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The impacts of production base relocation on port cluster competition: The case of the Pearl River Delta region.

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ABSTRACT: Due to increases in labor and operational costs within the Pearl River Delta (PRD) region, many manufacturing firms are relocating their plants to inland provinces in China. The existence of significant intra- and inter-port cluster competition means that this ongoing relocation process will not only affect the ports of Shenzhen and Hong Kong, but will also have an impact on ports in other clusters such as Shanghai in the Yangtze River Delta (YRD). Furthermore, since Hong Kong and Shenzhen share the same transportation corridor to inland China, the hinterland access condition is another concern to be examined. This paper employs an analytical economic model to investigate the implications of this process. With the model allowing for substitutable but differentiated services among the three competing ports, the finding in all cases shows that the process will harm the performance of the ports in PRD region, but will benefit the port YRD region. With respect to the impact of a change in hinterland access condition, the implications for Hong Kong are clear, but more complex for Shenzhen. This is because although it shares the same transport corridor to inland China with Hong Kong, it is also one of Hong Kong's competitors. Since Hong Kong also benefits from the hinterland access and/or negative externality improvement, such effect may either benefit or lower performance of Shenzhen port. The analytical results suggest that a more competitive port of Hong Kong will be in a better position to cooperate with the neighboring port of Shenzhen, and that it is important for Hong Kong to improve its cross-border cargo flows.

KEY WORDS: ***Production base relocation; port cluster competition; Pearl River Delta; hinterland access.***

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1. Introduction

China's industrial sector has long developed along the coastal regions of the country's eastern and southern provinces. Many manufacturing firms, both local and multinational corporations (MNCs), have established their production bases and manufacturing hubs in these areas, particularly within the Pearl River Delta (PRD) and the Yangtze River Delta (YRD). The prosperity of the manufacturing sector has also accelerated the development of other related industries including shipping and port services. The ports of Hong Kong and Shenzhen in the PRD region and the port of Shanghai in the YRD region have clearly benefited from the manufacturing boom in their catchment areas. This is evidenced by the extremely high level of growth in the volume of traffic served by these ports in the past three decades. All three ports ranked among the five busiest container ports in the world in 2011.

The economic development that has occurred since China launched its reform program in 1979, as well as preferential incentives from local governments, has led the PRD to becoming the most economically dynamic region in mainland China (Michael and Scott, 2007). The key growth engine has been the production and manufacturing sector. The PRD region has grown into one of the leading manufacturing hubs in the world for products such as electronics, furniture, shoes, fashion and textiles, toys, and telecommunications equipment. Many favorable factors have contributed to this success. The PRD region has excellent transport infrastructure, including ports, airports, highways, and rail systems. The logistics industry is well-developed and local customs services are efficient and business-friendly. The region has also attracted many emigrant workers from the labor-rich provinces of inland China. This has allowed the PRD to maintain its edge in both efficiency and cost competitiveness over other economies in Southeast Asia. In addition, provincial and municipal governments have offered very generous terms to investors, often in the forms of tax incentives and cheap land. All these factors have made the PRD the preferred location for manufacturers, especially those specializing in labor-intensive products. Indeed, ports in Southern China, notably Hong Kong and Shenzhen, have benefited greatly from economic growth within the Pearl River Delta (PRD) region in the past three decades.

However, the success experienced in the past is introducing new challenges today. Living costs have been rising rapidly in the PRD region, forcing manufacturing firms to constantly increase workers' remuneration. Wages have surged at an annualized rate of 17% (The Boston Consulting Group, 2011). Preferential policies offered by local governments are gradually being withdrawn from labor-intensive production operations, as municipal and provincial governments now aim to set aside more land and subsidies for high-tech and service-oriented industries. The comparative advantages of the Pearl River Delta for labor-intensive manufacturing are fading quickly. The constant increases in labor and operational costs within the PRD have forced many manufacturing firms to explore alternative locations, with a notable focus on inland areas. Although many provinces in Western and Northern China are economically less developed, they have abundant labor and land resources. The Chinese government is thus implementing a strategic plan to promote economic re-balancing among the provinces in the hope they can all achieve sustainable growth in the long run and income gap among the regions could be narrowed (Kuijs and Wang, 2005; Li and He, 2006; Wan et al., 2006; Qiao et al., 2008; Chen and Groeneworld, 2011). Many inland provinces and cities have regarded attracting relocated firms as an opportunity to catch up with or leapfrog their peers. Local governments and the central government have offered generous incentives including tax concessions, cheap land, and sometimes even free factory buildings to support investments in these inland provinces, thus further accelerating the relocation process. A survey conducted by the Hong Kong Trade Development Council (HKTDC, 2011a) reveals that many Hong Kong companies operating in the PRD have a positive view of the relocation option. The preferred location choices are areas close to Guangdong such as the provinces of Hunan, Sichuan, Hubei, and the district of Chongqing (HKTDC, 2011a, 2011b, 2011c). A number of high-tech manufacturers have already relocated their labor-intensive assembly and OEM production units. For example, Chongqing has become one of the world's major hubs for laptop computers, assembling about half of all units globally. Many iPhone and iPad OEM production units are also being relocated to the provinces of Sichuan and Henan.

The ongoing relocation process may pose significant challenges to the major ports in the PRD region, which have benefited substantially from the export and import growth driven by the manufacturing boom in the region. The ports of Hong Kong and Shenzhen may face some serious challenges if a large number of firms relocate their operations. Their hinterland access costs will increase, leading to reduced traffic volume. In addition, if production bases are relocated to provinces close to other gateway ports such as Shanghai, then a substantial volume of traffic may be switched to other ports. Because ports on the Yangtze River offer very competitive inland shipping services to a number of major cities and provinces in inland China, manufacturers that relocate to these areas could have lower transportation costs to Shanghai than to the PRD region, even if the geographic distances to the ports are similar. Traffic shifts can be substantial in such cases. Therefore, the relocation of manufacturing operations based in the PRD region will not only influence the performance of the ports of Hong Kong and Shenzhen, but may also reshape the competitive landscape among major port clusters in mainland China (e.g., as between the PRD port cluster and the YRD port cluster).

Evaluating the effects of this relocation process comprehensively is not a straightforward exercise. Given that the ports of Hong Kong and Shenzhen share common transportation corridors and transport infrastructure to inland China, the relocation process will have some externality effects on the two ports' hinterland logistics. If there is economy of scale in hinterland access, or a positive externality effect, sharing a common transport corridor will allow the two ports to lower their hinterland transportation costs. On the other hand, if there is substantial congestion in hinterland transport facilities, or a negative externality effect, then sharing a common transport corridor will increase the hinterland access costs of both ports. Because Hong Kong and Shenzhen provide substitutable services, an identical change in input costs may have different effects on the two ports.[1] In addition, firms may even take measures to increase their competitors' costs to gain a competitive advantage (Salop and Scheffman, 1983). Therefore, it is difficult to gauge the overall effects of the ongoing production base relocation process in the PRD region without conducting a comprehensive investigation.

The effects of hinterland access on port cluster competition have also been observed in other markets. Notteboom (2009a) points out that hinterland access moderates the relationships among major European ports and has profound implications for global supply chains. Although there is no lack of research on the geographical evolution of ports and terminals (see, for instance, Ng and Gujar (2009), Ng and Cetin (2012), and Padilha and Ng (2012)) and port competition (see, for instance, Notteboom (2009b), and Lam and Yap (2011)) few studies have systematically investigated the implications of a dynamic relocation process such as that occurring in the PRD region. Predictions on the impacts of production base relocation on port cluster competition thus remain untested to date. This paper aims to address this gap in the literature by investigating: (a) the implications of relocation on port performance in terms of port throughput, hinterland access costs, port charges, and market share distribution; (b) the implications of relocation on port competition within a port cluster (in this context, competition between Hong Kong and Shenzhen in the PRD); and (c) the implications of relocation on port cluster competition (in this case, competition between the PRD and YRD port clusters). This study provides fresh insights and important policy recommendations to stakeholders in the Chinese port industry. In addition, the analytical framework employed here can easily be extended to investigate other cases in which competing ports experience major changes in hinterland/input costs.

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[1] Fu et al. (2006) and Oum and Fu (2008) analyzed the effects of airport charge increases on competing airlines which provide differentiated services. In general, they concluded that an identical increase in input prices will have differential impacts on downstream competitive firms.

The remainder of this paper is organized as follows. Section 2 provides information on the overall background of port competition in the PRD region and the ongoing production base relocation process. Section 3 describes construction of an economic model used to provide analytical results. Section 4 summarizes and concludes the paper. The Appendix lists a number of mathematical derivations.

2. Port competition and production base relocation

The rapid economic growth of Greater China in recent decades has led to aggressive investments in the port sector. Many ports have been built or expanded. Three port clusters stand out along the coastal areas of mainland China: (1) the Bohai Bay port cluster, which includes the ports of Dalian, Qingdao, and Tianjin; (2) the YRD port cluster, in which Shanghai is the dominant port, followed by Ningbo and Zhoushan; and (3) the PRD port cluster, which has been largely dominated by Hong Kong and Shenzhen, but is complemented by follower ports such as Xiamen and Fuzhou. While these three port clusters compete with each other, competition among the ports within each cluster is even stronger. The following sub-sections first outline competition between and within the port clusters before providing some background information on the ongoing production base relocation process.

2.1 Intra- and inter-cluster port competition

The port of Hong Kong is strategically located in the Pearl River Delta. Supported by its high-quality infrastructure and business-friendly regulatory environment, the port has long served as a major gateway for shipping and trade to mainland China and Southeast Asia. It was one of the first Asian ports to become containerized, and has long been one of the world's leading ports in terms of shipping volume, productive efficiency, and service quality. In 1979, the Shenzhen Special Economic Zone was established north of Hong Kong's border with the mainland. In the following years, the PRD region as a whole attracted a tremendous amount of overseas investment, mostly in the manufacturing sector (Lin, 1997). This led to an explosion in demand for shipping and port services in the region. Given the less developed and poorly managed state of Shenzhen's port, Hong Kong benefited most from this growth in demand. However, from 1979 to 2004, Shenzhen invested over 30 billion yuan to improve its port infrastructure and related facilities. Restrictions on foreign investment in and management of the port sector were also lifted during this period, with some major terminals being privatized (Cullinane et al., 2004). This allowed the port of Shenzhen to grow rapidly and eventually surpass Hong Kong in terms of traffic volume. A similar development process also took place in the port of Shanghai in the Yangtze River Delta. Today, these three ports are among the five busiest container ports in the world. Their throughput volumes in recent years are summarized in Table 1.

Table 1: Container throughput and transshipment estimates for Hong Kong, Shenzhen and Shanghai (2003-2009)

Year/Port ('000 TEU)	2004	2005	2006	2007	2008	2009	2010 [a]
Hong Kong [b]							
Throughput	22,021	22,424	23,540	23,904	24,494	20,984	11,435
Transshipment Estimate	6,661	6,817	7,062	7,171	7,348	5,141	n.a.
Transshipment Incidence (%)	30.30	30.40	30.00	30.00	30.00	24.50	n.a.
Average growth in port throughput (2003-2010)[b]: 0.91%							
Shenzhen							
Throughput	13,562	15,899	18,171	21,117	21,416	18,105	10,354
Transshipment Estimate	2,215	2,689	3,302	3,759	4,888	3,640	n.a.
Transshipment Incidence (%)	16.33	16.91	18.17	17.80	22.82	20.10	n.a.
Average growth in port throughput (2003-2010) [b]: 8.01%							
Shanghai [b]							
Throughput	14,557	18,084	21,710	26,150	27,980	25,214	13,800
Transshipment Estimate	6,242	7,793	4,342	5,753	6,156	5,295	n.a.
Transshipment Incidence (%)	42.90	43.10	20.00	22.00	22.00	21.00	n.a.
Average growth in port throughput (2003-2010) [b]: 11.88%							

Sources: Drewry Shipping Consultants Ltd, with supplemental data for Shenzhen compiled from the China Ports Yearbook

Notes: [a] Due to data availability, container throughput statistics in 2010 were calculated from the first two quarters.

[b] Transshipment incidence figures are calculated after adjusting for estimated river traffic.

It is clear that Shenzhen experienced much faster growth than Hong Kong over the past three decades. The average annual growth in throughput in Hong Kong between 2003 and 2009 was a mere 0.38%, whereas the growth rate for Shenzhen during the same period was 10.24%. The port of Shanghai recorded an even higher average annual growth rate of 14.98% thanks to strong economic growth in the YRD region and competitive river transportation services along the Yangtze River. The rising power of the mainland ports, Shenzhen and Shanghai in particular, is changing the landscape of the port industry along China's coastal regions. Transshipment operations and aggressive investments in capacity at Shenzhen pose significant challenges to Hong Kong, which has traditionally served as both a major gateway to China and a transshipment hub in the region. Although UNESCAP (2005) predicted that the port of Hong Kong would remain a major logistics hub for the region, it is clear that it has been persistently losing its market share to rising mainland ports in the PRD and YRD regions. The overall picture that emerges from the evidence of recent years shows clear intra- and inter-port cluster competition.

2.2 Underlying incentives for industrial relocation from the PRD region

Continuously rising costs in the PRD region mean the local business environment has become increasingly unfavorable for manufacturing firms. Liao and Chan (2011) compiled a survey conducted by the Chinese Manufacturers' Association of Hong Kong (2008), suggesting the most influential/challenging business environment changes in the PRD region included RMB appreciation, inflation, and the upsurge in raw materials and, in particular, labor costs. As shown in Table 2, average wages in the manufacturing sector have increased sharply in all mainland China provinces. The average annual rate of growth in wages in Guangdong during the 2006 to 2010 period was 11.67%, lower than the national average of 14.45%. However, because the wage level has always been higher in Guangdong than in inland provinces, wage differences between Guangdong and inland provinces have barely narrowed. While municipal governments in the PRD region are somewhat concerned about the negative effects of rising labor costs, priority has increasingly been given to improving residents' living standards and upgrading the local economy to one relying more on high value-added manufacturing and service-oriented businesses. Therefore, some local governments are in favor of increasing salaries overall. For example, from 1 February 2012, the minimum wage in the Shenzhen Special Economic Zone increased by an additional 13.6%. Moreover, high fuel prices and hikes in power prices and electricity rates for industrial users have raised operational costs further at manufacturing plants across the country, especially in developed regions with their higher input price levels (HKTDC, 2012). The diminishing comparative advantages of the PRD region have put increasing pressure on manufacturers to relocate their production bases.

Table 2: Average wage in the manufacturing sector (unit: yuan/year)

Regions/ Years	Average wage					Average wage growth (%)					
	2006	2007	2008	2009	2010	2006	2007	2008	2009	2010	Ave.
Coastal regions											
Guangdong	19785	22547	24751	27578	31277	9.80	13.96	9.78	11.42	13.41	11.67
Fujian	15936	18391	20445	22631	26627	12.00	15.41	11.17	10.69	17.66	13.38
Jiangsu	19117	22510	25187	27765	32209	12.87	17.75	11.89	10.24	16.01	13.75
Shandong	15381	18477	21114	23930	27773	18.14	20.13	14.27	13.34	16.06	16.39
Shanghai	35453	37975	43678	46672	52163	18.83	7.11	15.02	6.85	11.77	11.92
Inner mainland China											
Chongqing	18163	21290	24249	27770	31894	16.93	17.22	13.90	14.52	14.85	15.48
Guangxi	17104	19408	21644	23508	26179	16.94	13.47	11.52	8.61	11.36	12.38
Jiangxi	13780	15423	17643	21508	25579	15.59	11.92	14.39	21.91	18.93	16.55
Ningxia	15970	19461	23015	24431	29560	17.82	21.86	18.26	6.15	20.99	17.02
Shaanxi	15955	17968	21034	23428	26015	18.87	12.62	17.06	11.38	11.04	14.20
Sichuan	16442	18906	22090	24448	28577	15.18	14.99	16.84	10.67	16.89	14.91
Yunnan	19131	20028	23613	23614	28550	11.45	4.69	17.90	0.00	20.90	10.99
National Total	17966	21144	24192	26810	30916	14.02	17.69	14.42	10.82	15.32	14.45

Source: China Statistical Yearbook 2007-2010, National Bureau of Statistics of China

Rising costs are clearly a "push factor" for manufacturing companies operating in the PRD region. Furthermore, the Chinese government's plan to achieve balanced growth across the country has resulted in some preferential incentives being offered to firms considering relocation. Such "pull factors" include incentives such as tax rebates, fast-tracked approval for the establishment of businesses, favorable land supply arrangements, and improved transport and logistics infrastructure from inland provinces to major gateway ports. The Ministry of Commerce has initiated plans designed to encourage investment in the central and western regions. The Ministry selected nine regions of central China as the first batch of areas designated for investment in April 2007. The second target areas were promoted in the following year, most in central and western parts of China as reported in Table 3 and Figure 1. Table 2 shows that wages in most of these designated areas are fairly competitive. Since they were designated as priority regions for relocation, many major manufacturing groups have announced plans to gradually relocate their plants from the PRD region to inland areas. For instance, in 2010, Flextronics expanded its production site at Ganzhou in the province of Jiangxi (PR Newswire, 2010; Global Supply Chain Council, 2010). Foxconn, a well-known OEM supplier for Apple Inc., plans to move its major production campus from Shenzhen to Langfang in Hebei province and to build a new plant in Zhengzhou, Henan (China Daily, 2010). In addition, it agreed to jointly invest in a laptop manufacturing hub in Chongqing with Hewlett-

Packard (China Daily, 2009). Due to increasingly restrictive environmental protection policies along the coastal provinces, many producers of chemicals, building materials, textiles, and paper, are also evaluating plans to relocate to inland areas (Liao and Chan, 2011; Zhao and Yin, 2011; Knowler, 2012).

Table 3: Areas designated for industrial relocation in 2007 and 2008

Region	Province/Municipality	City	
		First Batch	Second Batch
Central	Hubei	Wuhan	Yichang Xiangfan
	Hunan	Chenzhou	Yueyang Yiyang Yongzhou
	Henan	Xinxiang Jiaozuo	Luoyang Zhengzhou
	Jiangxi	Nanchang Ganzhou	Yian Shangrao
	Shanxi	Taiyuan	Houma processing zone
	Anhui	Hefei Wuhu	Anqing
Western	Guangxi		Nanning Qinzhou
	Sichuan		Chengdu Mianyang
	Chongqing		
	Shaanxi		Xi'an
	Ningxia		Yinchuan
	Yunnan		Kunming
Others	Hainan		Haikou
	Inner Mongolia		Baotou
	Heilongjiang		Harbin

Sources: Ministry of Commerce, People's Republic of China and Li & Fung Research Centre (2008)

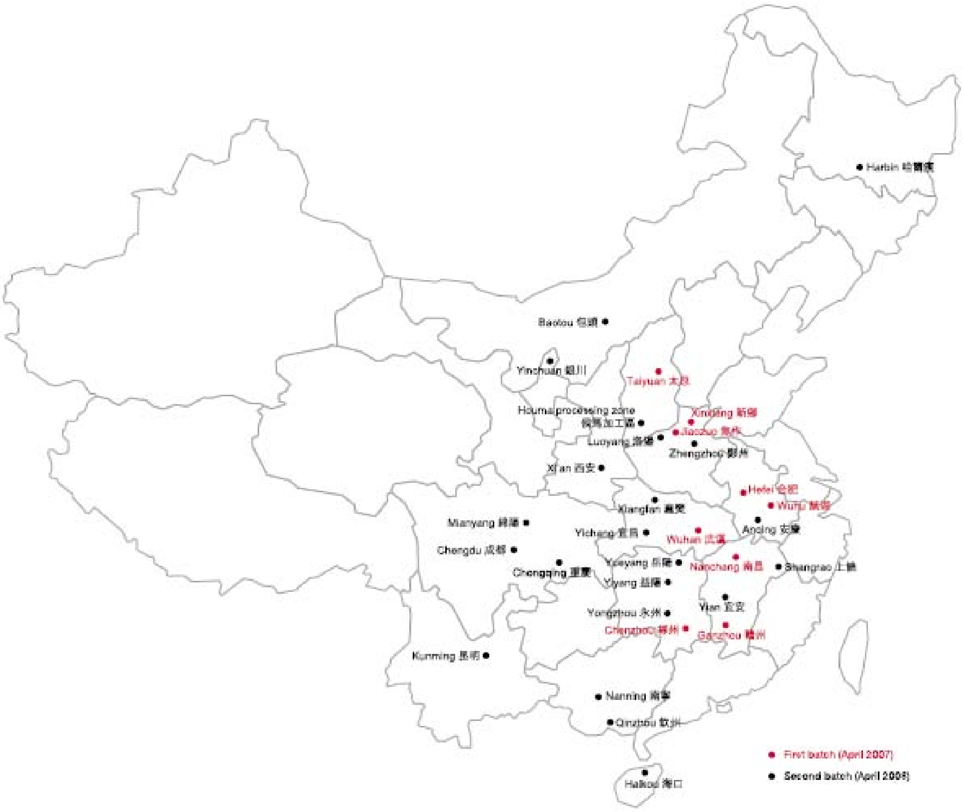

Figure 1: Areas designated for industry relocation by the Ministry of Commerce (as end-2008)

Sources: Ministry of Commerce, People's Republic of China and Li & Fung Research Centre (2008)

While many factors have had an influence on the port development, such as infrastructure development, inland transport condition, regulation, concentration / deconcentration, and port rivalry (Frankel, 1998; Robinson, 1998; Wang and Slack, 2000; Loo and Hook, 2002; Slack and Wang, 2002), the development of major ports in the PRD region is being significantly affected by the production base relocation away from the region in recent years. Together with weak demand following the global financial crisis that began in 2008, in the first quarter of 2011, container throughput of the ports of Hong Kong and Shenzhen rose only 2.4% and 3.6% respectively, representing a clear slowdown from past years (Shih, 2011). Although the effects of the global financial crisis will eventually recede, the long-term impacts of production base relocation will persist. Therefore, it is important that policy makers in Shenzhen and Hong Kong come up with long-term strategies to maintain their status as regional hub ports and gateways to mainland China. The following section attempts to model the performance implications of relocation for these two ports, thus enabling their stakeholders to formulate feasible plans for long-run growth.

3. A model of hinterland access in the presence of port competition

This section considers a case whereby many shippers (e.g. manufacturing companies) in the PRD region and nearby provinces in Southern China rely on two port clusters to provide them with international logistics services. Ports in Cluster 1, which include major ports in the PRD region, have been close to these firms, and thus provide them with almost all the shipping services they require. Cluster 1 has two competing ports denoted as Port 1 (Hong Kong) and

Port 2 (Shenzhen). The other port cluster, the Port Cluster 2 in the YRD region, currently provides few services to these shippers/manufacturers. However, if there is a continued trend of production base relocation, then in the long term, ports in this second cluster may be able to provide (relocated) firms with more competitive services. Port Cluster 2 comprises several ports including Ningbo and Shanghai. Shanghai is the clear leader among them and dominates the market in terms of market share and pricing capability. To take this consideration into account and ensure analytical tractability, the ports in this cluster are treated as a single (consolidated) "mega-port" denoted as Port 3. For ease of notation and discussion, the various ports involved in the model are referred to as Port 1 Hong Kong, Port 2 Shenzhen and Port 3 Shanghai. These three ports provide substitutable but differentiated services. Their demand equations are specified in equation (1):

$$\begin{cases} \rho_1 = \alpha_1 - \beta_1 q_1 - \gamma_2 q_2 - \gamma_3 q_3 \\ \rho_2 = \alpha_2 - \gamma_2 q_1 - \beta_2 q_2 - \gamma_1 q_3 \\ \rho_3 = \alpha_3 - \gamma_3 q_1 - \gamma_1 q_2 - \beta_3 q_3 \end{cases}, \qquad (1)$$

which corresponds to a representative consumer maximizing a quadratic utility function of $U(\vec{q}) = \sum_{i=1}^{3} \alpha_i q_i - \frac{1}{2}\left[\sum_{i=1}^{3} \beta_i q_i^2 + 2\gamma_1 q_2 q_3 + 2\gamma_2 q_1 q_2 + 2\gamma_3 q_1 q_3\right] + M$, where M is numeraire goods (money) and $\vec{q}$ denotes a vector of outputs (i.e. port throughputs) at the three ports. Assume that a port's price is more sensitive to its own output than to those of rival ports. That is, it is further assumed that $\beta_i > \gamma_i$ for all i.

For a (representative/average) shipper, the generalized cost of using port ρ_i is the sum of hinterland access costs h_i and port charges p_i:

$$\rho_i = h_i + p_i . \qquad (2)$$

The close proximity of Port 1 Hong Kong and Port 2 Shenzhen means they share the same transport corridor to inland provinces. Per unit logistics costs associated with hinterland access (e.g. the cost of moving a container from the production base to a PRD port) can be specified as:

$$h_i = g_1 d_i (1+\lambda), \quad i = 1,2,\ d_1 > d_2, \text{ and } \lambda \in (-1,1), \qquad (3)$$

which is a function of the unit transportation cost of moving a container one kilometer for Port Cluster 1 (the PRD region), denoted as g_1 ; distance d_i from the production base to Port i; and a parameter λ which captures the effect of the interdependence among the two ports' hinterland access costs. Overall, there may be two types of countervailing factors. On the one hand, if the hinterland access network had spare capacity, sharing a common transport corridor would lead to greater utilization of related facilities such as inland terminals/dry ports, warehouses, IT systems, and general administration functions. This would reduce the inland logistics costs of both ports, in which case $\lambda < 0$. On the other hand, if the hinterland access network is short of capacity, then sharing a common transport corridor is likely to lead to higher logistics costs due to congestion, in which case $\lambda > 0$. If there is no externality at all, then $\lambda = 0$. Suppose congestion costs are not usually as high as transportation costs themselves and so $\lambda \in (-1,1)$. The assumption that $d_1 > d_2$ indicates that for a shipper in mainland China, Hong Kong is more distant than Shenzhen, which simply reflects the geographic locations of the two ports.

Because only one port (Shanghai) is considered in the Port 3 cluster and thus has no externality effect, hinterland logistics costs for Port 3 are defined as in equation (4):

$$h_3 = g_3 d_3 . \tag{4}$$

Taking into account the generalized costs of using each port as defined in (2), the demand system (1) can be specified as functions of p_i as in equation (5):

$$\begin{cases} q_1 = \dfrac{(\beta_2\beta_3-\gamma_1^2)\left(\mathrm{P}_1-g_1d_1\lambda\right)-(\beta_3\gamma_2-\gamma_1\gamma_3)\left(\mathrm{P}_2-g_1d_2\lambda\right)-(\beta_2\gamma_3-\gamma_1\gamma_2)\mathrm{P}_3}{2\gamma_1\gamma_2\gamma_3+\beta_1\beta_2\beta_3-(\beta_1\gamma_1^2+\beta_3\gamma_2^2+\beta_2\gamma_3^2)} \\ q_2 = \dfrac{-(\beta_3\gamma_2-\gamma_1\gamma_3)\left(\mathrm{P}_1-g_1d_1\lambda\right)+(\beta_1\beta_3-\gamma_3^2)\left(\mathrm{P}_2-g_1d_2\lambda\right)-(\beta_1\gamma_1-\gamma_2\gamma_3)\mathrm{P}_3}{2\gamma_1\gamma_2\gamma_3+\beta_1\beta_2\beta_3-(\beta_1\gamma_1^2+\beta_3\gamma_2^2+\beta_2\gamma_3^2)} \\ q_3 = \dfrac{-(\beta_2\gamma_3-\gamma_1\gamma_2)\left(\mathrm{P}_1-g_1d_1\lambda\right)-(\beta_1\gamma_1-\gamma_2\gamma_3)\left(\mathrm{P}_2-g_1d_2\lambda\right)+(\beta_1\beta_2-\gamma_2^2)\mathrm{P}_3}{2\gamma_1\gamma_2\gamma_3+\beta_1\beta_2\beta_3-(\beta_1\gamma_1^2+\beta_3\gamma_2^2+\beta_2\gamma_3^2)} \end{cases}, \tag{5}$$

where $\mathrm{P}_1 = (\alpha_1 - p_1 - g_1 d_1)$; $\mathrm{P}_2 = (\alpha_2 - p_2 - g_1 d_2)$; and $\mathrm{P}_3 = (\alpha_3 - p_3 - g_3 d_3)$.

Assume the three ports have constant marginal operating costs c_i and follow a pattern of Cournot competition, the profit maximization problem of each port can be specified as:

$$Max_{q_i} \pi_i = (p_i - c_i) q_i , \tag{6}$$

where port charges $p_i = \rho_i - h_i$. The Cournot-Nash equilibrium is characterized by the first-order condition $\left(\partial\pi_i / \partial q_i\right) = 0$. Solving the system of equations, the following equilibrium output for each port can be obtained:

$$\begin{cases} q_1^* = \dfrac{(4\beta_2\beta_3-\gamma_1^2)(\mathrm{M}_1-g_1d_1\lambda)-(2\beta_3\gamma_2-\gamma_1\gamma_3)(\mathrm{M}_2-g_1d_2\lambda)-(2\beta_2\gamma_3-\gamma_1\gamma_2)\mathrm{M}_3}{2\left[4\beta_1\beta_2\beta_3+\gamma_1\gamma_2\gamma_3-(\beta_1\gamma_1^2+\beta_3\gamma_2^2+\beta_2\gamma_3^2)\right]} \\ q_2^* = \dfrac{-(2\beta_3\gamma_2-\gamma_1\gamma_3)(\mathrm{M}_1-g_1d_1\lambda)+(4\beta_1\beta_3-\gamma_3^2)(\mathrm{M}_2-g_1d_2\lambda)-(2\beta_1\gamma_1-\gamma_2\gamma_3)\mathrm{M}_3}{2\left[4\beta_1\beta_2\beta_3+\gamma_1\gamma_2\gamma_3-(\beta_1\gamma_1^2+\beta_3\gamma_2^2+\beta_2\gamma_3^2)\right]} \\ q_3^* = \dfrac{-(2\beta_2\gamma_3-\gamma_1\gamma_2)(\mathrm{M}_1-g_1d_1\lambda)-(2\beta_1\gamma_1-\gamma_2\gamma_3)(\mathrm{M}_2-g_1d_2\lambda)+(4\beta_1\beta_2-\gamma_2^2)\mathrm{M}_3}{2\left[4\beta_1\beta_2\beta_3+\gamma_1\gamma_2\gamma_3-(\beta_1\gamma_1^2+\beta_3\gamma_2^2+\beta_2\gamma_3^2)\right]} \end{cases}, \tag{7}$$

where $\mathrm{M}_1 = (\alpha_1 - c_1 - g_1 d_1)$; $\mathrm{M}_2 = (\alpha_2 - c_2 - g_1 d_2)$; and $\mathrm{M}_3 = (\alpha_3 - c_3 - g_3 d_3)$. Note that the condition for positive output equilibriums requires that:

$$\tilde{\lambda}_3 < \lambda < \min\left\{\tilde{\lambda}_1, \tilde{\lambda}_2\right\}, \tag{8}$$

where $\tilde{\lambda}_1 = \dfrac{(4\beta_2\beta_3-\gamma_1^2)\mathrm{M}_1-(2\beta_3\gamma_2-\gamma_1\gamma_3)\mathrm{M}_2-(2\beta_2\gamma_3-\gamma_1\gamma_2)\mathrm{M}_3}{g_1\left[d_1(4\beta_2\beta_3-\gamma_1^2)-d_2(2\beta_3\gamma_2-\gamma_1\gamma_3)\right]}$;

$\tilde{\lambda}_2 = \dfrac{-(2\beta_3\gamma_2-\gamma_1\gamma_3)\mathrm{M}_1+(4\beta_1\beta_3-\gamma_3^2)\mathrm{M}_2-(2\beta_1\gamma_1-\gamma_2\gamma_3)\mathrm{M}_3}{g_1\left[-d_1(2\beta_3\gamma_2-\gamma_1\gamma_3)+d_2(4\beta_1\beta_3-\gamma_3^2)\right]}$; and

$\tilde{\lambda}_3 = -\dfrac{-(2\beta_2\gamma_3-\gamma_1\gamma_2)\mathrm{M}_1-(2\beta_1\gamma_1-\gamma_2\gamma_3)\mathrm{M}_2+(4\beta_1\beta_2-\gamma_2^2)\mathrm{M}_3}{g_1\left[d_1(2\beta_2\gamma_3-\gamma_1\gamma_2)+d_2(2\beta_1\gamma_1-\gamma_2\gamma_3)\right]}$.

The output equilibriums in (7) lead to the following port charges:

$$\begin{cases} p_1^* = c_1 + \dfrac{\beta_1\left[(4\beta_2\beta_3-\gamma_1^2)(\mathrm{M}_1-g_1d_1\lambda)-(2\beta_3\gamma_2-\gamma_1\gamma_3)(\mathrm{M}_2-g_1d_2\lambda)-(2\beta_2\gamma_3-\gamma_1\gamma_2)\mathrm{M}_3\right]}{2\left[4\beta_1\beta_2\beta_3+\gamma_1\gamma_2\gamma_3-(\beta_1\gamma_1^2+\beta_3\gamma_2^2+\beta_2\gamma_3^2)\right]} \\ p_2^* = c_2 + \dfrac{\beta_2\left[-(2\beta_3\gamma_2-\gamma_1\gamma_3)(\mathrm{M}_1-g_1d_1\lambda)+(4\beta_1\beta_3-\gamma_3^2)(\mathrm{M}_2-g_1d_2\lambda)-(2\beta_1\gamma_1-\gamma_2\gamma_3)\mathrm{M}_3\right]}{2\left[4\beta_1\beta_2\beta_3+\gamma_1\gamma_2\gamma_3-(\beta_1\gamma_1^2+\beta_3\gamma_2^2+\beta_2\gamma_3^2)\right]} \\ p_3^* = c_3 + \dfrac{\beta_3\left[-(2\beta_2\gamma_3-\gamma_1\gamma_2)(\mathrm{M}_1-g_1d_1\lambda)-(2\beta_1\gamma_1-\gamma_2\gamma_3)(\mathrm{M}_2-g_1d_2\lambda)+(4\beta_1\beta_2-\gamma_2^2)\mathrm{M}_3\right]}{2\left[4\beta_1\beta_2\beta_3+\gamma_1\gamma_2\gamma_3-(\beta_1\gamma_1^2+\beta_3\gamma_2^2+\beta_2\gamma_3^2)\right]} \end{cases}. \quad (9)$$

The corresponding profits can then be calculated as:

$$\begin{cases} \pi_1^* = \beta_1\left(\dfrac{(4\beta_2\beta_3-\gamma_1^2)(\mathrm{M}_1-g_1d_1\lambda)-(2\beta_3\gamma_2-\gamma_1\gamma_3)(\mathrm{M}_2-g_1d_2\lambda)-(2\beta_2\gamma_3-\gamma_1\gamma_2)\mathrm{M}_3}{2\left(4\beta_1\beta_2\beta_3+\gamma_1\gamma_2\gamma_3-(\beta_1\gamma_1^2+\beta_3\gamma_2^2+\beta_2\gamma_3^2)\right)}\right)^2 \\ \pi_2^* = \beta_2\left(\dfrac{-(2\beta_3\gamma_2-\gamma_1\gamma_3)(\mathrm{M}_1-g_1d_1\lambda)+(4\beta_1\beta_3-\gamma_3^2)(\mathrm{M}_2-g_1d_2\lambda)-(2\beta_1\gamma_1-\gamma_2\gamma_3)\mathrm{M}_3}{2\left(4\beta_1\beta_2\beta_3+\gamma_1\gamma_2\gamma_3-(\beta_1\gamma_1^2+\beta_3\gamma_2^2+\beta_2\gamma_3^2)\right)}\right)^2 \\ \pi_3^* = \beta_3\left(\dfrac{-(2\beta_2\gamma_3-\gamma_1\gamma_2)(\mathrm{M}_1-g_1d_1\lambda)-(2\beta_1\gamma_1-\gamma_2\gamma_3)(\mathrm{M}_2-g_1d_2\lambda)+(4\beta_1\beta_2-\gamma_2^2)\mathrm{M}_3}{2\left(4\beta_1\beta_2\beta_3+\gamma_1\gamma_2\gamma_3-(\beta_1\gamma_1^2+\beta_3\gamma_2^2+\beta_2\gamma_3^2)\right)}\right)^2 \end{cases}. \quad (10)$$

The above equilibrium results enable the study to analyze the overall effects of production base relocation, possible externalities affecting hinterland access, and unit transportation costs by investigating comparative statics. The detailed derivations are summarized below.

3.1 *The effect of industrial relocation (d_i)*

If many manufacturing firms relocate their production base away from the PRD region, the distances to all ports will change. As shown in Appendix, the following analytical results can be obtained with respect to the distance changes:

The effects of a change in distance on the port's own performance:

$$\frac{\partial q_i^*}{\partial d_i} < 0, \ \frac{\partial p_i^*}{\partial d_i} < 0, \text{ and } \frac{\partial \pi_i^*}{\partial d_i} < 0, \quad \text{where } i = 1,..,3 \quad (11)$$

The effects of a change in distance on rival ports' performance:

$$\frac{\partial q_i^*}{\partial d_j} > 0, \ \frac{\partial p_i^*}{\partial d_j} > 0, \text{ and } \frac{\partial \pi_i^*}{\partial d_j} > 0, \quad \text{where } i, j = 1,..,3, \ i \neq j \quad (12)$$

The interpretation of these results is straightforward. As shippers (i.e. users of port services) move away from a port, the port's performance will suffer in terms of lower port throughput, reduced port service charges, and declining profitability. This will benefit its rival ports, which experience increasing output, a lift in revenue from port service charges and higher profits. That is, both Shenzhen and Hong Kong will suffer when manufacturing firms relocate away from the PRD region. However, Shanghai may benefit from such a pattern, as some relocated shippers could use Shanghai as a substitute gateway.

3.2 The effect of externalities on hinterland access costs

As explained above, there may be either positive and negative externality effects in hinterland access, as measured by the parameter λ. With the equilibrium outcomes characterized by equations (7), (9), and (10), it can be derived that:

For Hong Kong:

$$\frac{\partial q_1^*}{\partial \lambda} < 0, \ \frac{\partial p_1^*}{\partial \lambda} < 0, \text{ and } \frac{\partial \pi_1^*}{\partial \lambda} < 0 \tag{13}$$

For Shenzhen:

$$\frac{\partial q_2^*}{\partial \lambda} \geq 0, \ \frac{\partial p_2^*}{\partial \lambda} \geq, \text{ and } \frac{\partial \pi_2^*}{\partial \lambda} \geq \text{ when } d_1 - d_2 \geq \left(1 - \frac{2\beta_3\gamma_2 - \gamma_1\gamma_3}{4\beta_1\beta_3 - \gamma_3^2}\right) d_1; \tag{14.1}$$

$$\frac{\partial q_2^*}{\partial \lambda} < 0, \ \frac{\partial p_2^*}{\partial \lambda} < 0, \text{ and } \frac{\partial \pi_2^*}{\partial \lambda} < 0 \text{ when } d_1 - d_2 < \left(1 - \frac{2\beta_3\gamma_2 - \gamma_1\gamma_3}{4\beta_1\beta_3 - \gamma_3^2}\right) d_1 \tag{14.2}$$

For Shanghai:

$$\frac{\partial q_3^*}{\partial \lambda} > 0, \ \frac{\partial p_3^*}{\partial \lambda} > 0, \text{ and } \frac{\partial \pi_3^*}{\partial \lambda} > 0 \tag{15}$$

The implications for the ports of Hong Kong and Shanghai are clear. For Hong Kong, when there are increasing positive externalities (or decreasing negative externalities when λ is falling), such as stronger density effects leading to lowered hinterland access costs or reduced congestion in the shared hinterland transport corridor, traffic volume and port service charges at Hong Kong will increase, leading to higher profit. This will be bad news for the competing port of Shanghai, where performance will decrease as it now faces a more competitive rival port.

The implications for Shenzhen (Port 2 in our model) are more complex. When hinterland access is improved, two countervailing factors will influence the performance of Shenzhen. On the one hand, improved hinterland access will benefit Shenzhen by reducing hinterland logistics costs and thus the generalized costs of using Shenzhen. On the other hand, because Hong Kong and Shenzhen share a hinterland corridor, improved hinterland access also implies that Hong Kong will be more competitive. Therefore, the net effect on Shenzhen will depend on the relative size of these two effects. When hinterland access costs for Hong Kong are much larger than those for Shenzhen (in the sense that $d_1 - d_2 \geq \left(1 - \frac{2\beta_3\gamma_2 - \gamma_1\gamma_3}{4\beta_1\beta_3 - \gamma_3^2}\right) d_1$), improved hinterland access will benefit Hong Kong much more than it will benefit Shenzhen. In such a case, the negative competitive effect on Shenzhen will outweigh the positive effect of cost savings. As a result, Shenzhen will suffer overall from an improvement in hinterland access. Otherwise, if there is not much difference in the costs of hinterland access for Hong Kong and Shenzhen, then both ports will benefit from improved hinterland transport.

The ports of Shenzhen and Hong Kong are very close to each other geographically. This appears to suggest that $d_1 - d_2$ is small, and thus $(\partial q_2^* / \partial \lambda) < 0$ is likely to hold. In reality, however, there may be significant costs associated with delivering goods from inland provinces to Hong Kong, which has separate customs and operating regulations. In addition to costs associated with security checks and customs clearance, mainland Chinese drivers are prohibited from driving container trucks directly to port terminals in Hong Kong. Hong Kong drivers who get paid much more than their mainland counterparts are required to take over driving such trucks at the border. These special arrangements could make the hinterland access costs of Hong Kong much higher than those of Shenzhen. This is not a new finding: a survey conducted by the

Better Hong Kong Foundation (2004) shows that Hong Kong has lost competitiveness in comparison with Shenzhen due to higher transport costs for containers crossing the border. Trucking costs could increase substantially as a consequence of higher operating costs (parking, insurance and maintenance costs), cross-boundary regulation (costs associated with cross-boundary licenses and switching of drivers), and the low frequency of trips (McKinnon, 2011). The new finding in our model produced is that the cost of crossing the border to Hong Kong will influence Shenzhen's attitude toward cooperation on hinterland access. If cross-border costs are so high that Hong Kong has much higher overall hinterland access costs than Shenzhen (in the sense that $d_1 - d_2 \geq \left(1 - \frac{2\beta_3\gamma_2 - \gamma_1\gamma_3}{4\beta_1\beta_3 - \gamma_3^2}\right)d_1$ in our model), then Shenzhen will have no interest in working with Hong Kong to improve hinterland access. It will prefer to keep Hong Kong at a disadvantage due to its inconvenient hinterland access. However, if hinterland access costs to Hong Kong and Shenzhen are similar, then both ports will benefit from cooperating on such access. Therefore, they will have greater incentives to share their facilities and pool capacity (such as by sharing warehouses, dry port terminals, trucking services, and IT systems). Given the hard work carried out by the Hong Kong government and the port of Hong Kong to streamline cross-border cargo flows, it is likely that hinterland access costs for Shenzhen and Hong Kong are now close to each other. That is, the condition $d_1 - d_2 < \left(1 - \frac{2\beta_3\gamma_2 - \gamma_1\gamma_3}{4\beta_1\beta_3 - \gamma_3^2}\right)d_1$ is in reality likely to hold in the current market. Of course, more detailed empirical analysis is needed to confirm this intuition.

3.3 The effects of ground transportation costs

Hinterland access costs may change due to many factors such as the availability of new transport facilities (e.g. the availability of good rail transport services and the building of new highways), market structure changes in the logistics sector, or simply fluctuations in fuel prices. Some of these factors will lead to a general increase/decrease in the transportation costs associated with all three ports. In other cases, not all ports will be affected. The next analysis is to examine changes in the unit transportation costs of Port Cluster 1 (i.e. changes in parameter g_1 for Hong Kong and Shenzhen), as well as possible changes associated with transportation costs of the other cluster (i.e. transportation cost for Shanghai g_3). It can be shown that:

Effects on Hong Kong:

$$\frac{\partial q_1^*}{\partial g_1} < 0,\ \frac{\partial p_1^*}{\partial g_1} < 0,\ \text{and}\ \frac{\partial \pi_1^*}{\partial g_1} < 0;\ \text{and}\ \frac{\partial q_1^*}{\partial g_3} > 0,\ \frac{\partial p_1^*}{\partial g_3} > 0,\ \text{and}\ \frac{\partial \pi_1^*}{\partial g_3} > 0 \tag{16}$$

Effects on Shenzhen

$$\frac{\partial q_2^*}{\partial g_1} \geq 0,\ \frac{\partial p_2^*}{\partial g_1} \geq 0,\ \text{and}\ \frac{\partial \pi_2^*}{\partial g_1} \geq 0\ \text{when}\ d_1 - d_2 \geq \left(1 - \frac{2\beta_3\gamma_2 - \gamma_1\gamma_3}{4\beta_1\beta_3 - \gamma_3^2}\right)d_1; \tag{17.1}$$

$$\frac{\partial q_2^*}{\partial g_1} < 0,\ \frac{\partial p_2^*}{\partial g_1} < 0,\ \text{and}\ \frac{\partial \pi_2^*}{\partial g_1} < 0\ \text{when}\ d_1 - d_2 < \left(1 - \frac{2\beta_3\gamma_2 - \gamma_1\gamma_3}{4\beta_1\beta_3 - \gamma_3^2}\right)d_1; \tag{17.2}$$

$$\frac{\partial q_2^*}{\partial g_3} > 0,\ \frac{\partial p_2^*}{\partial g_3} > 0,\ \text{and}\ \frac{\partial \pi_2^*}{\partial g_3} > 0 \tag{17.3}$$

Effects on Shanghai:

$$\frac{\partial q_3^*}{\partial g_1} > 0,\ \frac{\partial p_3^*}{\partial g_1} > 0,\ \text{and}\ \frac{\partial \pi_3^*}{\partial g_1} > 0;\ \frac{\partial q_3^*}{\partial g_3} < 0,\ \frac{\partial p_3^*}{\partial g_3} < 0,\ \text{and}\ \frac{\partial \pi_3^*}{\partial g_3} < 0 \quad (18)$$

As evidenced by $\frac{\partial \pi_1^*}{\partial g_3} > 0$, $\frac{\partial \pi_2^*}{\partial g_3} > 0$, and $\frac{\partial \pi_3^*}{\partial g_1} > 0$, an increase in transportation costs at competing ports will always be good news. However, the effects of a rise in a port's own transportation costs may be complicated. For Hong Kong and Shanghai, rising transportation costs will always reduce their own performance in terms of traffic volume, port service charges, and operating profit. However, the situation may be more complicated in Shenzhen. Again, this is due to the fact that because Shenzhen is close to Hong Kong and they share a common transport corridor, a rise in transportation costs will have two implications: on the one hand, it will increase the general costs of using Shenzhen; on the other hand, as suggested by Salop and Scheffman (1983), a firm may benefit from an increase in input prices if it harms its competitors more. Therefore, if transport costs are significantly lower in Shenzhen than they are in Hong Kong, then a rise in transportation costs could benefit Shenzhen. Again, this shows the importance of cross-boundary costs for the port of Shenzhen. Given the hard work conducted by the Hong Kong government and the port of Hong Kong to streamline cross-border cargo flows referred to earlier, it is likely that Shenzhen and Hong Kong now have similar hinterland access costs. Thus, both Shenzhen and Hong Kong have an incentive to work together to reduce their hinterland access costs.

4. Summary and conclusion

Southern Chinese ports, notably Hong Kong and Shenzhen, have benefited greatly from economic growth within the Pearl River Delta (PRD) region in the past three decades. However, in recent years, constant increases in labor and operational costs within the PRD region have forced many manufacturing firms to relocate further inland. At the same time, many provinces in Western and Northern China are economically less developed, but have abundant labor and land resources. The Chinese government is implementing a strategic plan to promote an economic rebalancing among the provinces in the hope they all achieve sustainable growth in the long run. This has triggered an ongoing process of relocation for many firms in the PRD region. Given the presence of significant intra- and inter-cluster competition in the Chinese port industry, this relocation process will not only affect the ports of Shenzhen and Hong Kong, but will also have an impact on ports in other clusters. Although previous studies have analyzed the implications of hinterland access, few have investigated the dynamic effects of production base relocation.

To fill this gap in the literature, this study develops an analytical framework to examine the effects of the ongoing trend of production base relocation. Among the novel features of this model are that it explicitly considers both intra- and inter-port cluster competition, and the possible (positive or negative) effects of externalities on port hinterland access. These features are important given that Hong Kong and Shenzhen share a transportation corridor to China's inland provinces. Hinterland access may be affected by economies of traffic density (i.e. a positive externality) or congestion effects (i.e. a negative externality). Our analytical results suggest that when production bases in the PRD region are moved further inland, an increase in hinterland access costs will reduce the overall performance of Hong Kong in terms of lower throughput, reduced port charges revenue, and a smaller operating profit. In contrast, the port of Shanghai will benefit from such externalities due to the increased incentives for some traffic to be shifted. In theory, the port of Shenzhen, which shares a transport corridor to inland provinces with Hong Kong, may either benefit or suffer from an increase in hinterland access costs. On the one hand, it will suffer from an increase in the total cost of using the port. On the other hand, an increase in transportation costs may do greater harm to Hong Kong and thus help Shenzhen gain a competitive advantage over its neighbor – an intuition similar to the well-known strategy of "raising rivals' costs". Therefore, Shenzhen will have an incentive to work with Hong Kong to improve their hinterland access only if Hong Kong has a good network connecting it to mainland China. That is, good cross-border infrastructure will facilitate cooperation between Shenzhen and Hong Kong. Given that the Hong Kong government and the port of Hong Kong have worked hard to improve cross-border cargo flows in recent years, it is likely that in the current market, both Shenzhen and Hong Kong have incentives to work together to address the ongoing production base relocation problem. While a detailed empirical investigation should be carried out to verify this conclusion for the PRD region, the general theoretical implication is clear: a more competitive port will be in a better position to cooperate with other stakeholders.

This study provides a number of valuable academic and practical insights. Southern China is a pioneering showpiece for the transformation of regional port governance within a rapidly developing economy where institutional frameworks are highly diversified. This study provides useful insights enabling decision-makers to develop pragmatic and sustainable regional governance policies for the future well-being of the PRD region. Given the key role played by ports as key nodal points of supply chains where different stakeholders interact, this paper contributes to the development of a fully-integrated regional port system within the PRD in particular and among gateway-hinterland regions in general. This paper has addressed the urgent need in re-establishing focus on the dynamics between ports and regional development. It is important to understand such dynamics between ports and regional development, and thus there is a need to formulate integrated and sustainable port and maritime logistical systems to improve the well-being and development of different geographical regions.

While this paper focuses on the PRD region, it is strongly believed that the analytical framework developed in this study can be easily extended to investigate other cases when competing ports experiences major changes in hinterland access costs. Although this study provides several constructive policy recommendations, there remain some areas needed for future research. The most important issue may be the empirical investigation in order to confirm the analytical findings in this paper. A comprehensive survey of the relocating manufacturers (i.e. new location and shipping volume) is also needed, so that the impact of the relocation process on major ports in the PRD region can be empirically measured. Despite intense competition within the port cluster in the PRD, the ports of Hong Kong and Shenzhen should cooperate in some operational issues, for example, the hinterland access improvement. However, since the institutional frameworks in these two areas are highly diversified, there is a need to take these factors into consideration to ensure the feasibility of such cooperation.

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Appendix analytical derivations and results on market equilibriums

A1. With respect to λ:

For Hong Kong (or Port 1)

$\frac{\partial q_1^*}{\partial \lambda} = -g_1\Sigma_1 < 0$, $\frac{\partial p_1^*}{\partial \lambda} = -\beta_1 g_1 \Sigma_1 < 0$, and $\frac{\partial \pi_1^*}{\partial \lambda} = -2\beta_1 g_1 q_1^* \Sigma_1 < 0$,

where $\Sigma_1 = \frac{d_1(4\beta_2\beta_3 - \gamma_1^2) - d_2(2\beta_3\gamma_2 - \gamma_1\gamma_3)}{2\left[4\beta_1\beta_2\beta_3 + \gamma_1\gamma_2\gamma_3 - (\beta_1\gamma_1^2 + \beta_3\gamma_2^2 + \beta_2\gamma_3^2)\right]} > 0$

For Shenzhen (or Port 2)

$\frac{\partial q_2^*}{\partial \lambda} = -g_1\Sigma_2$, $\frac{\partial p_2^*}{\partial \lambda} = -\beta_2 g_1 \Sigma_2$, and $\frac{\partial \pi_2^*}{\partial \lambda} = -2\beta_2 g_1 q_2^* \Sigma_2$,

where $\Sigma_2 = \frac{-d_1(2\beta_3\gamma_2 - \gamma_1\gamma_3) + d_2(4\beta_1\beta_3 - \gamma_3^2)}{2\left[4\beta_1\beta_2\beta_3 + \gamma_1\gamma_2\gamma_3 - (\beta_1\gamma_1^2 + \beta_3\gamma_2^2 + \beta_2\gamma_3^2)\right]}$, and the above expressions will be:

(1) positive when $d_2 \le \frac{(2\beta_3\gamma_2 - \gamma_1\gamma_3)}{(4\beta_1\beta_3 - \gamma_3^2)} d_1$ or $d_1 - d_2 \ge \left(1 - \frac{2\beta_3\gamma_2 - \gamma_1\gamma_3}{4\beta_1\beta_3 - \gamma_3^2}\right) d_1$; and

(2) negative when $d_2 > \frac{(2\beta_3\gamma_2 - \gamma_1\gamma_3)}{(4\beta_1\beta_3 - \gamma_3^2)} d_1$ or $d_1 - d_2 < \left(1 - \frac{2\beta_3\gamma_2 - \gamma_1\gamma_3}{4\beta_1\beta_3 - \gamma_3^2}\right) d_1$

For Shanghai (or Port 3)

$\frac{\partial q_3^*}{\partial \lambda} = g_1\Sigma_3 > 0$, $\frac{\partial p_3^*}{\partial \lambda} = \beta_3 g_1 \Sigma_3 > 0$, and $\frac{\partial \pi_3^*}{\partial \lambda} = \beta_3 g_1 q_3^* \Sigma_3 > 0$,

where $\Sigma_3 = \frac{d_1(2\beta_2\gamma_3 - \gamma_1\gamma_2) + d_2(2\beta_1\gamma_1 - \gamma_2\gamma_3)}{2\left[4\beta_1\beta_2\beta_3 + \gamma_1\gamma_2\gamma_3 - (\beta_1\gamma_1^2 + \beta_3\gamma_2^2 + \beta_2\gamma_3^2)\right]} > 0$

A2. With respect to d_i:

For Hong Kong (or Port 1)

$\frac{\partial q_1^*}{\partial d_1} = -g_1(1+\lambda)\mathrm{E}_{11} < 0$, $\frac{\partial p_1^*}{\partial d_1} = -\beta_1 g_1(1+\lambda)\mathrm{E}_{11} < 0$, and $\frac{\partial \pi_1^*}{\partial d_1} = -2\beta_1 g_1 q_1^*(1+\lambda)\mathrm{E}_{11} < 0$;

$\frac{\partial q_1^*}{\partial d_2} = g_1(1+\lambda)\mathrm{E}_{12} > 0$, $\frac{\partial p_1^*}{\partial d_2} = \beta_1 g_1(1+\lambda)\mathrm{E}_{12} > 0$, and $\frac{\partial \pi_1^*}{\partial d_2} = 2\beta_1 g_1 q_1^*(1+\lambda)\mathrm{E}_{12} > 0$;

$\frac{\partial q_1^*}{\partial d_3} = g_3\mathrm{E}_{13} > 0$, $\frac{\partial p_1^*}{\partial d_3} = \beta_1 g_3 \mathrm{E}_{13} > 0$, and $\frac{\partial \pi_1^*}{\partial d_3} = 2\beta_1 g_3 q_1^* \mathrm{E}_{13} > 0$;

where $E_{11} = \dfrac{(4\beta_2\beta_3 - \gamma_1^2)}{2\left[4\beta_1\beta_2\beta_3 + \gamma_1\gamma_2\gamma_3 - (\beta_1\gamma_1^2 + \beta_3\gamma_2^2 + \beta_2\gamma_3^2)\right]} > 0$,

$E_{12} = \dfrac{(2\beta_3\gamma_2 - \gamma_1\gamma_3)}{2\left[4\beta_1\beta_2\beta_3 + \gamma_1\gamma_2\gamma_3 - (\beta_1\gamma_1^2 + \beta_3\gamma_2^2 + \beta_2\gamma_3^2)\right]} > 0$, and

$E_{13} = \dfrac{(2\beta_2\gamma_3 - \gamma_1\gamma_2)}{2\left[4\beta_1\beta_2\beta_3 + \gamma_1\gamma_2\gamma_3 - (\beta_1\gamma_1^2 + \beta_3\gamma_2^2 + \beta_2\gamma_3^2)\right]} > 0$

For Shenzhen (or Port 2)

$\dfrac{\partial q_2^*}{\partial d_1} = g_1(1+\lambda)E_{12} > 0$, $\dfrac{\partial p_2^*}{\partial d_1} = \beta_2 g_1(1+\lambda)E_{12} > 0$, and $\dfrac{\partial \pi_2^*}{\partial d_1} = 2\beta_2 g_1 q_2^*(1+\lambda)E_{12} > 0$;

$\dfrac{\partial q_2^*}{\partial d_2} = -g_1(1+\lambda)E_{22} < 0$, $\dfrac{\partial p_2^*}{\partial d_2} = -\beta_2 g_1(1+\lambda)E_{22} < 0$, and $\dfrac{\partial \pi_2^*}{\partial d_2} = -2\beta_2 g_1 q_2^*(1+\lambda)E_{22} < 0$;

$\dfrac{\partial q_2^*}{\partial d_3} = g_3 E_{23} > 0$, $\dfrac{\partial p_2^*}{\partial d_3} = \beta_2 g_3 E_{23} > 0$, and $\dfrac{\partial \pi_2^*}{\partial d_3} = 2\beta_2 g_3 q_2^* E_{23} > 0$;

where $E_{22} = \dfrac{(4\beta_1\beta_3 - \gamma_3^2)}{2\left[4\beta_1\beta_2\beta_3 + \gamma_1\gamma_2\gamma_3 - (\beta_1\gamma_1^2 + \beta_3\gamma_2^2 + \beta_2\gamma_3^2)\right]} > 0$, and

$E_{23} = \dfrac{(2\beta_1\gamma_1 - \gamma_2\gamma_3)}{2\left[4\beta_1\beta_2\beta_3 + \gamma_1\gamma_2\gamma_3 - (\beta_1\gamma_1^2 + \beta_3\gamma_2^2 + \beta_2\gamma_3^2)\right]} > 0$

For Shanghai (or Port 3)

$\dfrac{\partial q_3^*}{\partial d_1} = g_1(1+\lambda)E_{13} > 0$, $\dfrac{\partial p_3^*}{\partial d_1} = \beta_3 g_1(1+\lambda)E_{13} > 0$, and $\dfrac{\partial \pi_3^*}{\partial d_1} = 2\beta_3 g_1 q_3^*(1+\lambda)E_{13} > 0$;

$\dfrac{\partial q_3^*}{\partial d_2} = g_1(1+\lambda)E_{23} > 0$, $\dfrac{\partial p_3^*}{\partial d_2} = \beta_3 g_1(1+\lambda)E_{23} > 0$, and $\dfrac{\partial \pi_3^*}{\partial d_2} = 2\beta_3 g_1 q_3^*(1+\lambda)E_{23} > 0$;

$\dfrac{\partial q_3^*}{\partial d_3} = -g_3 E_{33} < 0$, $\dfrac{\partial p_3^*}{\partial d_3} = -\beta_3 g_3 E_{33} < 0$, and $\dfrac{\partial \pi_3^*}{\partial d_3} = -2\beta_3 g_3 q_3^* E_{33} < 0$;

where $E_{33} = \dfrac{(4\beta_1\beta_2 - \gamma_2^2)}{2\left[4\beta_1\beta_2\beta_3 + \gamma_1\gamma_2\gamma_3 - (\beta_1\gamma_1^2 + \beta_3\gamma_2^2 + \beta_2\gamma_3^2)\right]} > 0$

A3. With respect to g_i***:***

For Hong Kong (or Port 1)

$\frac{\partial q_1^*}{\partial g_1} = -(1+\lambda)\Sigma_1 < 0$, $\frac{\partial p_1^*}{\partial g_1} = -\beta_1(1+\lambda)\Sigma_1 < 0$, and $\frac{\partial \pi_1^*}{\partial g_1} = -2\beta_1 q_1^*(1+\lambda)\Sigma_1 < 0$;

$\frac{\partial q_1^*}{\partial g_3} = d_3 \mathrm{E}_{13} > 0$, $\frac{\partial p_1^*}{\partial g_3} = \beta_1 d_3 \mathrm{E}_{13} > 0$, and $\frac{\partial \pi_1^*}{\partial g_3} = 2\beta_1 d_3 q_1^* \mathrm{E}_{13} > 0$

For Shenzhen (or Port 2)

$\frac{\partial q_2^*}{\partial g_1} = -(1+\lambda)\Sigma_2$, $\frac{\partial p_2^*}{\partial g_1} = -\beta_2(1+\lambda)\Sigma_2$, and $\frac{\partial \pi_2^*}{\partial g_1} = -2\beta_2 q_2^*(1+\lambda)\Sigma_2$,

which will be:

(1) positive when $d_2 \le \frac{(2\beta_3\gamma_2 - \gamma_1\gamma_3)}{(4\beta_1\beta_3 - \gamma_3^2)} d_1$ or $d_1 - d_2 \ge \left(1 - \frac{2\beta_3\gamma_2 - \gamma_1\gamma_3}{4\beta_1\beta_3 - \gamma_3^2}\right) d_1$; and

(2) negative when $d_2 > \frac{(2\beta_3\gamma_2 - \gamma_1\gamma_3)}{(4\beta_1\beta_3 - \gamma_3^2)} d_1$ or $d_1 - d_2 < \left(1 - \frac{2\beta_3\gamma_2 - \gamma_1\gamma_3}{4\beta_1\beta_3 - \gamma_3^2}\right) d_1$

$\frac{\partial q_2^*}{\partial g_3} = d_3 \mathrm{E}_{23} > 0$; $\frac{\partial p_2^*}{\partial g_3} = \beta_2 d_3 \mathrm{E}_{23} > 0$; and $\frac{\partial \pi_2^*}{\partial g_3} = 2\beta_2 d_3 q_2^* \mathrm{E}_{23} > 0$

For Shanghai (or Port 3)

$\frac{\partial q_3^*}{\partial g_1} = (1+\lambda)\Sigma_3 > 0$, $\frac{\partial p_3^*}{\partial g_1} = \beta_3(1+\lambda)\Sigma_3 > 0$, and $\frac{\partial \pi_3^*}{\partial g_1} = 2\beta_3 q_3^*(1+\lambda)\Sigma_3 > 0$;

$\frac{\partial q_3^*}{\partial g_3} = -d_3 \mathrm{E}_{33} < 0$, $\frac{\partial p_3^*}{\partial g_3} = -\beta_3 d_3 \mathrm{E}_{33} < 0$, and $\frac{\partial \pi_3^*}{\partial g_3} = -2\beta_3 d_3 q_3^* \mathrm{E}_{33} < 0$