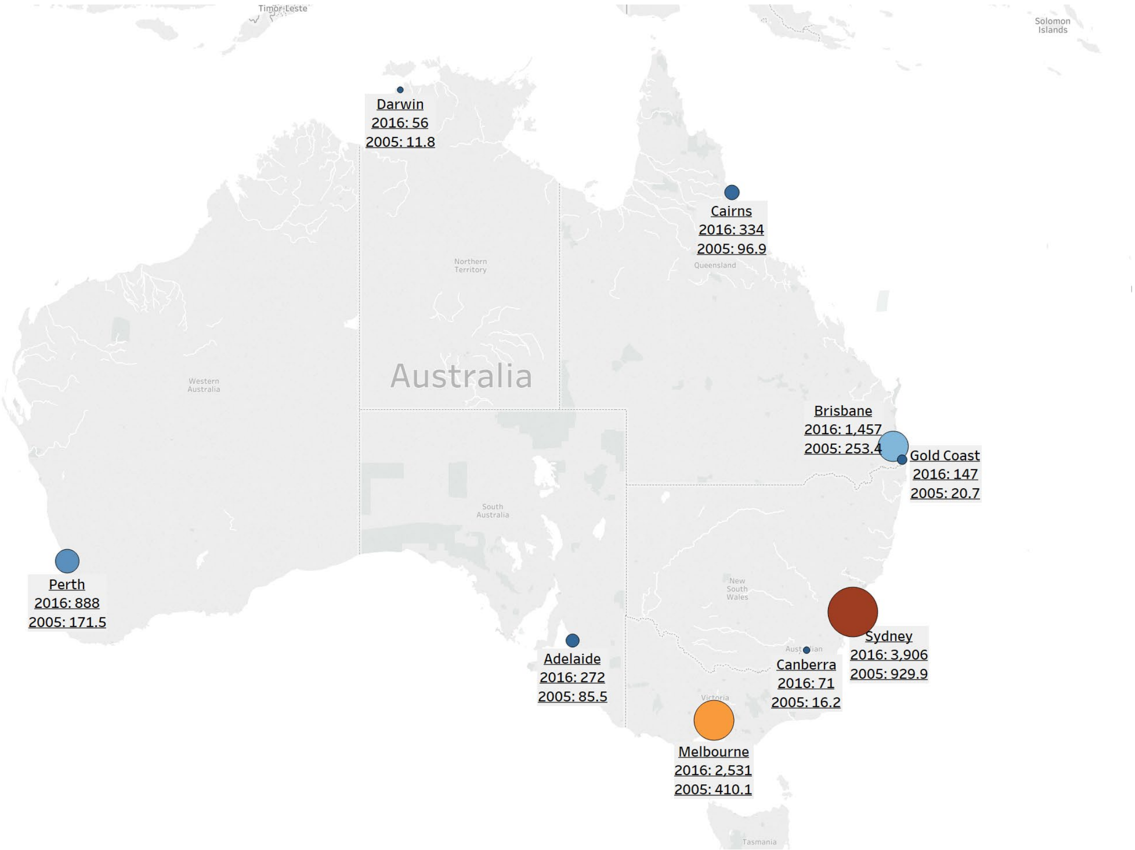

Figure 5: Comparison of overall connectivity for Australian cities (the size of the circle represents the level of connectivity in 2016).

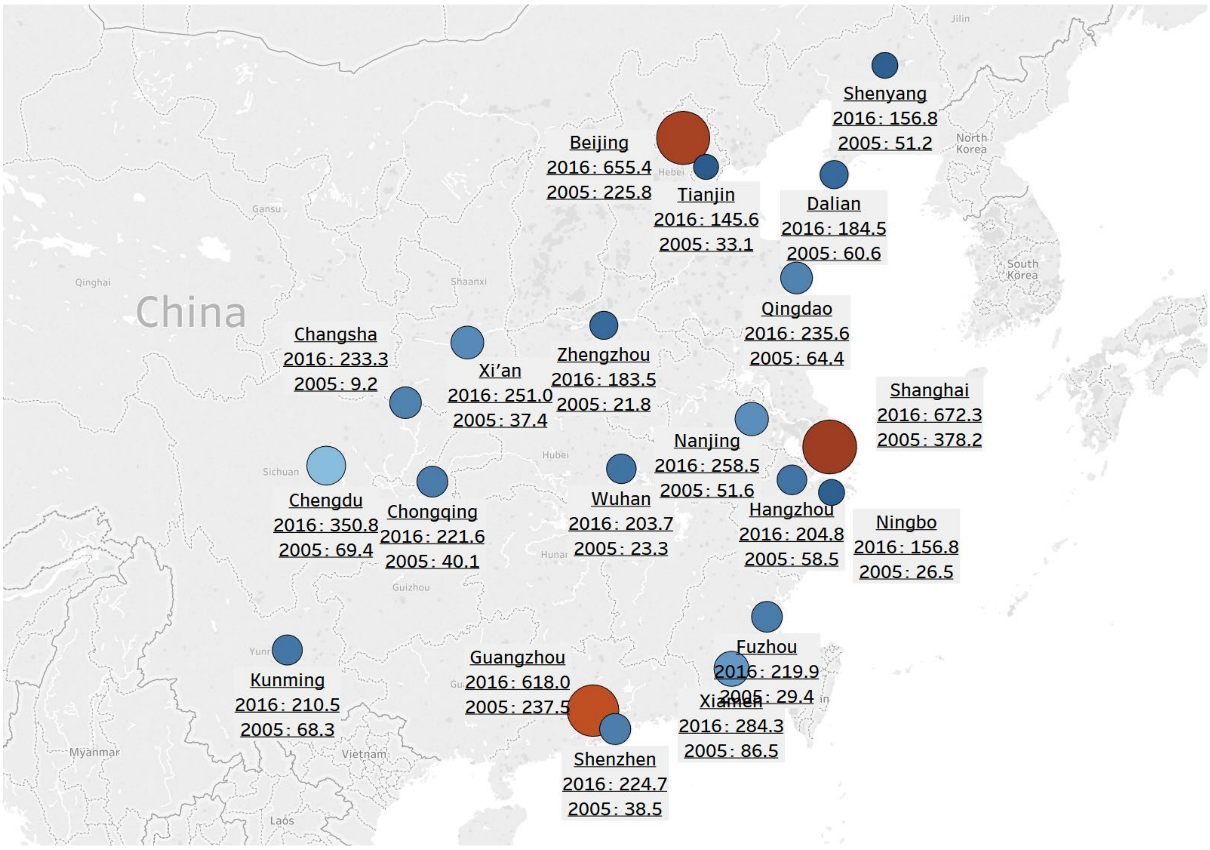

Figure 6: Comparison of overall connectivity for Chinese cities (the size of the circle represents the level of connectivity in 2016).

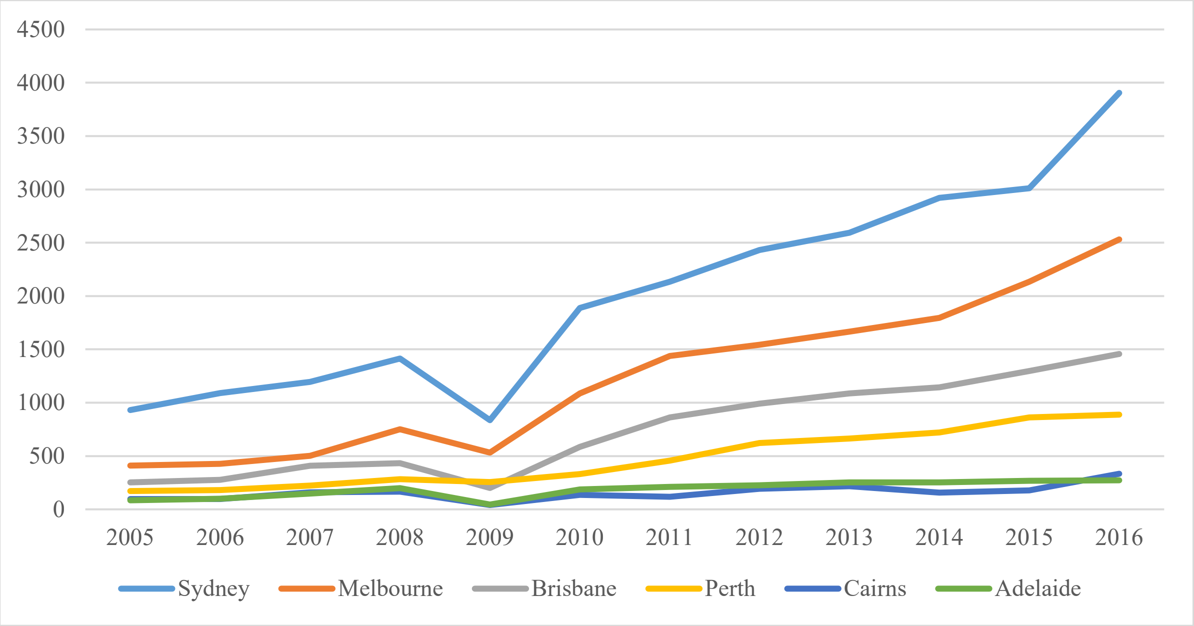

Figure 7: Overall connectivity (vertical axis) evolution trend at major Australian airports, 2005–16.

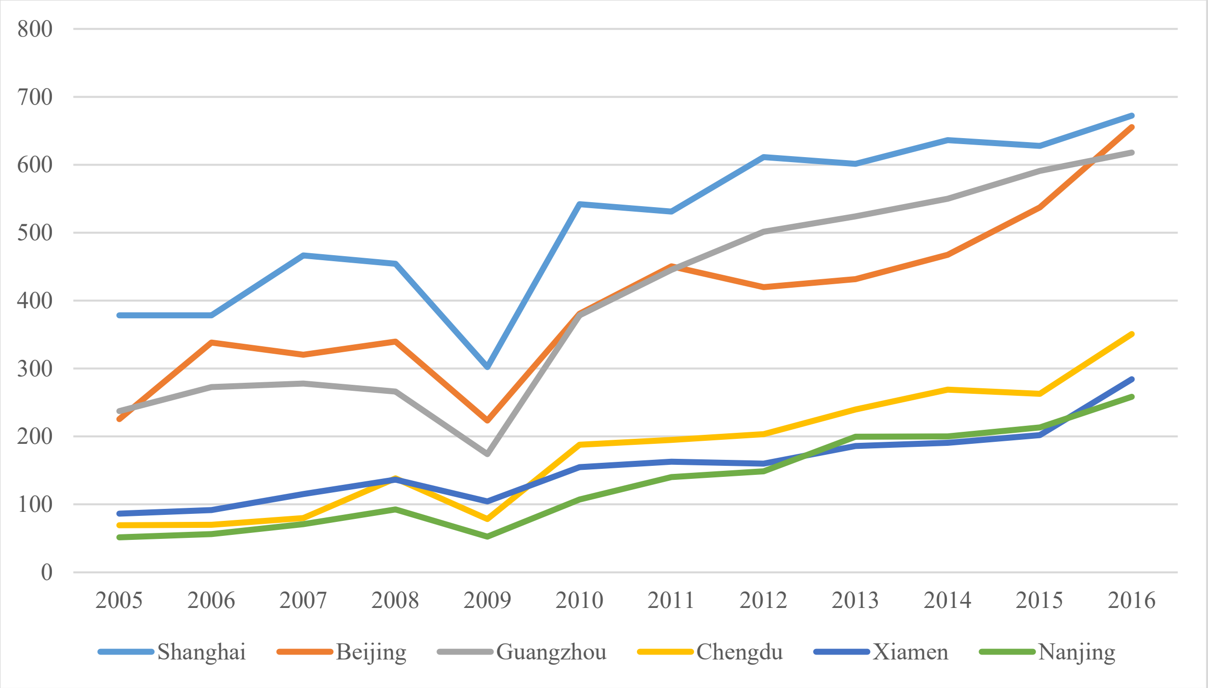

Figure 8: Overall connectivity (vertical axis) evolution trend at major Chinese airports, 2005–16.

We have calculated the loss of the overall connectivity between China and Australia if a carrier is excluded from the network in 2016. The results are reported in Table 1. If China Southern dropped out in 2016 the overall air connectivity between the two countries would suffer a loss of 39.1%. The exit of China Eastern would result in a reduction in connectivity by 20%, followed by Air China's 17.7%, Qantas' 14% and Cathay Pacific's 12.6%.

Table 1: The loss of overall connectivity if an airline ceased operation in 2016.

Airline	**Loss of air connectivity**
China Southern	39.1%
China Eastern	20.0%
Air China	17.7%
Qantas	14.0%
Cathay Pacific	12.6%
Cathay Dragon	11.3%
Singapore Airlines	6.1%
Xiamen Airlines	4.9%
Shenzhen Airlines	3.0%
Thai Airways	2.8%
Korean Air	2.1%
Virgin Australia	1.8%

3.3 Hub connectivity

The level of centrality at the transfer airport represents the service level of the airport as a transfer hub. Table 2 presents the top ten airports that had the highest hub connectivity in selected years from 2005 to 2012. Figures 9 and 10 show the map of centrality for the major cities in 2005 and 2016, respectively. In 2005 the top ten were Guangzhou, Sydney, Hong Kong, Kuala Lumpur, Tokyo Narita, Singapore, Seoul Incheon, Bangkok, Shanghai Pudong and Brisbane while in 2016 they were Guangzhou, Beijing, Shanghai Pudong, Hong Kong, Seoul Incheon. Sydney, Taipei, Singapore, Bangkok and Chengdu. Throughout the period, Guangzhou remained the best connected city except in the 2008–09 period when Guangzhou was hit severely by the global financial crisis: Hong Kong took the first place then. In 2005 the connectivity of top ten airports varied from 142.45 to 489.18 while the range was between 269.81 and 2045.01 in 2016. China's three gateway cities experienced the largest increases.

Table 2: The top ten transfer hubs between China and Australia from 2005 to 2016.

2005	Centrality	2008	Centrality	2011	Centrality	2014	Centrality	2016	Centrality
Guangzhou	489.18	Hong Kong	718.80	Guangzhou	1382.01	Guangzhou	1782.26	Guangzhou	2045.01
Sydney	267.14	Guangzhou	431.85	Hong Kong	825.85	Shanghai Pudong	990.43	Beijing	1279.97
Hong Kong	250.64	Tokyo Narita	362.72	Beijing	694.32	Hong Kong	855.37	Shanghai Pudong	1099.44
Kuala Lumpur	232.69	Seoul Incheon	353.38	Shanghai Pudong	655.87	Beijing	739.68	Hong Kong	860.96
Tokyo Narita	220.84	Shanghai Pudong	334.16	Seoul Incheon	436.66	Seoul Incheon	490.78	Seoul Incheon	560.29
Seoul Incheon	207.51	Beijing	333.31	Sydney	358.25	Bangkok	381.89	Sydney	530.06
Singapore	202.54	Sydney	318.39	Singapore	244.66	Sydney	380.82	Taipei	455.85
Bangkok	182.43	Singapore	258.68	Bangkok	208.39	Singapore	305.43	Singapore	404.68
Shanghai Pudong	171.80	Kuala Lumpur	216.31	Kuala Lumpur	196.29	Kuala Lumpur	304.84	Bangkok	382.28
Brisbane	142.45	Bangkok	178.47	Melbourne	173.57	Taipei	288.05	Chengdu	269.81

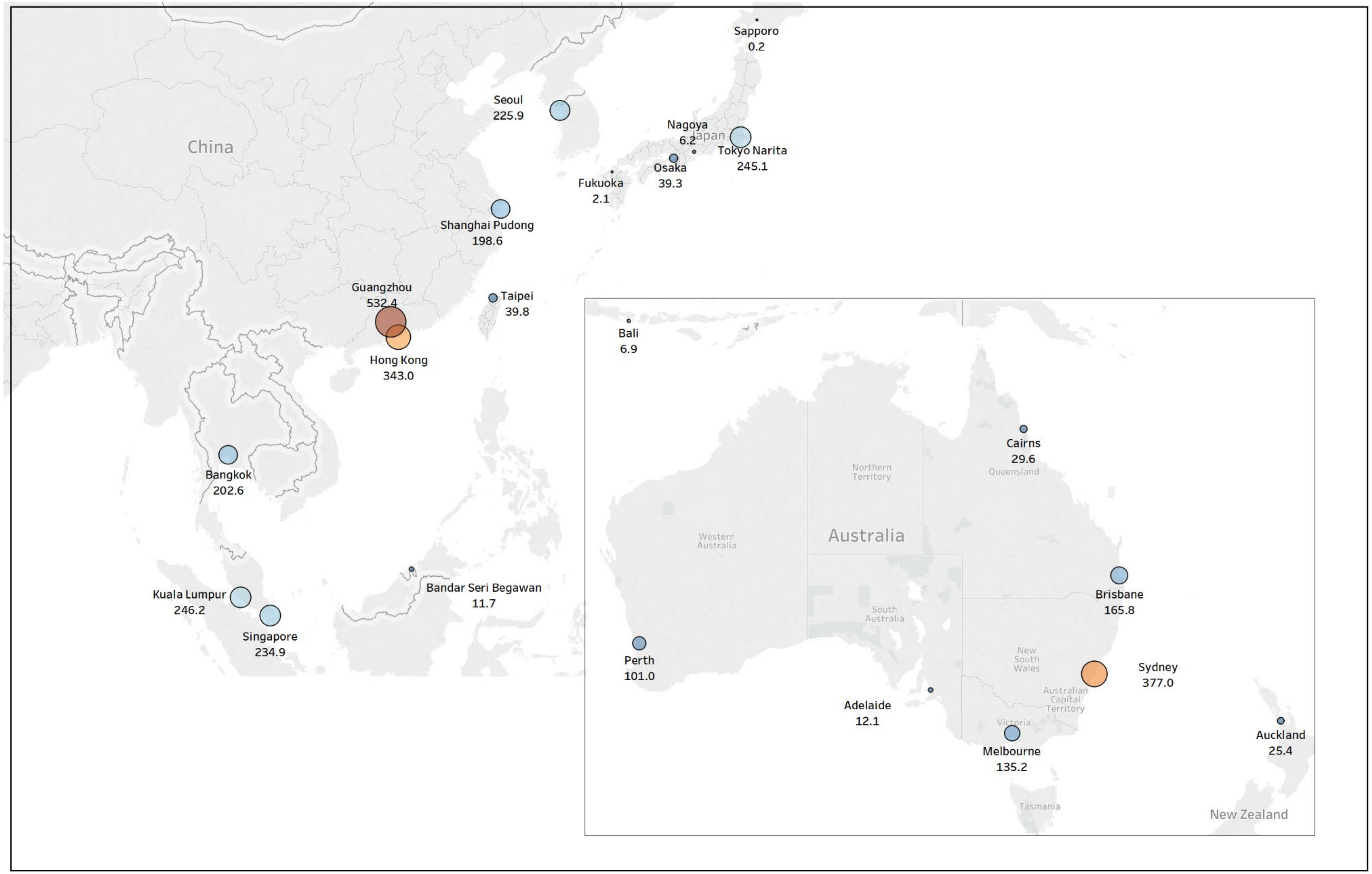

Figure 9: Centrality map of major transfer hubs between Australia and China in 2005.

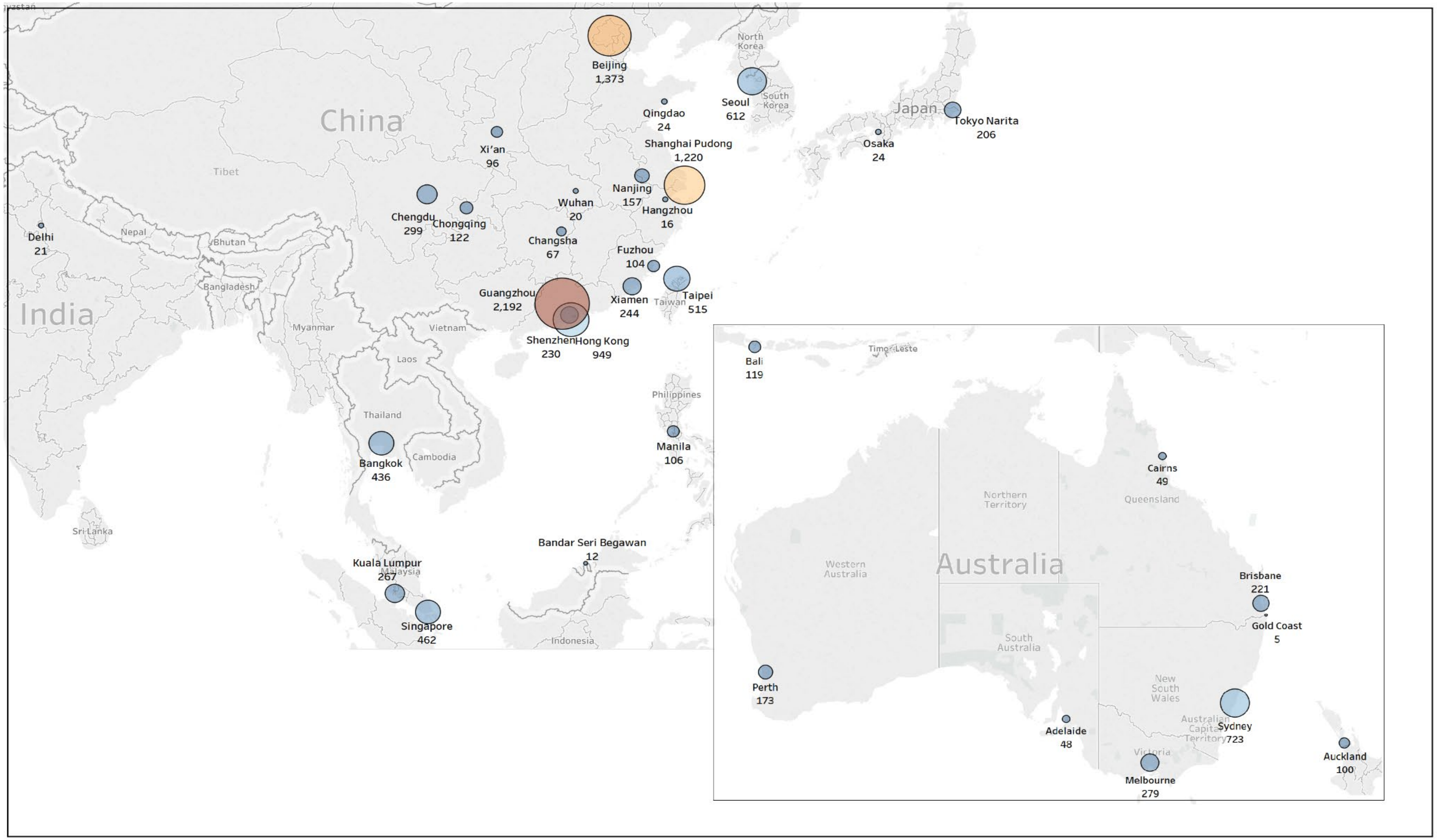

Figure 10: Centrality map of major transfer hubs between Australia and China in 2016

Figure 11 presents the evolution of the centrality of the major transfer hubs between Australia and China for the period 2005–16. It can be seen that Guangzhou secured its strong status as a transfer hub through China Southern's services. The gaps between Guangzhou and the other transfer hubs widened after 2010. China Southern began an aggressive marketing campaign in 2009 and increased its flight routes to all major Australian capital cities, including Adelaide, Brisbane and Perth. In 2012 China Southern signed a strategic cooperation agreement with Tourism Australia to build the 'Canton Route' – the route connecting Europe, Asia and Australia. From 2012 to 2016 the number of transit passengers using the 'through check-in' service increased from 458,000 to 1.74 million and the 'through checked' bags increased from 481,000 to 2.02 million. All these actions stimulated the demand for China Southern's services to Australia and secured its leading role in the China–Australia market, thereby strengthening Guangzhou's transfer hub status (China Southern, 2018).

Both Hong Kong and Guangzhou are located in the south of China. This strategic location has made them ideal transfer points for passengers travelling between China and Australia. It can be seen that Hong Kong, a traditional transit hub for Chinese travelling to Australia, has maintained a quite stable level of centrality since 2007. It is still an ideal transfer hub, considering its convenient airport facilities and Cathay Pacific's extensive network (Tsui et al., 2017). In 2016, about 13% of the passengers travelling from China to Australia made a transfer at Hong Kong. Compared with China's main airports, including Beijing, Shanghai and Guangzhou, the transfer procedures and signs at Hong Kong Airport are much clearer and easier to follow. Cathay Pacific and its wholly owned subsidiary, Cathay Dragon, operate flights to and from many first and second tier cities in China and transport the passengers to other parts of the world via Hong Kong. Air China and Cathay Pacific have a cross shareholding structure: Air China owns 30% of Cathay Pacific and Cathay Pacific has 18% of Air China. Cathay Pacific can take advantage of its alliance with Air China to continue to strengthen Hong Kong's hub status.

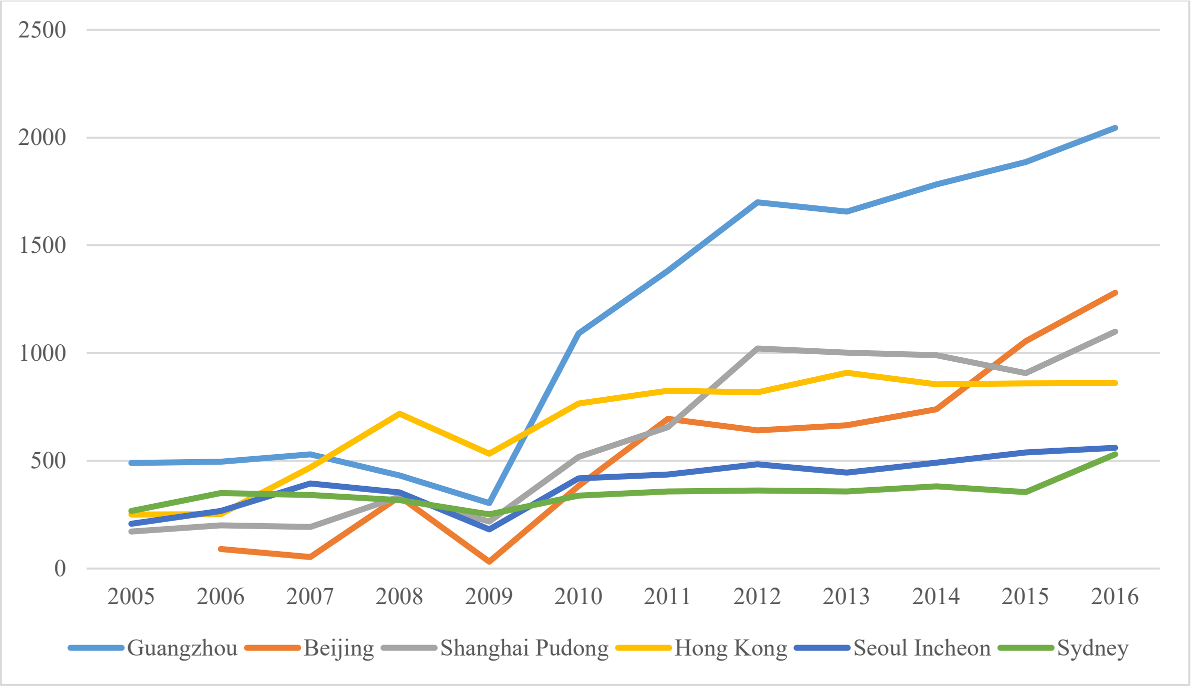

Figure 11: Evolution of the hub connectivity (vertical axis) of major transfer hubs between Australia and China, 2005–16.

After 2010 Shanghai Pudong Airport was in the second or third place as a transfer hub. However, given that the calculation of connectivity for Shanghai Pudong does not include Shanghai Hongqiao Airport, the actual level of centrality of Shanghai Pudong should be higher than that presented in Table 2. Shanghai-based China Eastern and Qantas have had a codesharing agreement for a long time. In 2014 the Australian antitrust body approved the two carriers setting up a joint venture that allows them to coordinate schedules and pricing as well as the use of airport facilities such as lounges. The strong partnership between China Eastern and Qantas has strengthened Shanghai Pudong's hub status as it offers greater convenience for passengers travelling to their final destinations via Shanghai. However, the lack of fast and reliable connections between Shanghai Hongiqao and Shanghai Pudong Airports may impede the further development of Shanghai Pudong into a transfer hub as most domestic flights depart from and arrive in Shanghai Hongqiao. One solution, which is being considered, is to construct a high-speed railway between the two airports.

Singapore is a natural choice as a transfer point because of its geographic location and close economic links with China and Australia. As a result, it remained in the top ten transfer hubs during the study period. In 2010 the ASEAN-China Air Transport Agreement was signed to establish an unlimited air service arrangement (passengers and cargo) between China and members of the Association of Southeast Asian Nations (ASEAN), which has helped boost the air services between China and Singapore. It is expected that Singapore will remain an important transfer hub with the open skies arrangement.

It is worth noting that Korean airlines seized the opportunity in the last decade or so to operate flights to many Chinese medium-sized cities and to transport Chinese passengers to international destinations, including Australia, via Seoul. Korean airlines offer very competitive prices, which have attracted passengers from north and northeast China. It is expected that Seoul will continue to be a significant transfer hub for Chinese passengers in the immediate future, given the close economic and cultural ties between the two countries and especially considering that Korea has been actively seeking an open skies agreement with China to strengthen Seoul's hub status.

Any Chinese airline wanting to launch a service from a China to Australia would consider Sydney as the first destination. It is, therefore, not surprising to see that Sydney has been consistently ranked as a key transfer hub. The China–Australia open skies agreement is the catalyst for the continual growth in air passenger traffic between the two countries. Sydney Airport has some constraints that restrict its transfer hub status. A flight curfew is one example: it means an effective closure of the airport between 11 p.m. and 6 a.m. daily. The airport is also restricted to a maximum of 80 aircraft movements per hour (i.e., 20 every 15 minutes) between 6 a.m. and 11 p.m.: again, this limits traffic growth.

5. Conclusion and implications

This paper has adopted a connectivity model to measure direct and indirect air connectivity between China and Australia, taking into consideration factors such as capacity, velocity and the quality of transfer. Compared with other connectivity measures, the proposed ConnUM incorporated more service quality dimensions and, therefore, can better reflect the quality and quantity of the air service provisions of a city, pairs of cities and intercity networks.

In the case of China and Australia, our direct connectivity measure shows that Sydney was in a leading position throughout the study period. This is not surprising as many Chinese immigrants and students choose to live and study in Sydney. Visiting friends and relations was significant part of air travel between Australia and China (O'Connor and Fuellhart, 2014). For Chinese cities, Shanghai Pudong led in direct connectivity prior to 2011, followed by Guangzhou and Beijing. However, Guangzhou surpassed Shanghai Pudong from 2011 and became the best connected Chinese city with Australia.

For overall connectivity, Australia's gateway cities' (Sydney and Melbourne) have much higher connectivity than their Chinese counterparts (Beijing, Shanghai and Guangzhou). In China, the connectivity scores of gateway cities were on average two to three times higher than those of most secondary cities in 2016. In contrast, Sydney's overall connectivity was four to fourteen times as high as that of some capital cities such as Perth and Adelaide. This may suggest that air transport in China has become more dispersed than in Australia. In fact, from 2005 to 2016, the dominant role of Sydney and Melbourne in terms of their ability to attract new air services substantially strengthened, suggesting a certain degree of inertia in the overall geography of Australia's air transport. O'Connor et al. (2018) attribute such geographic inertia to airlines' preference to basing their organisations and operations in large cities. As a result, LEK (2017) found that there is limited Chinees dispersion of visitors beyond Australian east coast cities, due in part to the lack of iconic attractions and Mandarin translation services.

The concentration and geographic inertia of air services may limit the the policy to change the spatial distribution of income and opportunity from large cities to regional areas (O'Connor et al., 2018). For example, the overcrowding problem in Sydney and Melbourne has elicited much debate as to how to move people from large cities to regional areas. One proposal suggests that new migrants should stay in the regions for five years before they can move to big cities. However, any proposals of this kind need to consider the role of air services. This research finds that Australia's small cities have a quite low air connectivity with China, suggesting that they do not have a sufficient number of flights to the major hubs. Wang et al. (2019) claim that economic activities in regional areas is more sensitive to the development of the airline industry. Therefore, the effective policy implementation of shifting people from Sydney and Melbourne should consider support measures in increasing regional airports' connectivity with the outside world.

This is the first research that examines the connectivity of the major hub airports for passenger travel between China and Australia. The results of this research have significant policy implications for aviation authorities and airport managements in terms of developing and defending an airport's hub status of. Guangzhou has forged its status as an emerging transfer hub thanks to the quick expansion of China Southern, suggesting that an airport's home airline is the key driver in growing an airport's connectivity. Hong Kong's hub status can be further strengthened by cooperation between Cathay Pacific and its Chinese strategic partners. When a city has two airports, constructing a high-speed transport link and coordinating flight schedules between them will enhance the city's overall connectivity. Shanghai's air connectivity would be much higher if a high-speed railway could link its two airports. When Beijing's second airport opens in 2019, the same issue will arise. Finally, open skies arrangements for Singapore, South Korea and Malaysia with China and Australia could help retain the transfer hub status of Singapore, Seoul and Kuala Lumpur, respectively, with those two countries. Similar strategies could be used by other airports in this region to build their hub status.

Acknowledgement

The authors wish to thank Professor Kevin O'Connor, and the anonymous reviewers for their insightful comments and constructive suggestions.

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Appendix 1: Overall air connectivity (direct and indirect connectivity) of Australian airports.

Airport	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Sydney	929.92	1090.10	1195.62	1413.57	835.86	1887.04	2135.96	2431.86	2593.29	2922.04	3011.50	3905.72
Melbourne	410.14	428.10	501.19	750.63	530.42	1086.57	1437.21	1542.76	1667.23	1795.22	2134.56	2531.19
Brisbane	253.35	278.05	409.24	433.94	200.18	586.14	863.41	990.76	1086.61	1142.59	1296.97	1456.86
Perth	171.49	180.43	221.95	282.13	257.14	329.82	457.36	621.03	663.56	720.07	861.46	887.87
Cairns	96.87	96.95	160.08	166.82	40.61	134.19	119.09	191.30	215.51	156.61	177.13	333.52
Adelaide	85.46	98.68	148.87	197.45	44.88	186.41	211.46	224.55	253.92	251.99	267.43	272.25
Gold Coast	20.74	26.57	24.57	33.42	27.96	59.10	58.30	70.02	85.45	84.42	91.77	146.78
Canberra	16.17	26.05	24.84	20.14	11.93	24.92	24.49	31.65	32.42	36.55	33.91	70.70
Darwin	11.83	12.21	13.39	16.45	10.25	17.11	21.47	31.92	47.79	53.14	48.54	56.46
Hobart	11.62	12.94	14.31	17.76	10.13	22.86	25.67	22.67	25.37	23.88	24.34	39.90
Launceston	4.65	5.46	5.77	7.21	5.52	14.65	15.54	14.33	17.47	22.25	20.48	28.41
Tamworth	6.07	10.75	11.33	8.50	4.75	15.41	12.47	16.03	14.27	14.37	14.74	24.02
Wagga Wagga	7.23	11.74	13.15	10.15	5.80	12.05	12.74	14.42	12.74	18.04	17.28	22.86
Albury	7.72	13.25	12.90	11.74	4.71	13.16	14.27	14.66	14.42	16.63	13.77	22.24
Dubbo	6.25	10.46	11.46	7.69	4.62	11.44	10.33	10.74	13.06	14.28	13.25	21.24
Armidale	4.33	7.31	9.52	8.30	4.95	9.47	8.88	9.23	11.16	13.97	12.45	17.10
Newcastle	3.40	4.03	4.76	4.47	2.51	6.22	9.02	9.45	11.63	10.47	12.49	16.76
Townsville	1.93	2.26	1.90	2.61	1.21	3.83	6.26	7.99	8.02	7.33	9.88	15.50
Toowoomba											7.81	14.88
Melbourne Avalon	4.92	6.52	7.78	9.22	3.48	6.87	7.61	5.89	6.30	8.55	8.18	13.24
Mildura	1.22	1.14	1.81	3.04	1.99	5.69	6.38	6.10	7.40	8.62	10.05	11.63
Ballina	3.48	4.37	3.62	4.69	2.22	4.70	5.29	5.68	5.97	7.35	7.38	11.47
Devonport	0.91	0.62	1.33	2.70	1.81	5.70	6.07	6.20	6.75	7.82	9.53	10.21
Moree	0.62	1.44	1.61	1.77	1.44	3.77	4.69	4.25	1.63	5.80	6.33	7.78
Mackay	0.50	0.45	0.96	1.49	0.78	3.04	5.00	5.24	8.38	7.11	7.69	7.38

Appendix 2: Overall air connectivity (direct and indirect connectivity) of Chinese airports.

Airport	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Shanghai Pudong	378.16	378.57	466.57	454.08	302.23	542.18	530.97	611.40	601.44	636.13	627.60	672.32
Beijing	225.78	338.42	320.25	339.64	223.47	380.74	450.53	420.08	431.60	467.50	537.06	655.43
Guangzhou	237.49	272.68	277.82	265.95	174.04	378.42	445.41	501.25	524.19	549.78	591.20	617.96
Chengdu	69.38	70.18	79.78	138.47	78.38	187.84	195.15	203.49	239.66	268.93	262.83	350.81
Xiamen	86.46	91.85	115.28	136.70	104.46	154.84	163.07	160.17	185.90	190.89	201.98	284.27
Nanjing	51.58	56.44	70.95	92.54	52.50	107.19	140.15	148.83	199.53	199.97	213.56	258.47
Xi'an	37.43	54.43	53.24	64.55	31.56	80.26	99.95	140.23	147.26	161.57	196.97	250.97
Qingdao	64.43	67.49	128.06	150.07	63.19	125.22	137.13	143.28	163.33	172.14	183.14	235.63
Changsha	9.23	29.15	55.57	74.16	42.94	88.85	128.12	134.25	141.24	164.37	205.20	233.27
Shenzhen	38.54	35.02	35.34	46.16	22.25	58.34	95.12	84.32	111.06	138.25	161.60	224.70
Chongqing	40.07	45.81	49.60	76.89	42.98	96.43	103.78	108.39	110.35	152.45	177.87	221.60
Fuzhou	29.36	25.77	41.15	59.49	46.69	81.40	102.24	109.46	133.55	143.39	158.60	219.87
Kunming	68.28	73.35	87.52	106.98	50.88	110.85	141.31	174.02	179.99	190.62	189.87	210.54
Hangzhou	58.52	51.56	96.33	129.74	59.91	112.54	122.36	118.18	126.97	140.13	157.42	204.83
Wuhan	23.30	29.08	50.65	67.94	39.75	87.43	100.75	124.65	146.61	150.61	167.26	203.73
Dalian	60.56	68.85	131.22	145.66	63.29	146.80	146.21	160.63	157.01	163.67	153.53	184.51
Zhengzhou	21.80	21.08	28.26	36.99	25.19	68.33	86.84	96.68	121.25	132.69	150.04	183.52
Ningbo	26.46	23.05	37.47	52.60	37.03	79.71	98.07	121.79	98.46	99.23	122.51	156.80
Shenyang	51.18	58.63	66.92	72.19	40.31	96.90	99.71	110.62	111.23	120.38	122.43	156.78
Tianjin	33.12	35.09	48.85	54.70	31.35	81.70	87.24	103.94	90.59	99.81	119.00	145.61
Haikou	29.85	41.21	50.82	70.12	36.65	62.34	72.93	96.40	93.37	101.37	107.58	139.23
Shanghai Hongqiao	16.11	15.97	17.33	21.35	9.19	49.40	72.27	73.46	74.05	77.90	88.66	138.13
Nanning	18.96	23.62	28.85	35.71	19.85	55.41	73.61	67.51	83.26	94.50	94.87	129.28
Hefei	7.11	10.14	10.64	14.73	12.96	46.93	61.72	68.12	74.28	74.56	98.88	124.75
Changchun	13.00	15.97	25.84	42.45	29.52	70.72	78.28	87.88	95.70	97.69	108.36	122.30
Taiyuan	13.29	15.50	17.95	18.74	9.05	30.15	54.60	77.77	78.75	85.68	95.01	114.58
Shantou	20.55	20.97	27.73	38.27	23.36	59.62	71.73	76.00	68.62	76.06	100.15	112.21
Sanya	25.96	25.44	24.73	39.63	21.99	60.24	75.64	87.87	100.60	103.46	100.60	111.00
Guiyang	31.03	31.57	34.48	45.78	30.96	58.56	70.16	69.55	73.22	83.11	88.45	110.01
Jinan	18.51	20.42	18.34	25.41	9.23	36.95	45.82	51.79	65.74	75.22	87.30	107.33