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International air network structures and air traffic density of world cities

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Abstract

This paper examines international air passenger and cargo flows within and among Asia, Europe, and America and the degree of air traffic density for major cities worldwide, using a basic gravity model composed of GDP, population, distance, and several dummy variables. The results reveal that many cities are strengthening their position as international air transportation hubs, especially: Tokyo, Hong Kong, Singapore, London, Paris, Frankfurt, Amsterdam, New York, and Miami. Finally, the results show that the air traffic density of three cities, Seoul, Hong Kong, and Amsterdam, is growing at an extraordinary rate.

Key Words: Air transport; Air cargo; Networks; Hub and spoke; Gravity model

1. Introduction

Problems of hub location have drawn considerable attention, particularly in Europe and Asia. These regions have witnessed intense competition among major cities to become key traffic hubs for international air transportation. Some national governments have responded by opening new airports: Munich (1992), Osaka (1994), Denver (1995), Kuala Lumpur (1998), Hong Kong (1998), Shanghai (1999), Seoul (2001), Guangzhou (2004), Nagoya (2005), and Bangkok (2006); whereas, others, such as Tokyo, Singapore, and Taipei, have responded by expanding runways and terminals.

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To date, some research has analyzed international urban systems from the viewpoint of international air traffic flows, including worldwide urban systems (Keeling, 1995; Rimmer, 1996; Matsumoto, 2004), urban systems within the US and Canada (Murayama, 1991a, 1991b), and Asian urban systems (Matsumoto, 2003), some of which focus in particular on Japan and Korea (Park, 1995). However, these studies have not fully delineated the overall international urban systems. Consequently, work has been conducted in the fields of economic geography and regional science to determine the spatial orders or rules of air passenger and cargo flows. Taaffe (1962), for example, attempted to apply the gravity model to air passenger flows in the US to examine spatial organization.

Simple gravity models employing population and distance variables have been used to predict passenger numbers (Harvey, 1951; Richmond, 1955); these were later modified to embrace other variables such as income, education level, the accumulation level of enterprises, and measures of city characteristics such as location advantages and climate (Lansing and Blood, 1958; Lansing et al., 1961). Studies have also focused on the supply aspect by introducing fare, time, and service frequencies (Howrey, 1969), and by using delineations for business passengers, tourist passengers, and cargoes (Long, 1970).

The chief objective of the research is to analyze the international air network structures within and among the Asian, European, and American regions from the standpoint of urban systems, and reveal the degree of air traffic density for major cities worldwide using a gravity model.

2. Data and method

The work presented extends previous work (*see* Matsumoto, 2004) by: (1) separating international air network structures for passengers and cargo to precisely describe airport traffic volumes; (2) using extended data-set, recorded annually; (3) using GDP per capita taken from the “Statistical Yearbook (UN),” instead of the “International Financial Statistics Yearbook (IMF).” As the UN data better reflects the actual dollar income levels when comparing incomes expressed in US dollars across multiple countries; and (4) introducing city-dummy variables separately for additional cities in the passenger and cargo models.

Given that the applicable data on international air traffic flows between cities is only available from 1982 in a standard format from the International Civil Aviation Organization (ICAO), it became the initial year in this research. ICAO data was also used to determine the distance between cities. The data on GDP per capita was taken mainly from the United Nations (UN), and converted to constant U.S. dollars (1990 prices) as mentioned earlier. With regard to population data, the concept of urban agglomeration, rather than the concept of a city, is used since the former is considered to be a better reflection of the population in the areas surrounding airports. The population data used is from the UN World Urbanization Prospects (2003). The cities and city-pairs selected were based on airport traffic volume exceeding five million passengers or two hundred thousand tons of cargo in 2000, and those that had air traffic flows exceeding ten thousand passengers or one hundred tons of cargo each year. Since cities are the basic unit of analysis, airport numbers are aggregated in cities that have multiple airports. The regions analyzed are those defined by the Airports Council International (ACI).[1] The ACI definitions provide the best reflection of economic relationships across countries.

A gravity model is employed to examine the city air traffic density. Separate specifications of the model are used for each region and for each passenger and cargo (the dependent variables). The explanatory variables are GDP, population, and distance. City-dummy variables (see Appendix A for a listing) are separately introduced for the passenger and cargo models. The entry rule for introducing city-dummy variables was over fifteen million passengers and over eight hundred thousand tons of cargo (as of 2000). However, some replacements had to be made for the sake of convenience (data availability): the selection of Rome instead of Milan and Manchester in the passenger specification for intra-Europe.

The variable *e* is raised to the power of the coefficients of the city-dummy variables, and indicates the number of times that the air traffic volumes of these cities can be explained by

[1] The regions are defined as Asia (East Asia, Southeast Asia, South Asia, West Asia up to Pakistan, Central Asia, and Oceana), Europe (Western Europe, Eastern Europe, Northern Europe, and Southern Europe including the former Soviet Union up to the Ural Mountains), and America (North America, Latin America, and the Caribbean).

the three basic factors: GDP, population, and distance. These values are interpreted as city air traffic density. In other words, in this analysis, city air traffic density is defined as the spillover of international air traffic flows that can be explained by the three basic factors[2]. The model used is as follows:

$$T_{ij} = A \frac{(G_i G_j)^{\alpha} (P_i P_j)^{\beta} e^{\delta D_1} e^{\varepsilon D_2} e^{\zeta D_3} \ldots e^{\phi D_{17}} e^{\chi D_{18}} e^{\psi D_{19}}}{(R_{ij})^{\gamma}} \qquad (1)$$

Where T_{ij} is the net volume of international air passengers over ten thousand or net volume of international air cargoes over one hundred tons between $city_i$ and $city_j$ in 2000, G_i is the real GDP per capita in 2000 of the country in which $city_i$ is located, expressed in US dollars at the 2000 exchange rate and constant 1990 prices, G_j is the real GDP per capita in 2000 of the country in which $city_j$ is located, expressed in US dollars at the 2000 exchange rate and constant 1990 prices, P_i is the population (in thousands) of $city_i$ in 2000, P_j is the population (in thousands) of $city_j$ in 2000, R_{ij} is the distance between $city_i$ and $city_j$ in kilometers, D is the city-dummy variables (shown in Appendix A), and A is the constant. After transforming Eq. (1) into log form, an ordinary least-squares (OLS) regression analysis was used.

3. International urban systems in terms of air traffic flows

Figs. 1 and 2 show the international air network structures in *Asia* in 2000 for passengers and cargo. As can be seen from the figures, Hong Kong had the largest international airport traffic volume in Asia.

Fig. 1. and Fig. 2.

The second largest volumes were found in Tokyo and Singapore. Seoul, Bangkok, and Taipei were ranked in the second tier, followed by Osaka, Kuala Lumpur, and Sydney in the third. With regard to the number of city-pair passengers, the Hong Kong-Taipei city pair

[2] In addition, other effects of city air traffic density will be included in the size of *e*. ICAO data on international air traffic flows are “ticket-based.” In other words, if one flies from Tokyo to London via Seoul, two tickets are issued: Tokyo to Seoul and Seoul to London. In this case, Seoul functions as the hub airport; thus, the value of *e* for Seoul becomes larger.

was ranked first, followed by Singapore-Kuala Lumpur, Tokyo-Seoul, Bangkok-Singapore, and Hong Kong-Bangkok, all of which transported over two million passengers. Nine city-pairs had between one and two million passengers, one of which is the Tokyo-Hong Kong corridor. Concerning cargo volume, nine city-pairs had over one hundred thousand tons of cargo. The top corridors in this group were Tokyo-Hong Kong, Osaka-Hong Kong, and Tokyo-Taipei.

Fig. 3. and Fig. 4.

Figs. 3 and 4 show the international air network structures in *Europe* in 2000 for passengers and cargo. London was the first origin/destination in this region, as well as globally, followed by Paris, Frankfurt, and Amsterdam. Close behind these four cities were Brussels and Zurich, both of which can be considered to be second tier. Copenhagen, Madrid, Rome, and others were ranked third tier. With regard to international air passenger flows, only one city-pair, London-Amsterdam, transported over three million passengers, while two city-pairs, London-Dublin and London-Paris, conveyed between two and three million passengers. Concerning international air cargo flows, only one city-pair (London-Frankfurt) transported over forty thousand tons of cargo; one (London-Amsterdam) had between twenty and thirty thousand tons of cargo; and eleven (including Paris-Cologne and Paris-Frankfurt) had between ten and twenty thousand tons of cargo.

Fig. 5. and Fig. 6.

Figs. 5 and 6 show the international air network structures in *America* in 2000 for passengers and cargo. New York was ranked first with regard to international airport traffic, followed by Miami and Los Angeles, then Chicago, Toronto, and San Francisco. Concerning international air passenger flows among the cities, New York-Toronto conveyed over one million passengers. Miami formed the center for international air cargo flows in this region, as it was either an origin or destination in the top five city-pairs, the two key ones being: Miami-Santiago and Miami-Bogota. In general, international air traffic flows among the cities in this region were lighter than they were in other regions.

Fig. 7. and Fig. 8.

Finally, Figs. 7 and 8 show the international air network structures among *Asia*, *Europe*, and *America* in 2000 for passengers and cargo. With regard to international airport traffic, the following cities were ranked in the first tier: Tokyo, Hong Kong, Singapore, London, Paris, Frankfurt, Amsterdam, and New York. With respect to international air traffic flows among these regions, Tokyo, London, and New York were the three *global cores*. Concerning air passenger flows, London-New York had the heaviest air passenger flows in the world, with nearly four million passengers. In addition, ten city-pairs transported between one and two million passengers: Tokyo-Honolulu, Paris-New York, and London-Los Angeles. Regarding air cargo flows, nine city-pairs had over one hundred thousand tons of cargo. The top corridors in this group were London-New York and Tokyo-New York.

4. Results

Table 1 shows the results for Asia in 2000. The overall model fit is relatively good and the estimated values of the parameters are significant at the 1% level, except for: Tokyo, Seoul, and Taipei in the passenger specification; and Tokyo, Osaka, and Taipei in the cargo specification. However, most of these exceptions are significant at the 5% level.

Table 1

The estimated values of the GDP parameters for passengers and cargo are relatively small. This implies lessening importance of the GDP variable in explaining air traffic flows. The estimated value of the parameter for the population variable in the cargo model is about twice that in the passenger model. This may partly reflect the vertical division of labor in high-tech industries among developed and developing countries. For example, intermediate goods in such industries are produced in countries that have an abundance of inexpensive labor. The estimated value of the distance parameter is approximately twice as large for passengers as it is for cargo, indicating that passengers are more sensitive to the length of their journey. Statistics involving *e* raised to the power of the dummy variable coefficients partly reveal the high air traffic density of Hong Kong, Singapore, and Bangkok. In particular, the results for cargo reflect the high air traffic density of Hong Kong, which lies on the outskirts of China, and Singapore, with the latter functioning as transshipment base for the Asian region.

In order to examine temporal changes in the parameter values, analysis was also done on air traffic flows between 1982 and 1999. As a whole, the GDP, population, and distance parameters for passengers declined over this period, as was also true with respect to the GDP and distance parameters for cargo, although the population coefficient increased. The decline in the distance parameter for passengers implies that air passengers travel with less and less regard to journey length, which may have implications for the development of hub-and-spoke systems in international aviation. The analysis shows the GDP's importance as a driving force of air traffic flows has decreased as a result of increased equality in the economic power of Asian countries. With respect to cargo, the increase in population may be a reflection of the increase in the vertical division of labor, for example, the division caused when Japanese firms shift production to NIEs, ASEAN countries, or China. With regard to the passenger parameter for individual cities, Tokyo, Seoul, and Hong Kong exhibited a strong positive trend, while Taipei, Bangkok, and Singapore remained nearly constant. Tokyo's passenger flows rose remarkably between 1990 and 1995, almost certainly due to the appreciation of the yen during that period. Concerning cargo, the dummy variables indicate the strong positive trend for Osaka, Seoul, and Hong Kong: Singapore, slightly positive; Tokyo and Bangkok, nearly constant; and Taipei, a decline. In Osaka, the suppressed demand for international air cargo may be explained by the dint of a new airport. The later growth curb in Tokyo may be attributed largely to the capacity limits of its international airport.

Table 2

Table 2 shows the results for Europe in 2000. The diagnostic statistics suggest a fairly good overall fit as all individual parameters are significant at the 1% level, with the exception of the dummy variables for Rome and Madrid in the passenger model, and distance and the dummy variable for Paris in the cargo model (Rome for the passenger model and distance for the cargo model have a counter intuitive sign). The distance parameters in Europe are smaller than those in other regions, possibly because Europe is relatively compact in terms of geography. London and Amsterdam can be said to be the key hubs for passengers and Frankfurt for cargo. The dummy variable for Amsterdam in the passenger model reflects a strong upward trend, as does the dummy variable for London in the cargo model.

Table 3

Table 3 gives the results for America in 2000. The overall model fit is not good, although the estimated parameter values for the basic explanatory variables (GDP, population, and distance) and the dummy variable for Miami in the passenger specification are significant at the 1% level. In the case of cargo, the variables for GDP, Los Angeles, and New York are non-significant, with the GDP having a counter intuitive sign. This occurs because international air traffic flows are relatively limited in this region and scarce between North- and South-America. Historically, South-American countries have strong links with Spain and Portugal, their former colonizers. Thus, the omission of variables may be a problem in the models for this region. Miami can be said to be a hub in this region with regard to both passenger and cargo traffic, and particularly dominant in terms of international cargo flows, reflecting its role as a gateway among North America, Latin America, and the Caribbean. Conversely, Toronto does not play a very important role within this region. With reference to passengers, three US cities increased in importance, while Toronto gradually decreased in importance.

Table 4

Finally, Table 4 shows the regression results across these three regions for 2000. The data modestly fits the model and the estimated parameters for the basic explanatory variables are significant at the 1% level for both the passenger and cargo specifications. However, many city-dummy variables are not significant at the 5% level. Some cities, such as Zurich, Brussels, Copenhagen, and Miami, are significant within their own region but non-significant across regions. Meanwhile, others, such as Madrid and Los Angeles, are non-significant in their own region but significant across regions. From the viewpoint of international urban systems, these statistics reflect each city’s position relative to the global urban systems.

5. Discussion

The gravity model, introduced in the article, composed of GDP, population, distance, and city-dummy variables underlines that Tokyo, Hong Kong, and Singapore are positioned as the key hubs in Asia in terms of international air traffic flows, with Seoul and Hong Kong reflecting high increase in air traffic density. In Europe, London, Paris, Frankfurt, and Amsterdam hold supremacy as the hubs for international air traffic, and Amsterdam is unsurpassed in its strengthening of position. In America, New York and Miami display high air traffic density. However, in terms of intercontinental air traffic, some cities seem to be declining in air traffic density, such as Zurich, Brussels, Copenhagen, and Miami. While others, such as Madrid and Los Angeles, seem to be establishing themselves as hubs.

Changes in the air traffic density of cities result from various factors, as discussed in the article, such as the growth of national economies, developments in aircraft technology (e.g. longer haul aircraft), changes in the type of passengers carried (e.g., the split between business and leisure travel), changes in the availability of airport capacity, and changes in bilateral air service agreements. There are also other effects of city air traffic density included in the size of e, such as transferring passengers and cargo transshipments. According to annual reports of individual airports, mostly in Europe or US the transfer rate is from 30% to 50% of the total airport throughput. However, airports in Asia, at present, are below this level, but are increasing transfer traffic and transshipments. Airlines worldwide are being integrated into the three branded alliances: SKYTEAM, ONEWORLD, and STAR. The strategy of airlines to join or seek alliances with other carriers is strongly affected by city air traffic density. Measuring and comparing the competitive position of airports in terms of air network connectivity and hub development remains to be elaborated on. In such an extension of the work presented here, we suggest to include domestic air traffic flows.

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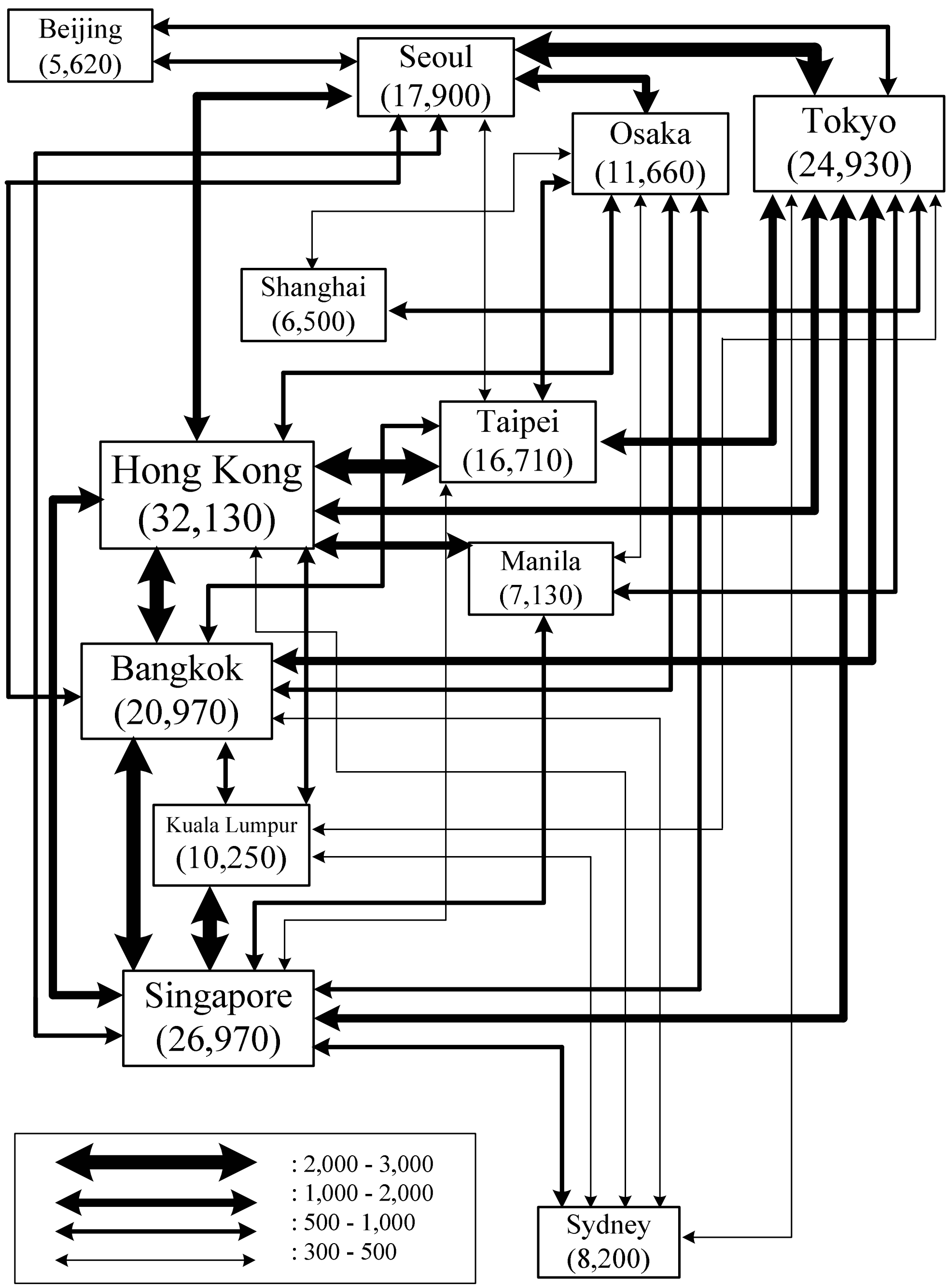

Fig. 1. International air passenger network structures in Asia, 2000.

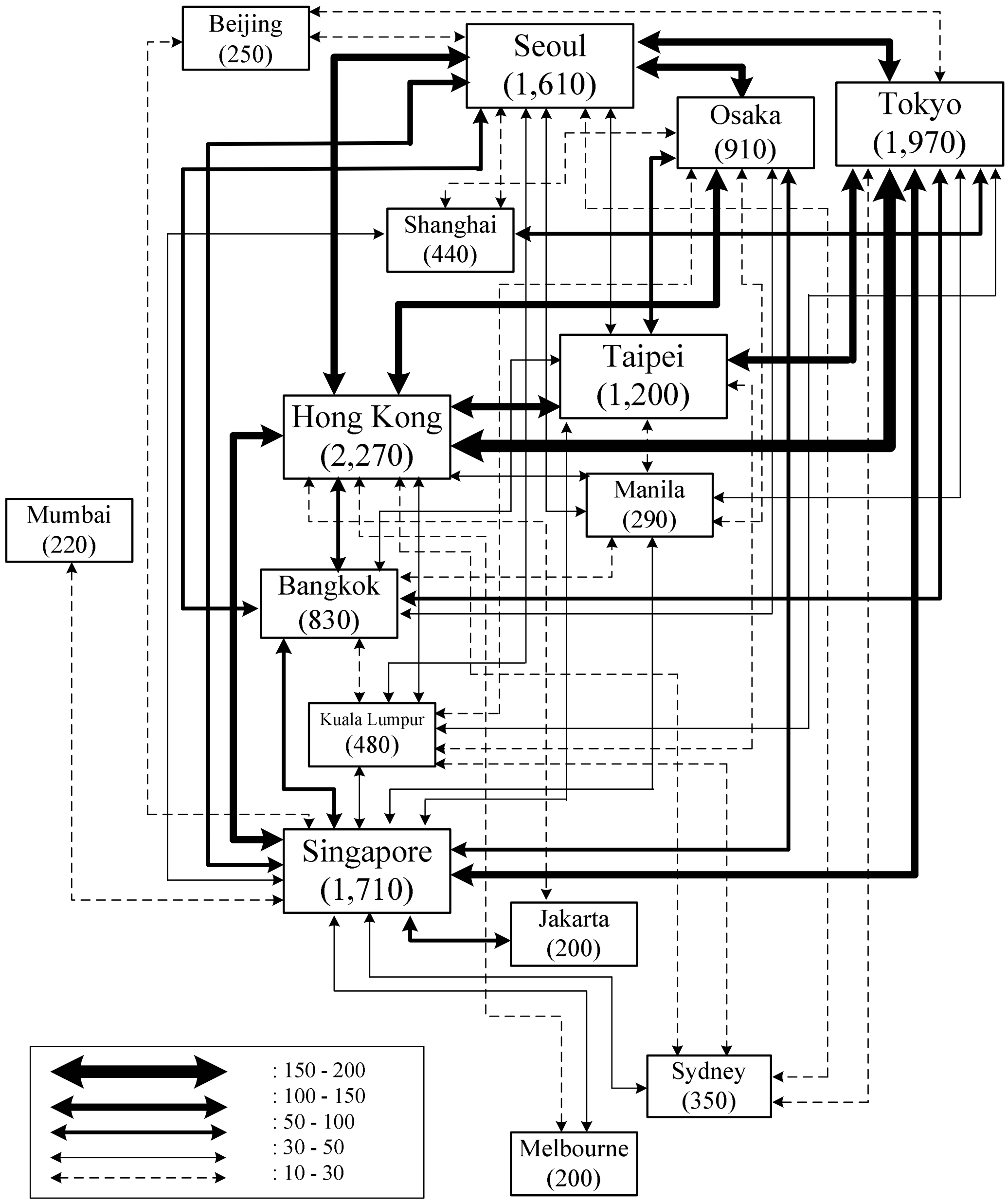

Fig. 2. International air cargo network structures in Asia, 2000.

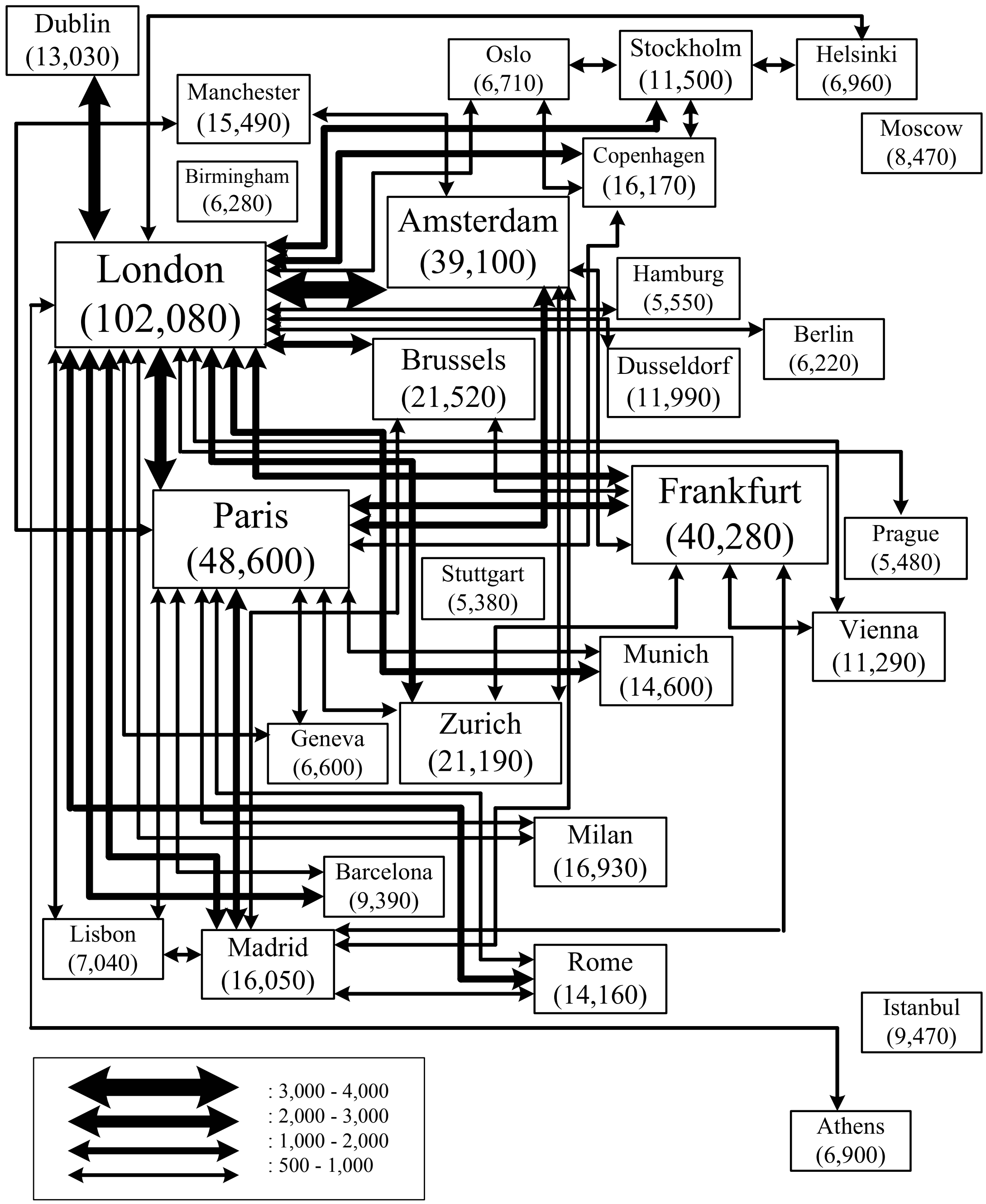

Fig. 3. International air passenger network structures in Europe, 2000.

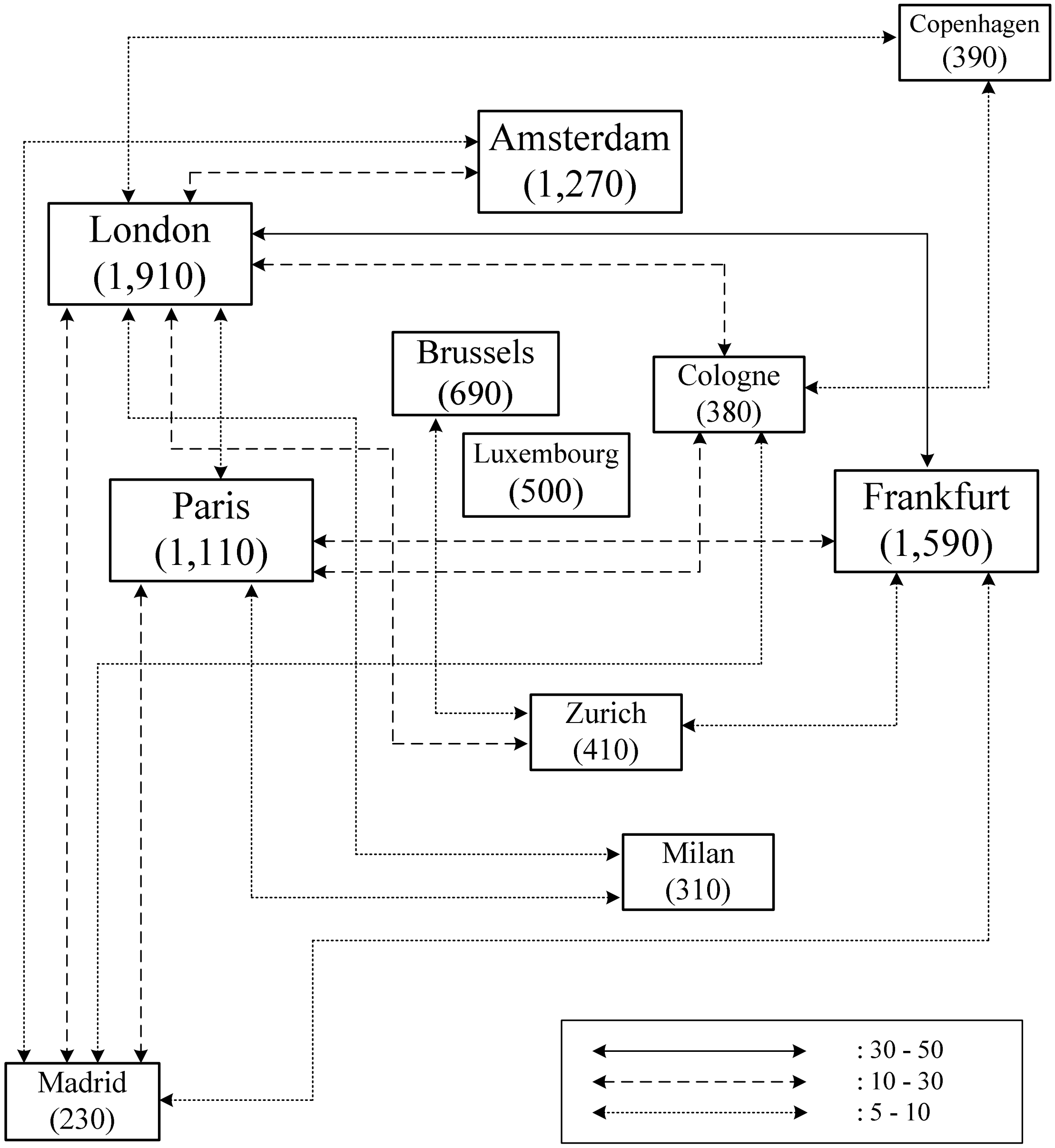

Fig. 4. International air cargo network structures in Europe, 2000.

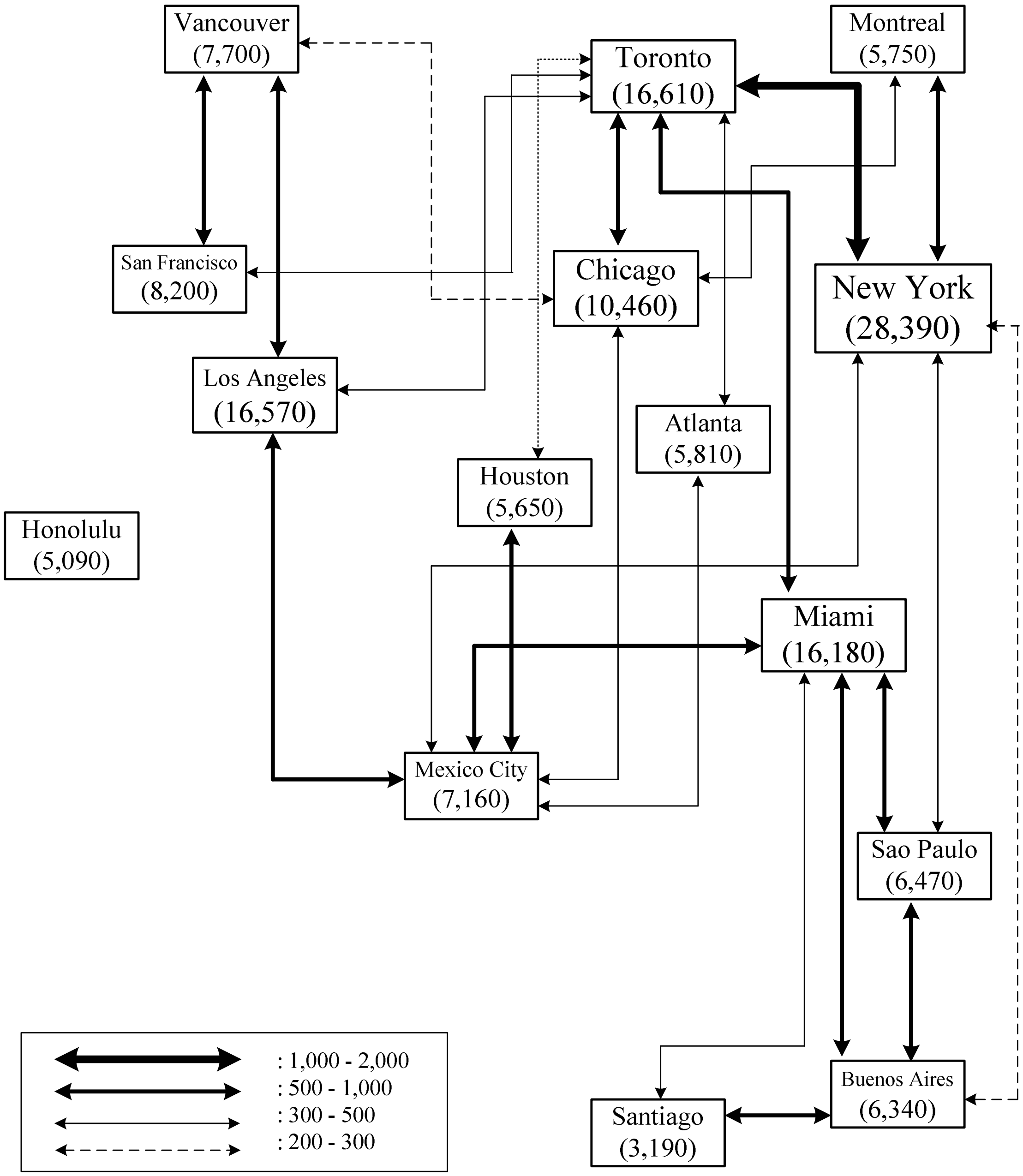

Fig. 5. International air passenger network structures in America, 2000.

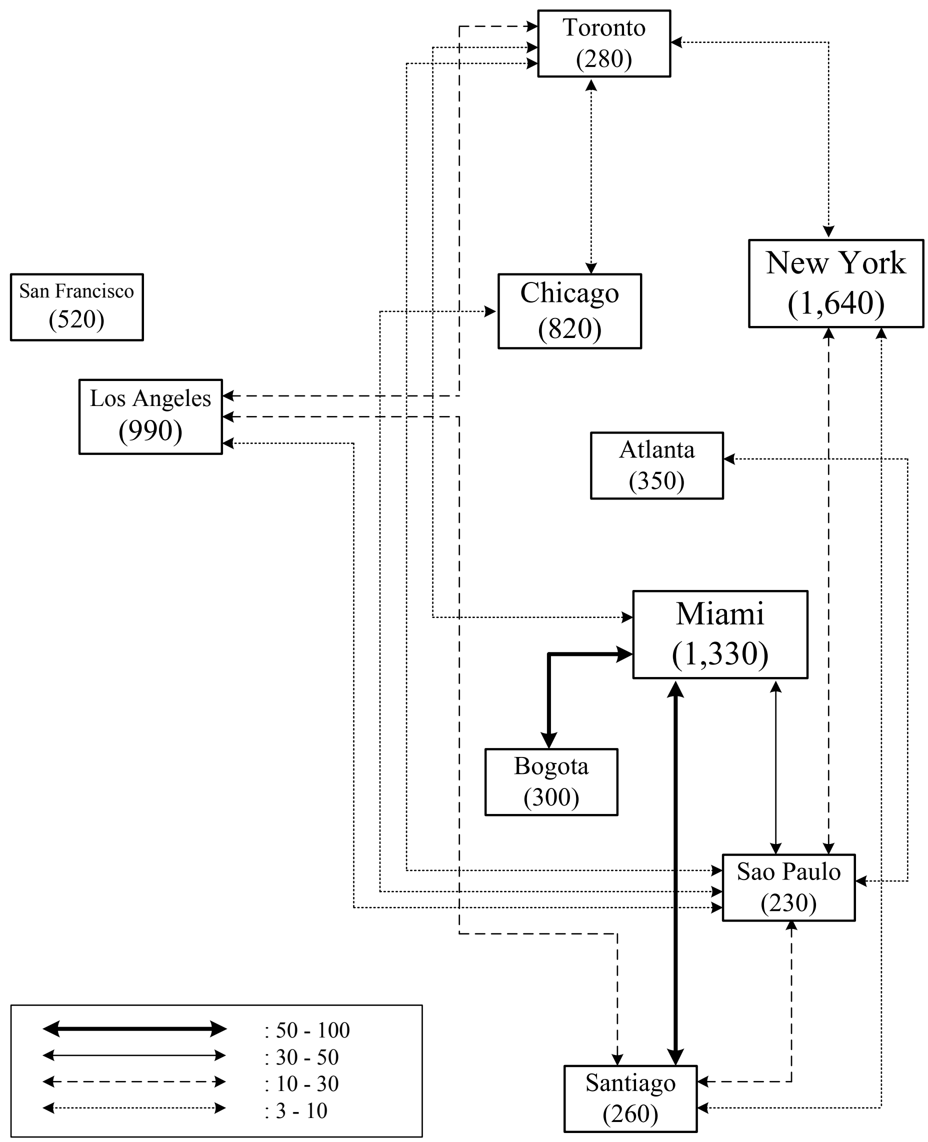

Fig. 6. International air cargo network structures in America, 2000.

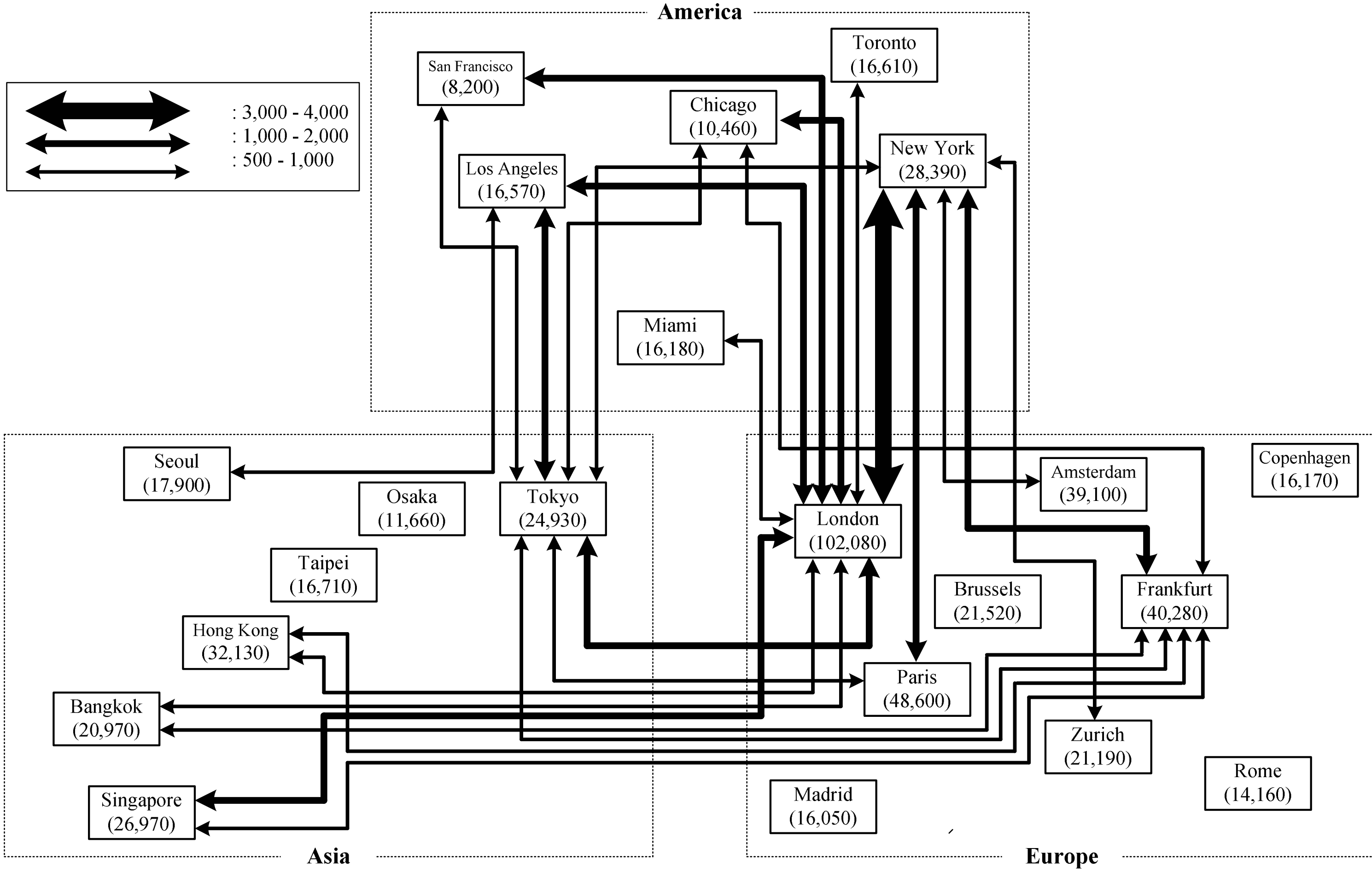

Fig. 7. International air passenger network structures among Asia, Europe, and America, 2000.

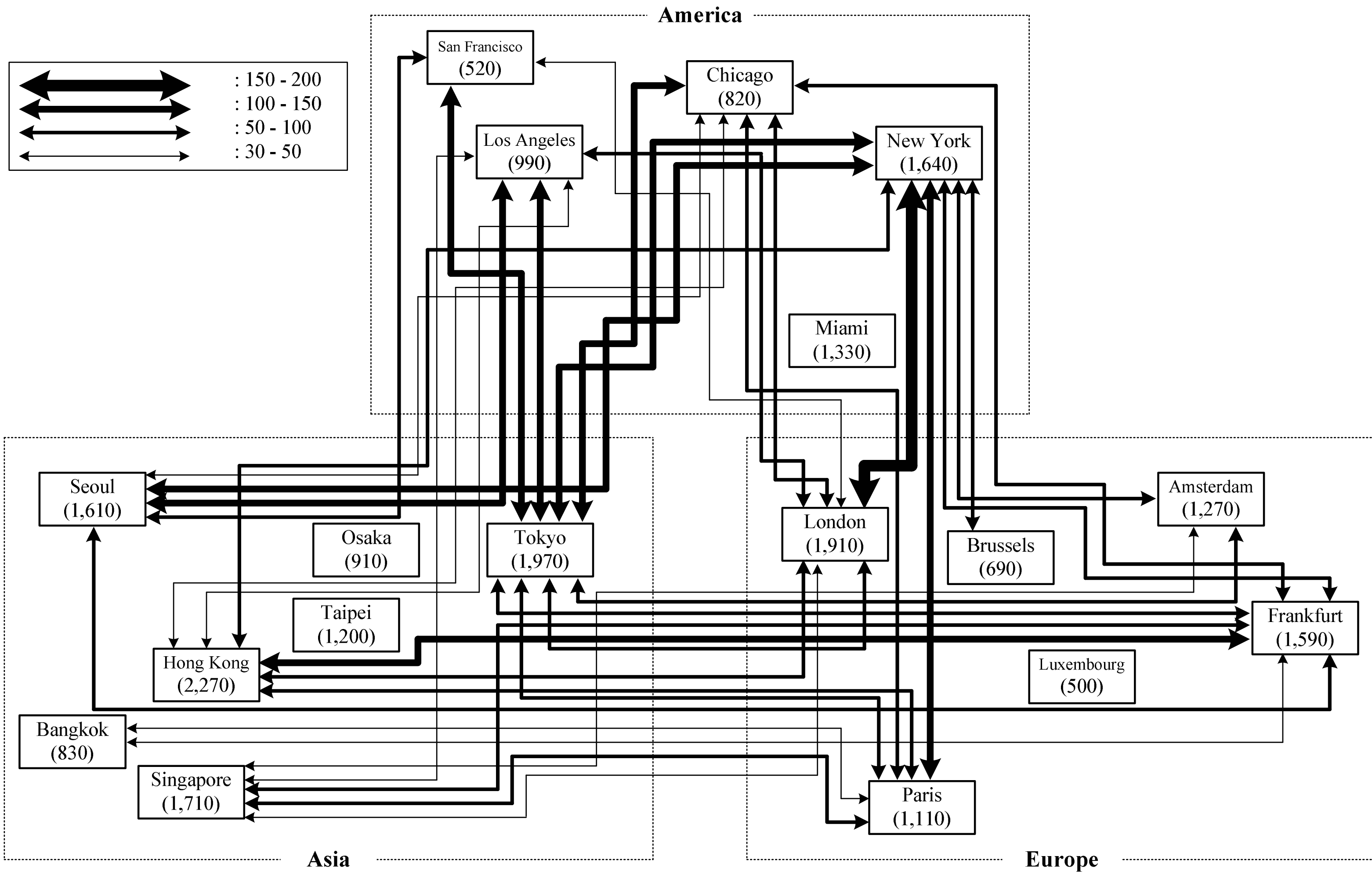

Fig. 8. International air cargo network structures among Asia, Europe, and America, 2000.

Table 1

Regression coefficients for intra-Asia, 2000

		Passenger	Cargo
Constant	lnA	9.21	1.07
		(9.60)	(0.69)
GDP	α	0.19	0.19
		(5.23**)	(3.35**)
Population	β	0.19	0.33
		(4.81**)	(5.20**)
Distance	γ	0.54	0.30
		(6.55**)	(2.50*)
Tokyo	**δ**	**0.58 [1.78]**	**0.98 [2.67]**
		(2.29*)	(2.53*)
Osaka	**ε**	—	**0.81 [2.24]**
		—	(2.27*)
Seoul	**ζ**	**0.45 [1.57]**	**1.03 [2.81]**
		(1.94)	(2.98**)
Taipei	**η**	**0.49 [1.63]**	**0.85 [2.33]**
		(1.72)	(2.17*)
Hong Kong	**θ**	**0.81 [2.26]**	**1.68 [5.35]**
		(3.86**)	(5.39**)
Bangkok	**ι**	**0.96 [2.62]**	**1.33 [3.79]**
		(5.14**)	(5.06**)
Singapore	**κ**	**0.88 [2.42]**	**1.56 [4.74]**
		(5.13**)	(6.05**)
Adj.R^2		0.70	0.84
D.F.		209	213

Notes: Figures in parentheses are t-values; ** and * indicate significant at the 1% and 5% levels, respectively.
Figures in [ ] are e raised to the power of the coefficients of the city-dummy variables.

Table 2

Regression coefficients for intra-Europe, 2000

		Passenger	Cargo
Constant	lnA	3.52	-0.72
		(3.69)	(-0.46)
GDP	α	0.26	0.17
		(8.97**)	(3.58**)
Population	β	0.26	0.24
		(7.05**)	(3.90**)
Distance	γ	0.21	-0.01
		(3.35**)	(-0.09)
London	**δ**	**1.60 [4.94]**	**1.07 [2.92]**
		(12.93**)	(5.54**)
Paris	**ε**	**0.84 [2.32]**	**0.49 [1.64]**
		(5.86**)	(2.05*)
Frankfurt	**ζ**	**0.98 [2.66]**	**1.39 [4.01]**
		(7.46**)	(6.68**)
Rome	**η**	**-0.05 [0.95]**	**—**
		(-0.25)	—
Madrid	**θ**	**0.25 [1.28]**	**—**
		(1.70)	—
Zurich	**ι**	**0.99 [2.69]**	**—**
		(7.15**)	—
Amsterdam	**κ**	**1.37 [3.93]**	**1.14 [3.13]**
		(8.74**)	(4.69**)
Brusseles	**λ**	**0.94 [2.55]**	**—**
		(6.40**)	—
Copenhagen	**μ**	**0.69 [2.00]**	**—**
		(4.67**)	—
Adj.R^2		0.63	0.45
D.F.		443	380

Table 3

Regression coefficients for intra-America, 2000

		Passenger	Cargo
Constant	lnA	6.53	1.66
		(7.60)	(1.32)
GDP	α	0.24	-0.10
		(6.83**)	(-2.04*)
Population	β	0.30	0.47
		(8.99**)	(8.82**)
Distance	γ	0.59	0.13
		(7.99**)	(1.15)
New York	**δ**	**0.41 [1.51]**	**0.43 [1.54]**
		(2.07*)	(1.35)
Los Angeles	**ε**	**0.41 [1.51]**	**0.37 [1.45]**
		(1.81)	(1.10)
Miami	**ζ**	**1.44 [4.23]**	**2.76 [15.85]**
		(8.08**)	(10.65**)
Toronto	**η**	**-0.14 [0.87]**	**—**
		(-0.72)	—
Adj.R^2		0.42	0.42
D.F.		289	249

Table 4

Regression coefficients for inter-continent, 2000

		Passenger	Cargo
Constant	lnA	8.48	1.09
		(5.07)	(0.53)
GDP	α	0.31	0.32
		(9.01**)	(7.29**)
Population	β	0.25	0.33
		(5.46**)	(5.39**)
Distance	γ	0.83	0.52
		(5.21**)	(2.70**)
Tokyo	**δ**	**0.38 [1.46]**	**0.57 [1.76]**
		(1.77)	(2.07*)
Osaka	**ε**	—	**0.08 [1.08]**
		—	(0.26)
Seoul	**ζ**	**0.02 [1.02]**	**0.40 [1.49]**
		(0.08)	(1.24)
Taipei	**η**	**0.12 [1.13]**	**0.06 [1.07]**
		(0.28)	(0.15)
Hong Kong	**θ**	**0.80 [2.22]**	**1.10 [3.00]**
		(3.18**)	(3.67**)
Bangkok	**ι**	**1.12 [3.05]**	**1.16 [3.18]**
		(3.94**)	(3.26**)
Singapore	**κ**	**0.47 [1.60]**	**1.08 [2.95]**
		(1.86)	(3.40**)
London	**λ**	**0.83 [2.29]**	**0.46 [1.58]**
		(5.68**)	(2.59**)
Paris	**μ**	**0.62 [1.86]**	**0.86 [2.37]**
		(3.28**)	(3.85**)
Frankfurt	**ν**	**0.65 [1.92]**	**1.17 [3.23]**
		(4.20**)	(6.32**)
Rome	**ξ**	**-0.23 [0.80]**	—
		(-0.80)	—
Madrid	**ο**	**0.89 [2.42]**	—
		(3.78**)	—
Zurich	**π**	**0.38 [1.46]**	—
		(1.71)	—
Amsterdam	**ρ**	**0.95 [2.58]**	**1.47 [4.35]**
		(4.78**)	(6.21**)
Brusseles	**σ**	**0.17 [1.18]**	—
		(0.63)	—
Copenhagen	**τ**	**0.13 [1.14]**	—
		(0.40)	—
New York	**υ**	**0.38 [1.47]**	**0.63 [1.87]**
		(2.20*)	(2.90**)
Los Angeles	**φ**	**0.84 [2.31]**	**0.78 [2.19]**
		(3.62**)	(2.68**)
Miami	**χ**	**0.71 [2.04]**	**1.02 [2.79]**
		(1.41)	(1.61)
Toronto	**ψ**	**-0.49 [0.61]**	—
		(-2.05*)	—
Adj.R^2		0.42	0.47
D.F.		364	383

Appendix A

City-dummy variables introduced to each region.

		D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}
Intra-Asia	Passenger	Tokyo	Seoul	Taipei	Hong Kong	Bangkok	Singapore				
	Cargo	Tokyo	Osaka	Seoul	Taipei	Hong Kong	Bangkok	Singapore			
Intra-Europe	Passenger	London	Paris	Frankfurt	Rome	Madrid	Zurich	Amsterdam	Brussels	Copenhagen	
	Cargo	London	Paris	Frankfurt	Amsterdam						
Intra-America	Passenger	New York	Los Angeles	Miami	Toronto						
	Cargo	New York	Los Angeles	Miami							
Inter-continent	Passenger	Tokyo	Seoul	Taipei	Hong Kong	Bangkok	Singapore	London	Paris	Frankfurt	Rome
	Cargo	Tokyo	Osaka	Seoul	Taipei	Hong Kong	Bangkok	Singapore	London	Paris	Frankfurt

		D_{11}	D_{12}	D_{13}	D_{14}	D_{15}	D_{16}	D_{17}	D_{18}	D_{19}
Inter-continent	Passenger	Madrid	Zurich	Amsterdam	Brussels	Copenhagen	New York	Los Angeles	Miami	Toronto
	Cargo	Amsterdam	New York	Los Angeles	Miami					