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# Port competition and network polarization at the East

## Asian maritime corridor

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# **Port competition and network polarization at the East Asian maritime corridor**

## **Abstract**

Port competition is often analyzed based on individual characteristics of seaports rather than inter-port connections. A maritime network perspective is applied to the circulation of liner vessels between East Asian ports in order to reveal their relative position in 1996 and 2006. Main results confirm the progress of secondary ports over their major competitors, reflecting the importance of local port policies. However, the overall structure of the regional network tends to remain polarized by few major hub ports resisting to internal and external threats.

*Key Words: Asia, Centrality, Hub port, Liner shipping, Network analysis, Nodal region*

## **Concurrence portuaire et polarisation réticulaire au sein du corridor maritime d'Asie orientale**

## **Résumé**

L'analyse de la concurrence portuaire se base souvent sur les caractéristiques individuelles des ports plutôt que sur les connections interportuaires. L'analyse réseau de la circulation des porte-conteneurs entre les ports d'Asie orientale permet de révéler leur position relative en 1996 et 2006. Les résultats confirment la montée de ports secondaires face à leurs concurrents principaux, reflétant par là l'importance des politiques portuaires locales. Cependant, la structure d'ensemble du réseau régional reste polarisée par quelques hubs majeurs parvenant à surmonter leurs difficultés internes et externes.

*Mots-clés : Analyse de réseau, Asie, Centralité, Lignes régulières, Port hub, Région nodale*

## 1. INTRODUCTION

Traditionally in port geography, port development has been approached under two main perspectives, maritime and continental. Scholars have thus put more emphasis on hinterland connections (Van Klink, 1998) while others have insisted on the importance of maritime forelands (Marcadon, 1988). These two dimensions were initially assembled by Vigarié (1979) in his concept of “port triptych” where the foreland, the hinterland, and the port itself altogether constitute a spatial system on its own. More recently, the explanatory power of such concept has been criticized due to changing distribution patterns and the unprecedented importance of global firms in port selection and competition, calling for renewed frameworks referring to value chains and integrated networks (Robinson, 2002). However, despite such conceptual moves, the analysis of port competition remains largely specialized on one aspect only of the port triptych. Furthermore, maritime forelands and shipping networks in general have received far less attention than land-based transport systems, of which hinterlands and ports themselves. Scholars often provide a simplified picture of maritime linkages among seaports showing port traffic and main shipping corridors.

This paper wishes exploring port competition through a maritime network perspective. It proposes a systematic comparison of the relative situation of ports within a given regional network. The case of East Asia is proposed because this region offers particular interest for the study of maritime dynamics compared with Europe or North America, where continental hinterlands are the key influence in port competition (Lee et al., 2008). While such issues are well documented by recent research on East Asia as a whole (Taillard, 2004; Gipouloux, 2009), and on regional port dynamics more specifically (Yap et al., 2006), this area has never been formally analyzed through this methodology. This is surprising, given the widely accepted importance of the “East Asian maritime corridor”, which is one of the world’s few maritime-based geographical entities. By looking at the relative attributes of ports in the regional network, we expect to verify the existence of this corridor and to assess how this structure has evolved in the recent decade. Rapid port growth and fierce competition over transshipment activities may have modified the pattern to a certain extent that is difficult to reveal solely based on official port statistics. Notably, the current challenges faced by East Asia’s main hub ports such as Singapore, Hong Kong, Kaohsiung (Taiwan), and Busan (South Korea) are believed to have put in question their supremacy over their emerging competitors within and outside national boundaries. The

extent to which internal (e.g. congestion, rising costs, lack of space for further expansion) and external threats (i.e. competition) truly resulted in a different network hierarchy is worth analyzing and has not yet been demonstrated.

The remainder of this paper is organized as follows. Section 2 reviews recent literature on port competition, insisting on the rarity of – and potential for – conventional network analysis applied to maritime networks using data on vessel movements. Main results in section 3 relate changes in network structure and ports' centrality (1996-2006) with observations obtained from recent literature and field work. The last section 4 concludes about the implications of the results for port policy and further analysis of maritime networks.

## **2. METHODOLOGY FOR A MARITIME NETWORK ANALYSIS**

### **2.1 PORT COMPETITION FROM A MARITIME NETWORK PERSPECTIVE**

Port competition can be approached through a variety of issues, such as concession granting, diversion and concentration of port traffic, investment in port infrastructure, and subsidisation of hinterland connections (Huybrecht et al., 2002). While it is beyond the scope of this paper to review exhaustively each of those aspects, one may refer to several recent efforts towards a synthesis of available indicators and operational concepts. For instance in Europe, Joly and Martell (2003) offered a comparison based on infrastructure characteristics, Ducruet and Van der Horst (2009) proposed measuring a level of transport integration. Concentration dynamics within port systems are often studied using total throughput (see Ducruet et al., 2009a for a synthesis). The analysis of hinterlands is more complex due to the intermingling of interested parties locally as in Rotterdam (Van der Horst and De Langen, 2008), and because port-related traffic on the land leg is difficult to access (Debrue and Guerrero, 2008). Throughout the literature on the attractiveness of ports in the selection process, a debate goes on about the respective importance of quantitative factors (e.g. monetary cost and time) and qualitative factors (e.g. location and overall service quality), as seen in the studies of Ng (2006, 2009) on European ports, Song and Yeo (2005), Chang et al. (2008), and Tongzon (2009) on Asian ports.

Maritime forelands and networks have been rarely studied as systematically as other transport systems. Although competition is a *relative process* by which ports aim at capturing traffic within a given region, the patterns of inter-port relations are not well-

known and most research relies on individual characteristics. The analysis of maritime dynamics often remains limited to the application of concentration indexes (Notteboom, 2006) and shift-share analysis (Lee and Kim, 2009) on port traffic statistics. Geographers provide either theoretical explorations about the emergence of hub ports (Fleming and Hayuth, 1994) or case studies of individual ocean carriers such as the respective networks of Maersk (Frémont, 2007) and Coscon (Rimmer and Comtois, 2005). This paper is closer to former studies of maritime networks on a regional level, such as the ones on the Caribbean (McCalla, 2008) and the Mediterranean (Cisic et al., 2007), which are based on the services offered by main ocean carriers. It takes also inspiration from the pioneering work of Joly (1999) who used vessel movement data to describe the structure of the global maritime network. Such methodology can be improved and applied to East Asia, which has been relatively ignored under such perspective, despite recent endeavour proposing measures of port connectivity (Low et al., 2009).

## **2.2 TRACKING THE CIRCULATION OF VESSELS**

Inter-port vessel movements are used in order to analyze the relative situation of seaports within a given network. Data was purchased from Lloyd's Marine Intelligence Unit (LMIU), a world leader in shipping intelligence and information whose global database covers approximately 98% of the world fleet of containerships. Original data is presented through daily movements with ports of call, date of call, and capacity of the vessel, among other<sup>2</sup>. Two important aspects can be obtained from such methodology: individual attributes of performance and centrality, and general attributes that relate to the structure of the whole network, in terms of connectivity and polarization. Some important aspects of data preparation and aggregation should be specified before going further.

First, the geographical limits of the study area were arbitrarily defined as a region extending from Far-East Russia to Indonesia including Japan, South Korea, China, Taiwan, Philippines, Malaysia, Singapore, Brunei, Vietnam, Thailand, and Cambodia. Close partners or members of the ASEAN or Asia-Pacific area such as Australia, New Zealand, Papua New Guinea, Pacific Islands and the Americas were excluded so as to restrain the study to Asian countries.

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<sup>2</sup> Other information such as flag, year of build, operating company has not been used in this paper but they represent important research potential for further research. Possible outcomes from an application to North Korea's maritime connections are proposed by Ducruet, Roussin and Jo (2009b) at: [http://www.ejri.net/board/bbs/board.php?bo\\_table=journal\\_02&wr\\_id=25](http://www.ejri.net/board/bbs/board.php?bo_table=journal_02&wr_id=25)

Second, vessel movements were aggregated from daily to yearly flows by summing the capacity of each vessel call by inter-port link and by port after one year of circulation, for both 1996 and 2006. This allows for avoiding the influence of seasonal effects on the overall structure of the network. In addition, official port statistics often refer to yearly throughput figures, which may be compared with our new indicators.

Third, all types of services were aggregated in terms of function (e.g. hub-and-spoke, line-bundling) or scale (e.g. local, intra-Asian, round-the-world). Not only such information is not explicit in the original data, but also we believe that the hypothesized “corridor” structure emerges from the intermingling of all those services. Isolating specific services or carriers would, therefore, be in contradiction with the search for a general spatial configuration or morphology.

Fourth, we wish to analyze inter-port relations through two different perspectives: direct and indirect relations. Direct relations simply follow successive port calls from the circulation pattern of the vessels, while indirect relations include couples of ports which have not been directly connected, what is a specificity of liner shipping with intermediate calls and loops<sup>3</sup>. Those are two different ways to look at the structure of a given network, the latter (indirect links) being more industry-specific than the first. Figure 1 provides a simplified view about data preparation:

- from the vast complexity of liner services passing through seaports, we build a graph based on direct connections or based on all connections (direct *and* indirect) realized by vessels, condensing their circulation patterns after one year of daily movements;
- all individual graphs are merged into one single graph from which new port-related indicators can be obtained, such as maritime degree (i.e. number of connections) and betweenness centrality (i.e. number of positions on possible shortest paths). Result may vary according to the inclusion or exclusion of indirect connections.

As seen in Table 1, the complete graph is denser than the graph of direct connections, and the observed connectivity is higher for the complete graph as it is more

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<sup>3</sup> For instance, a vessel calling successively at Busan, Yokohama, and Shanghai creates two direct links (Busan-Yokohama and Yokohama-Shanghai) but also one indirect link (Busan-Shanghai). Thus, the analysis of indirect links includes all possible connections realized by the vessels regardless of the order of the calls.

complex<sup>4</sup>. In both graphs, the connectivity has increased, what supports the idea that competition may have modified the structure of the network in favour of emerging ports.

Lastly, the complete graph will be analyzed according to the “nodal flow” methodology (Nystuen and Dacey, 1961) in order to better observe polarization and interdependencies among East Asian ports. This approach that was widely applied to a large number of networks<sup>5</sup> takes into consideration the valuation of edges (i.e. connections) between the ports after the summation of vessel capacities. Within the complete connections (direct *and* indirect) of a given port, it only retains the one with the highest traffic flow. This dominant connection is thus the highest traffic share of each port with another port.<sup>6</sup> Of course, other thresholds may extend to the second and/or third nodal flows, but this paper opts for simplicity because such research in the maritime field is only at its eve.

[INSERT FIGURE 1 ABOUT HERE]

[INSERT TABLE 1 ABOUT HERE]

### **3. COMPETITION AND POLARIZATION AT EAST ASIAN PORTS**

#### **3.1 DIRECT CONNECTIONS**

The visualization of direct inter-port connections (Figure 2) highlights the very strong position of three main ports, namely Busan, Hong Kong, and Singapore. This confirms the usual rank of these ports based on official statistics of container traffic volume. In 1996, the corridor is heavily concentrated between Singapore and Hong Kong, while Busan’s function is more dedicated to tranship smaller traffic volumes within Northeast Asia. The highest centrality at Busan is thus explained by the spatial scattering of nearby Japanese, Chinese, and Russian ports that are less equipped with modern handling technologies. In addition to this intermediacy, Busan also exploits its centrality that is its national gateway function handling about 90% of South Korea’s international trade. The network is highly polarized as all other ports have a moderate centrality, except

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<sup>4</sup> Measures were obtained from TULIP software: <http://tulip.labri.fr/>

<sup>5</sup> See for instance Cattan (2004) and Grubestic et al. (2008) for applications on airline networks.

<sup>6</sup> The concept of “hub dependence” (i.e. level of dependence of a port upon another port within a given region) based on this nodal flow could have revealed how North Korean ports have gradually become “hub dependent” upon South Korean ports at a time of humanitarian support and acute crisis (Ducruet, 2008).



for some large gateway cities (e.g. Jakarta, Manila) and the special case of Kaohsiung (Taiwan) ensuring the China link through Hong Kong. In 2006, the overall network structure is similar; Busan continues dominating the hierarchy of centrality. Other important hub ports have lost ground compared with 1996. Yet, the pursued development of the Chinese market (and of Chinese ports) is directly visible through the emergence of dense traffic links North of Hong Kong, notably with Shanghai and Qingdao. Such phenomenon does not contradict the permanency of Busan's predominance since one can observe similar links connecting the latter with the aforementioned Chinese ports. However, Shanghai seems to position as a very central port in the new pattern where all main flows converge, as opposed to the previous pattern where it was nothing but a satellite of Hong Kong.

Changes and permanencies are also a reflection of local factors that can be classified as follows:

- *Stability and stagnation of traditional main ports:* most of centrally located ports in 1996 have enjoyed lower growth on average. This is particularly true for Japanese ports (e.g. Yokohama, Kobe, Nagoya, and Moji) and for the port gateways of some giant cities such as Keelung (Taipei), Manila, and Bangkok. Those are the only ones to see their centrality lower in 2006 than in 1996, especially Bangkok with 25% decrease. For Japanese ports, this trend may come less from rising handling costs than from the extended influence of Busan and Shanghai over Japanese ports in the network. This is accelerated by the government's environmental policy favouring short-sea shipping with those hubs rather than trucking, while avoiding the development of new modern infrastructure close to urban areas (Shinohara, 2009). For Southeast port cities, location within dense urban environments and congestion are among prime factors behind relative decline of their position regionally (Ducruet and Lee, 2006). Other top ports such as Busan, Hong Kong and Singapore have kept their position. The relative permanency of the corridor structure (i.e. the Singapore-Busan axis) may be explained by efficient planning policies locally, which allowed these main ports sustaining their predominance over neighbouring ports despite efforts in the latter to become more competitive (Lee and Ducruet, 2009). Despite recent studies showing the retreat of Hong Kong from its hub function towards a more diversified gateway or global city function

(Cullinane et al., 2004; Wang, 2009), this port seems to have overcome local constraints and regional competition from Shenzhen.

- *Challenge of secondary ports:* as underlined in Table 2, the correlation of degree and centrality with their respective growth is negative. This means that less central ports grow faster, both as an effect of limitations in large ports (Hayuth, 1981), shipping lines' strategies notably in Asia (Slack and Wang, 2003), and through public investment in new port or port expansion projects, such as in Korea (i.e. Incheon and Gwangyang Free Economic Zones), China (i.e. Shenzhen, Ningbo, Xiamen, Qingdao), Indonesia (i.e. Surabaya and Jakarta), and Malaysia (i.e. Port Klang). Especially for Shenzhen, Port Klang, and Indonesian ports, the strategy is to lower their domination by neighbouring large hubs (i.e. Hong Kong and Singapore respectively) through massive investment in new infrastructure and direct call capture (Wang, 1998). One exception is Shanghai, which was already well positioned in 1996 but whose growth in degree and centrality has surpassed other ports of similar initial rank, thus reaching the top of the East Asian hierarchy of centrality in 2006. The growth of Shanghai's centrality is by far the highest among all largest ports of the region, what reflects the rather aggressive strategy of catching direct calls from global shipping lines and liner alliances (Wang and Slack, 2004).

From such analysis we can conclude that the network attributes of East Asian ports clearly confirm current dynamics of port development and competition in this region where drastic changes has occurred during the 1990s and early 2000s. Established main ports have managed keeping their relative position despite local and regional threats, while the network has become denser at the advantage of rapidly growing ports that capture an increasing market share.

[INSERT FIGURE 2 ABOUT HERE]

[INSERT TABLE 2 ABOUT HERE]

### **3.2 THE COMPLETE GRAPH**

Despite satisfactory results from the previous analysis, we wish to look at the network through another perspective by adding indirect connections. We see in Figure 3 some interesting deviation from the graph of direct connections. By taking into account the complexity of liner shipping (i.e. intermediate port calls) this methodology reveals another dimension of the East Asian port hierarchy. In 1996, Hong Kong is now the most central port (compared with Busan in the previous analysis), followed by Singapore, Busan, Nagoya and Yokohama. Indeed, Hong Kong has a better position than Busan when including indirect connections because it combines hub functions with a commercial gateway function for South China. Main Japanese ports are also better represented in the complete graph due to their gateway function serving large urban areas. In 2006, the impact of local port development in Indonesia is more visible, notably through the strikingly high centrality of Surabaya. This may be explained by rapid growth in inter-island shipping within East Indonesia for which Tanjung Perak (Surabaya) is the main hub, based on ambitious local development of port terminals and industrial districts (Ports and Harbors, 2004). Jakarta as well has invested in upgrading local port infrastructure and free-zone development at Tanjung Priok port in order to lower its dependence upon the Singapore hub (Ghani, 2006). Singapore has surpassed Hong Kong as the most central port of the region, but its Malaysian competitor Port Klang has gained grounds in the hierarchy. Although Shanghai has reached a high rank as well, before Busan and after Hong Kong, Northeast Asian ports seem to have a far less important position than Southeast Asian ports. This would indicate that the Southeast sub-region has remained polarized by few main hubs while the Northeast sub-region has become more evenly distributed with the growth of Chinese ports.

The evolution of individual attributes presented in Table 3 shows comparable trends with the ones observed at the graph of direct connections: less central ports in 1996 have higher growth (of both degree and centrality scores) on average, with the exception of Shanghai as a large fast-growing port. Such ports are mostly Chinese ports (e.g. Tianjin, Qingdao, Dalian, Shenzhen, Ningbo, and Xiamen), but also Incheon and Port Klang. Manila, Bangkok, and large Japanese ports have seen their centrality decreasing despite the overall increase in network connectivity between 1996 and 2006. Established hubs such as Hong Kong, Singapore, Busan, and Taiwanese ports have a stable position with low-paced growth.

[INSERT FIGURE 3 ABOUT HERE]

[INSERT TABLE 3 ABOUT HERE]

### 3.3 THE NODAL FLOW GRAPH

One last analytical step aims at revealing the relative position of East Asian ports by simplifying the complete graph through the “nodal flow” methodology. This methodology must complement previous analytical steps by revealing the extent and spatial reach of ports’ polarization in the network. Results for all ports are presented in Figure 4, while Figures 5a and 5b zoom on specific ports.

The graph of nodal flows brings out interesting evidence that does not entirely match previous results. The overall structure is in accordance with the fact that three main ports (i.e. Busan, Hong Kong, and Singapore) are the cores of the network at both years. A more scrutinized observation reveals that conversely to previous analysis, the structure has remained very stable over time: the three major hubs alone polarize the entire region without being threatened by important newcomers. Hong Kong is the dominant node of the network, probably due to its central position between Northeast and Southeast Asian regions. Zooming on the main hub’s nodal regions provides more clues about their geographic coverage.

[INSERT FIGURE 4 ABOUT HERE]

In 1996, Busan polarizes mostly second-order Japanese ports located in the Western regions (Figure 5a), together with Far-East Russian ports; Singapore exerts its centrality upon Southeast Asian ports, and the rest (of which China, Japan, and Taiwan) is under the dominance of Hong Kong, except from some large gateways. Hong Kong remains the key node of the entire network: his position as bridge between Northeast and Southeast Asia is still very clearly apparent and this is not being challenged by any other ports. In 2006, this same structure is also apparent, but some noticeable changes can be underlined:

- *South Korea*: Busan has extended and diversified its “tributary area” by including more many ports and notably more Chinese ports such as Yantai, Weihai, and Tianjin in North China, while Qingdao possesses its own tributary area. This is the result of a very efficient planning policy aiming at relieving congestion locally while maintaining Busan’s attractiveness through Busan New Port and Free Economic Zone construction in the early 2000s in a context of a wider strategy for South Korea to become Northeast Asia’s logistics hub (Frémont and Ducruet, 2005). Busan port authority is currently planning to open its new container terminal at the Russian port of Nakhodka for maintaining and extending its regional influence (KMI, 2008). This is also backed by a number of incentive strategies such as mileage, tariff discount, exemption of port dues and so on. The case of Incheon is also explained by strong government involvement in upgrading and extending local port facilities through the “Pentaport project” including a new container terminal since 2004, aiming at making Incheon the hub of the Yellow Sea (Ducruet, 2007);
- *Indonesia and Malaysia*: Surabaya and Port Klang have increased their position to a great extent (cf. Figure 5b). Although they remain dominated by Singapore, they now polarize their respective Indonesian and Malaysian sub-regions. This new position is thus explained by the reception of more direct calls and by the shift of some local ports from Singapore’s influence under their own influence. Surprisingly, Port Klang, not Tanjung Pelepas, has extended its polarization. This is somewhat counterintuitive given the shift of Maersk and Evergreen from Singapore to Tanjung Pelepas in 2000. Port Klang has developed through government incentive as Malaysia’s main gateway port while Singapore has improved its customer-friendly policy to maintain and attract shipping lines (Lee and Ducruet, 2009);
- *China*: Shanghai’s tributary area has also diversified from only Chinese ports in 1996 to a mixture of Japanese, Chinese, Yellow Sea Korean ports, and Russian ports in 2006, but the width of its polarization has not much increased in terms of the number of ports (i.e. from 6 to 9 dominant connections), notably compared with the wide extension of the tributary areas of Surabaya and Port Klang as previously observed. It remains polarized by Hong Kong as a secondary pole in the East Asian network. This is rather surprising given the ambition of Shanghai playing a key role

in producer services (i.e. global city strategy) and in traffic concentration and distribution through the opening of Yangshan port (i.e. hub function strategy). Perhaps, the grand strategy of developing an international shipping centre supported by central and local governments is not yet achieved sufficiently at the time of the study, due to the expected completion of the Yangshan project in 2010<sup>7</sup>, as Shanghai has developed primarily as a gateway port for the Yangtze corridor rather than as a hub port for transshipment. Still, Shanghai polarizes more many ports than Shenzhen, which is supposed to have become Hong Kong's rival since the late 1990s. Just like Shanghai, Shenzhen is mostly a gateway port serving its local and regional hinterlands with no clear ambition to exert hub function over neighbouring ports. Competition with Hong Kong is thus landward rather than seaward, what explains the relatively low position of Shenzhen in the figures;

- *Taiwan*: Kaohsiung and Keelung have faced the stagnation of their traffic in the 2000s due to the underestimation of Chinese port growth, as reflected in the reduction of the number of weekly calls between 1997 and 2002 at Kaohsiung for instance (Tai and Hwang, 2005), what is also an effect of industrial relocations from Taiwan dragon to China. This has motivated the promotion by the government of a metropolitan new port project since early 2009: two container terminals opened at Taipei-Keelung to support the global city's trading needs, resulting in less cargo flows at Kaohsiung as an effect of domestic competition. Kaohsiung lost 11% of container cargoes in February 2009, the biggest lost after its opening, while major shipping lines such as Evergreen, Yangming and Wanhai may shift fro Kaohsiung to Taipei (Cargonews Korea, 2009).

[INSERT FIGURES 5a and 5b ABOUT HERE]

#### 4. CONCLUSION

This paper has tackled the difficulty analyzing port competition within a given regional area through relative rather than individual measures of performance. Our results

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<sup>7</sup> The first phase commenced operations in 2004 (+ 2.2 million TEUs), the second phase was opened in December 2006 (72 hectares and 15 quay cranes), while the third and last phase should be realized from 2007 to 2012 resulting in a total of 15 million TEUs and 30 container berths.

show that several secondary ports have strived for competitiveness and survival through direct competition with dominant hubs. This competition is notably based on the geographical diversification of their connections through the extension of their market coverage. The above changes indicate certain implications: when making port choices, liners take the maintenance of market coverage and frequency of services as important factors of consideration, while allowing certain diversities and flexibilities within niche areas, depending on changing trade patterns and new opportunities. Last results show the permanency of main ports located on main trunk lines as they maintain their predominance over transshipment activities as opposed to local or feeder ports. In addition, local policies of main ports succeeded keeping and extending their position in spite of strong external and internal threats. While the tremendous growth in traffic volume at Chinese ports under the period of study is reflected in the overall increase of their position in the network, our results provide an alternative viewpoint that is the permanency of the dominance of established hub ports along the East Asian maritime corridor. This research suggests that the position of ports in the liner network is mostly a reflection of the impact of local port policies (e.g. technological advance, infrastructure expansion) rather than the sole result of shipping lines' strategies. Despite the growing spatial freedom of liner networks as depicted in a vast literature, shipping lines remain highly dependent upon local factors.

In terms of methodology, this paper has compared results from three approaches: direct links, complete links, and nodal flows. Results obtained from direct links tend to corroborate well-known port rankings based on official port statistics. The inclusion of indirect links, which is believed to better match the reality of shipping, provides slightly different results valuing not only hub functions but also trade functions. Finally, the search for nodal regions in the East Asian maritime network brings out a clear picture of the geographic extent and evolution of the influence of main ports and emerging ports, reflecting upon current strategies and obstacles. More efforts are needed to improve such results, notably by searching for a relationship between network position and more classical measures of port performance, such as traffic volume and infrastructure efficiency, and by comparing our results with more qualitative aspects of nowadays' port development. In addition, updating the data would allow evaluating the impact of current port development projects.

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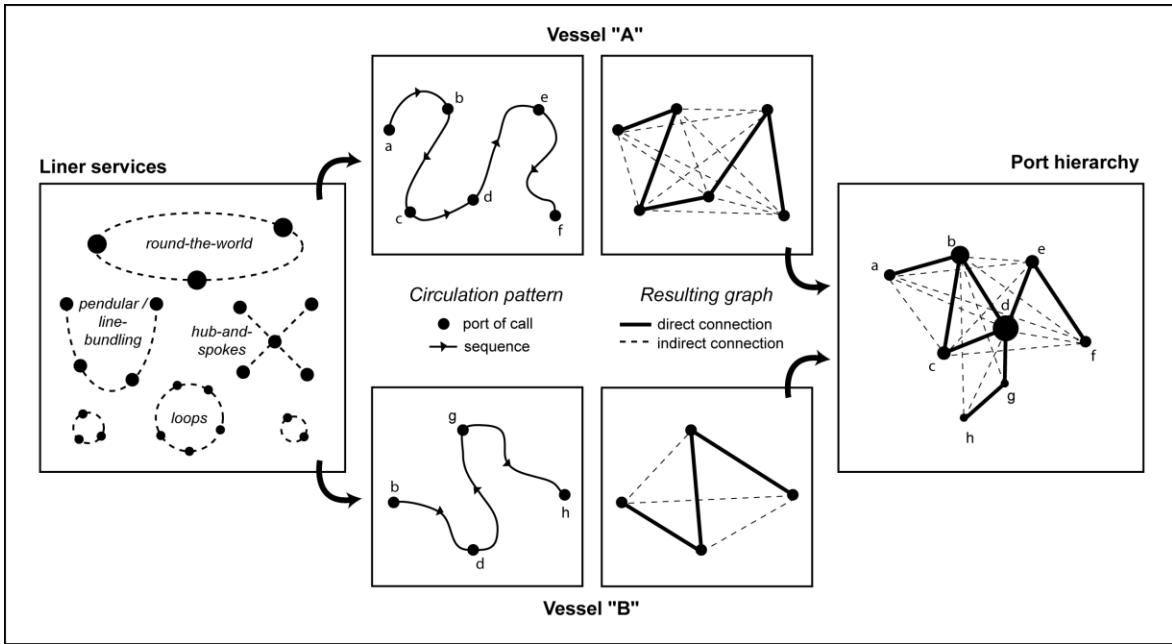


Figure 1. From vessel circulations to graph building and port hierarchy

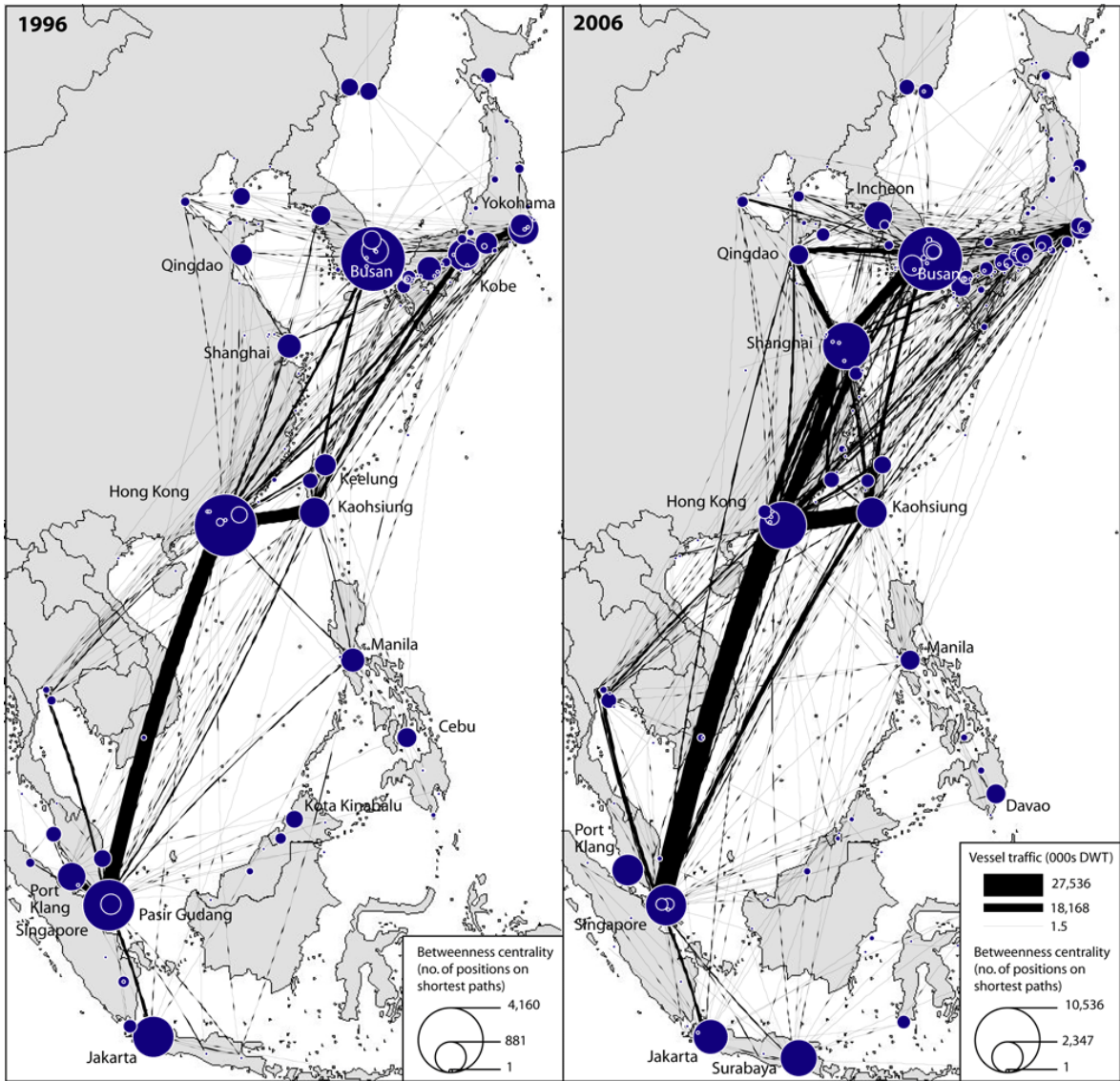


Figure 2. Graph of direct connections among East Asian ports, 1996-2006

Source: realized by authors based on LMIU data

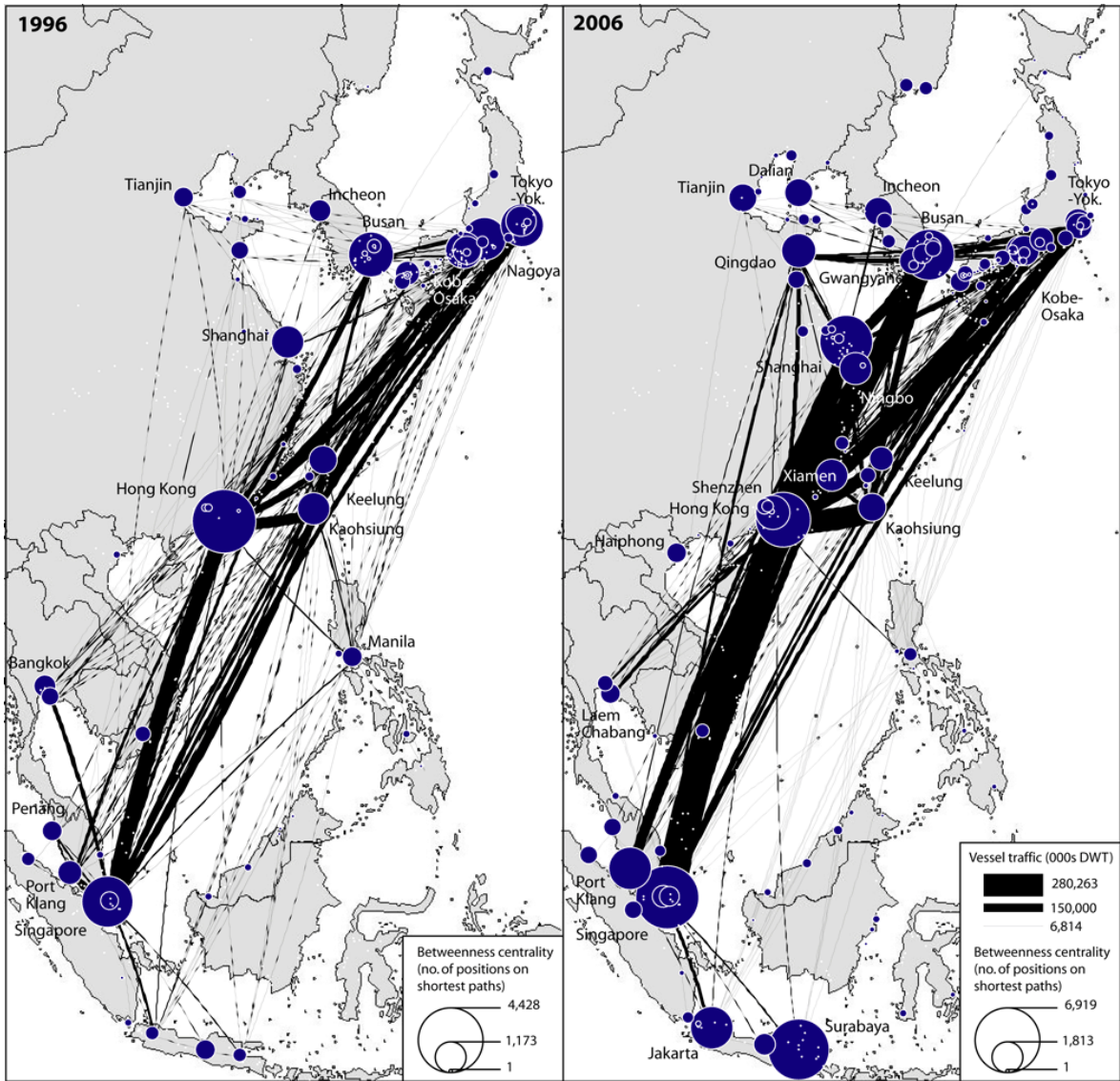


Figure 3. Complete graph among East Asian ports, 1996-2006

Source: realized by authors based on LMIU data

*N.B. only edges representing over 0.05% of total traffic volume are kept in the figure*

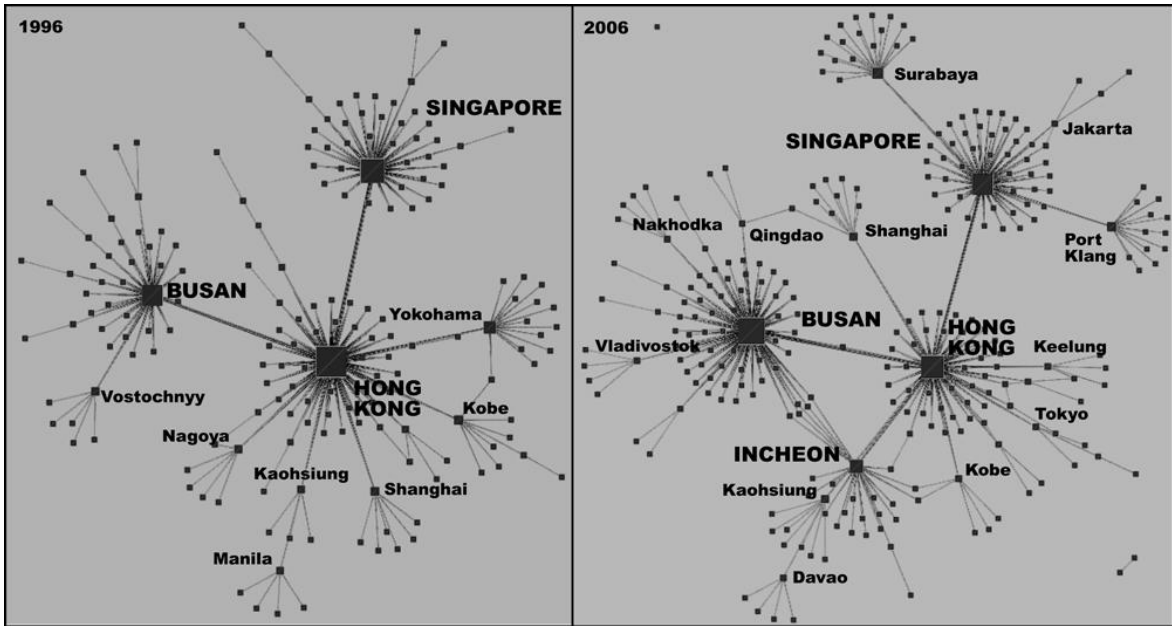


Figure 4. Graph of nodal flows, 1996-2006

Source: realized by authors based on LMIU data

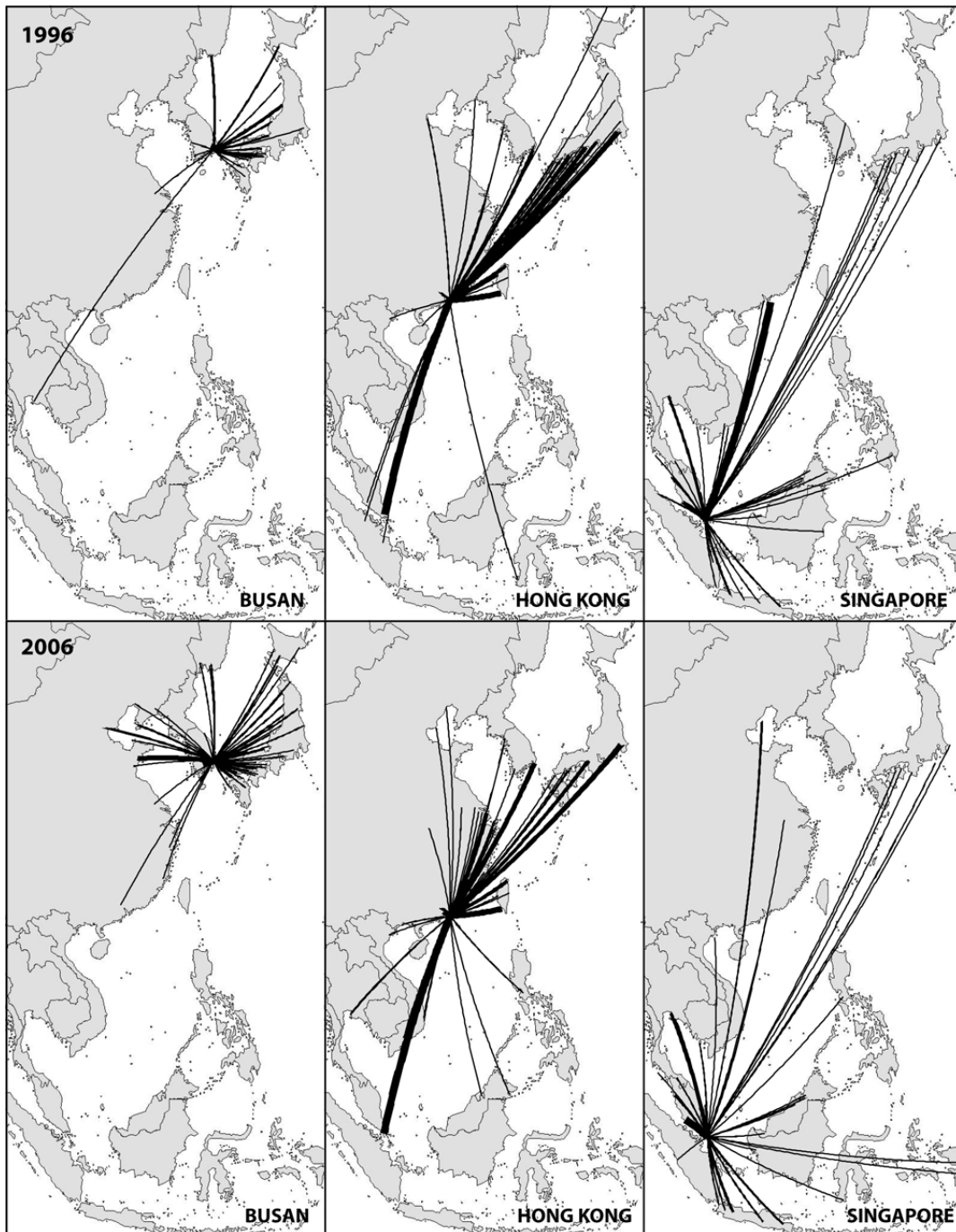
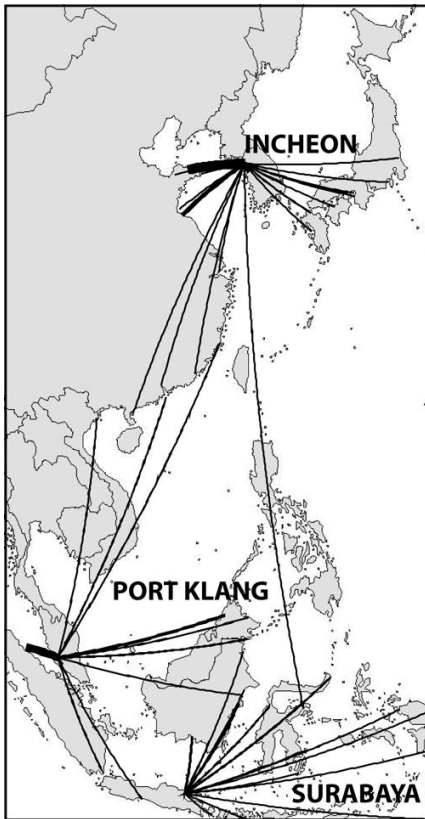


Figure 5a. Nodal regions of main East Asian hub ports, 1996-2006

Source: realized by authors based on LMIU data



**Figure 5b. Nodal regions of emerging East Asian hub ports, 2006**

Source: realized by authors based on LMIU data



Type	Edges		Optimal / observed connectivity	
	1996	2006	1996	2006
Direct connections	996	3,068	36.05	29.04
Complete graph	2,556	6,650	12.75	12.43

**Table 1. Characteristics of the East Asian maritime network, 1996-2006**

Source: realized by authors based on LMIU data

Port name	Country code	Maritime degree			Betweenness centrality		
		1996	2006	A [log06/ log96]	1996	2006	B [log06/ log96]
Busan	KOR	89	160	1.13	7,396	11,282	1.05
Singapore	SGP	74	133	1.14	7,277	11,284	1.05
Hong Kong	CHN	84	159	1.14	6,394	11,200	1.06
Yokohama	JPN	63	84	1.07	2,531	2,026	0.97
Shanghai	CHN	51	166	1.30	2,520	11,843	<b>1.70</b>
Kobe	JPN	61	82	1.07	2,307	1,110	0.91
Keelung	TWN	52	81	1.11	2,079	1,383	0.95
Kaohsiung	TWN	56	108	1.16	2,059	3,142	1.06
Nagoya	JPN	50	81	1.12	1,969	1,128	0.93
Moji	JPN	39	63	1.13	1,184	566	0.90
Tianjin	CHN	36	68	1.18	1,067	796	0.96
Incheon	KOR	30	93	1.33	1,054	2,542	1.13
Osaka	JPN	46	81	1.15	973	1,464	1.06
Ulsan	KOR	31	65	1.22	802	827	1.00
Port Klang	MYS	29	85	1.32	685	3,760	1.26
Manila	PHL	37	67	1.16	600	946	1.07
Bangkok	THA	27	44	1.15	574	114	0.75
Pasir Gudang	MYS	27	54	1.21	527	912	1.09
Tokyo	JPN	38	81	1.21	485	1,320	1.16
Qingdao	CHN	25	108	<b>1.45</b>	269	3,206	1.44
Hakata	JPN	28	72	1.28	259	683	1.17
Taichung	TWN	25	59	1.27	193	551	1.20
Jakarta	IDN	16	69	<b>1.53</b>	180	5,278	<b>1.65</b>
Laem Chabang	THA	22	65	1.35	94	681	1.44
Surabaya	IDN	13	63	<b>1.62</b>	77	8,582	<b>2.09</b>
Dalian	CHN	21	87	<b>1.47</b>	66	1,491	<b>1.74</b>
Xiamen	CHN	20	81	<b>1.47</b>	39	1,737	<b>2.04</b>
Ningbo	CHN	15	102	<b>1.71</b>	28	2,412	<b>2.34</b>
Shenzhen	CHN	17	84	<b>1.56</b>	31	1,706	<b>2.17</b>
Gwangyang	KOR	3	91	<b>4.11</b>	2	1,281	<b>10.32</b>
<i>Average growth</i>		1.37			1.54		
<i>R<sup>2</sup> with growth</i>		0.80			0.68		

**Table 2. Network attributes of main East Asian ports, 1996-2006 (direct connections)**

Source: realized by authors based on LMIU data

*N.B. growth values higher than average are in bold*

Port name	Country code	Maritime degree			Betweenness centrality		
		1996	2006	A [ $\log_{06}/\log_{96}$ ]	1996	2006	B [ $\log_{06}/\log_{96}$ ]
Hong Kong	CHN	144	207	1.07	4,428	5,230	1.02
Singapore	SGP	120	187	1.09	3,065	6,919	1.10
Busan	KOR	124	203	1.10	2,179	4,535	1.10
Nagoya	JPN	124	145	1.03	2,061	1,090	0.92
Yokohama	JPN	127	143	1.02	1,995	1,145	0.93
Kobe	JPN	117	159	1.06	1,559	1,557	1.00
Shanghai	CHN	92	210	<b>1.18</b>	1,189	5,016	<b>1.20</b>
Kaohsiung	TWN	103	155	1.09	1,173	1,462	1.03
Tokyo	JPN	106	146	1.07	986	1,227	1.03
Keelung	TWN	97	136	1.07	900	1,001	1.02
Osaka	JPN	97	162	1.11	866	1,586	1.09
Port Klang	MYS	80	154	<b>1.15</b>	685	3,154	<b>1.23</b>
Moji	JPN	87	111	1.05	644	407	0.93
Bangkok	THA	76	102	1.07	536	436	0.97
Incheon	KOR	77	157	<b>1.16</b>	516	1,473	1.17
Penang	MYS	69	93	1.07	473	609	1.04
Tianjin	CHN	67	157	<b>1.20</b>	471	1,456	<b>1.18</b>
Manila	PHL	69	94	1.07	435	290	0.93
Laem Chabang	THA	67	111	1.12	389	639	1.08
Qingdao	CHN	73	172	<b>1.20</b>	382	2,165	<b>1.29</b>
Hakata	JPN	74	137	<b>1.14</b>	288	727	1.16
Dalian	CHN	59	154	<b>1.24</b>	240	1,472	<b>1.33</b>
Surabaya	IDN	54	120	<b>1.20</b>	230	6,710	<b>1.62</b>
Jakarta	IDN	55	116	<b>1.19</b>	200	3,196	<b>1.52</b>
Shenzhen	CHN	45	156	<b>1.33</b>	122	1,970	<b>1.58</b>
Ningbo	CHN	46	158	<b>1.32</b>	93	1,803	<b>1.65</b>
Xiamen	CHN	40	155	<b>1.37</b>	58	1,814	<b>1.85</b>
Gwangyang	KOR	-	151	-	-	1,196	-
<i>Average growth</i>		<i>1.14</i>			<i>1.18</i>		
<i>R<sup>2</sup> with growth</i>		<i>0.69</i>			<i>0.62</i>		

**Table 3. Network attributes of main East Asian ports, 1996-2006 (complete graph)**

Source: realized by authors based on LMIU data

*N.B. growth values higher than average are in bold*