Post-entry Container Port Capacity Expansion

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Abstract

Port capacity development is a critical strategy for the growth of a new port, as well as for the development of the existing one, when both the new and existing ports serve the same hinterland but have different competitive conditions. To study this strategy, we develop a two-stage duopoly model that comprises pricing and capacity decisions of two heterogeneous players serving an increasing market. We identify the necessary condition for a port to increase profit through capacity expansion, and characterize the conditions when preemptive pricing by the dominating player is neither credible nor effective in preventing the growth of the smaller player. We also find the pure-strategy Nash equilibrium in the capacity expansion game for the two ports with different price sensitivities, and operation and capacity investment costs. We apply the model results to the container port competition between Hong Kong and Shenzhen after Shenzhen port started container operation in 1991. Our analysis explains the transition of market power from monopoly to duopoly, the fast development of Shenzhen Port, and the possible market structure changes with continuing demand increase.

Keywords: Market Preemption, Capacity Expansion, Pricing, Port Competition

1. Introduction

Economic theory holds that when a monopoly firm faces a new player in the market, it could adopt the preemptive pricing strategy, or install excessive capacity to protect its market status (Spence, 1977; Eaton and Lipsey, 1979; Wilson, 1992). On the other hand, intuition suggests that if the new player has a competitive advantage, such as a lower cost structure or a better location, neither preemptive pricing nor excessive capacity could effectively prevent the growth of the new comer. Then, what decision rules can market players use to determine the best strategies (expand or exit for the new player, and fight or accommodate for the existing one) when the competitive conditions between the two parties are different? Given that market entry is undeniable, and unequal competitive conditions persist, how will the market positions of the two players evolve when each maximizes its payoff using pricing and capacity expansion?

Determining the right strategy under such a situation is important to both private business operations and public policy making in a globalized economy. Existing businesses in the developed
economies, survived from a long history of market competition with peers from similar economic backgrounds, are being challenged by new competitors from emerging economies, who may enjoy better competitive conditions, such as lower labor costs, better accessibility of raw materials and component inputs, or being closer to the market. Business strategies, such as outsourcing, global sourcing, or even factory relocation, which may be useful in improving the competitiveness of established businesses, will exert negative impacts on the local economy and cause direct job losses - a critical element in public policy. Furthermore, for some industries, such as seaport, these business strategies may not be feasible. Consequently, both businesses in this industry and the local community may suffer from increased global competition (McCalla, 1999). Therefore, recognizing market transition, understanding possible competitive outcomes, and anticipating future market evolution can assist public policy makers in formulating appropriate decisions that can affect the development of both the industry and local economy.

Container ports, the key nodes in the world seaborne trade network that connects the integrated global economy, are actively competing with each other when they are serving an overlapping hinterland. Examples include Los Angeles and Long Beach; Seattle, Tacoma and Vancouver in North America (Luo and Grigalunas, 2003; McCalla, 1999); Antwerp, Rotterdam, Bremen and Hamburg in West Europe (Veldman and Buckmann, 2003); Singapore and Tanjung Pelepas in Southeast Asia (Tongzon, 2007); and Hong Kong and Shenzhen in South China. While some of these competing ports have similar conditions, others may be located in different countries or regions with different economic backgrounds, and thus are endowed with different comparative advantages — a key factor in determining the competitiveness of a port that, *inter alia*, determines its competition strategy and outcome.

The transition and evolution of container port markets in Hong Kong and the Pearl River Delta (PRD) region in Southern China provide an ideal setting for studying the general questions raised at the beginning of this section. To provide the necessary background for the modeling and analysis in this paper, we first present a summary description of the container port development and operation in the region.

1.1. Container Port Development and Management in the Pearl River Delta Region

Figure 1 shows the locations of the existing port facilities and the cargo generation centers in the PRD region. There are several ports in this area. Hong Kong Port (HKP) is located in the Hong Kong Special Administrative Region which has a developed economy. Within a 80 Km radius lies Shenzhen Port (SZP)- the new container port that competes with HKP, and Dongguan - the biggest manufacturing center in mainland China. Guangzhou Port, located at the vertex of the Pearl River Delta, is a local port with few direct calls from international shipping lines before 2006. Jiuzhou port and Gaolan port are not specialized in handling containerized cargo.

As the only container port in the PRD region before 1991, HKP served as the gateway to mainland China, especially the Southern China region which has been the most active, export oriented manufacturing center in the world since the mid 90s. Consequently, it become the world’s busiest container port for 15 years prior to 2004.

SZP consists of three container terminal groups (Mawan, Chiwan, Shekou) in the west of Shenzhen, and Yantian International Container Terminal(YICT) in the east. Started as a general cargo port in 1980, it began container operation in 1991, with a handling capacity of only half a million TEUs\(^1\). Because of its substantially lower costs in labor and coastal land, and better access

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\(^1\) Twenty-foot Equivalent Unit
to the cargo generation centers in the PRD area, especially the highly concentrated manufacturing center in Dongguan, SZP has evolved from a small player in the market with less than 1% market share in 1991, to an equal player with about 47% market share in 2008 (Figure 2), and has become the 4<sup>th</sup> busiest container port in the world.

Capacity-wise, SZP has increased from almost nothing before 1991, to approximately 11 million TEUs at the end of 2008. In contrast, only one terminal (CT9) was constructed for HKP during this period, which lifted its capacity from 11.4 million TEUs in early 90s to 14 million TEUs at 2003, a net increase of 2.6 million TEUs. Its capacity was further increased to approximately 19 million TEUs at HKP after 2005 through productivity improvement<sup>2</sup>. A comparison of container port capacity development paths from 1991 to 2008 is shown in Figure 2.

The decision makers for port development management and operation in both ports are similar, in contrast to the differences in their respective social and economic backgrounds. On both sides, the decisions on major port development projects are the responsibility of government agencies with the support of the major stakeholders. However, while the responsible government agency in Hong Kong organized the discussion of and gave permission to the port development proposal, its counterpart in Shenzhen invested heavily in the infrastructure development and invited global terminal operators to form joint-ventures in terminal operation. The decision-making processes on both sides are similar, requiring a lengthy public discussion before the final approval. Therefore, decisions on capacity development can be treated as public information. In addition, there is competition for who can be the operator for the new terminals in SZP. Although Hutchison Port Holdings (HPH, the current terminal operator in YICT) also has a big operation in HKP, it has a limited impact on the capacity development decision of SZP, because the government could invite other terminal operators should HPH decided not to be involved in the terminal operation in SZP.

Unlike capacity development, the operation decisions at both ports are purely made by the

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<sup>2</sup>No new terminal was added for this capacity increase (HKPDC, 2004).
operators themselves. Although there are publicized Terminal Handling Charges (THC) that carriers charge against shippers according to their shipping routes, the real charges between terminal operators and carriers are private information. However, as both ports are operating as private businesses, we can assume a profit maximization behavior in port operation, even though the actual port and terminal charges are not available.

The container port development and management in Southern China provide a model background setting to study the capacity development strategy when a monopoly faces a new player with better competitive conditions. We model the competition process using a duopoly game, where players compete using pricing as a short-term strategy and capacity investment as a long term one. It is well recognized that a port can use different measures to compete, such as improving service quality, upgrading inland accessibility, or expediting import/export documentation processes. Because they all have similar direct and immediate impacts on carriers’ port choice, we may aggregate their effects into the pricing strategy so as to avoid a third dimension in the game model. Capacity expansion can reduce marginal cost through both economies of scale in output and the reduction in congestion, thus ensuring long term competitiveness in pricing. Since we are interested in the capacity expansion decision after the entry of a new firm, the preemptive measures considered in this paper is a post-entry preemption, representing the efforts of the ex-monopoly port to curb the growth of the new port. Finally, through studying the capacity development strategies for both ports over the period between 1991 and 2008 when the demand in container trading increased rapidly, we can explain the transition and evolution of the market power after the entry of the new port.

1.2. Literature Review

Most studies in optimal port capacity and pricing decisions are for single ports. For example, Jansson and Shneerson (1982) and Noritake and Kimura (1983) used queuing theory to determine the optimal number of berths in a port; Devanney and Tan (1975) used dynamic programming to analyze optimal pricing and timing for capacity expansion, and Allahviranloo and Afandizadeh (2008) considered the optimal port investment in a country. Such studies examined optimal port
capacity from various perspectives, including profit maximization, although most ports are managed by a public body.

A number of authors studied port competition in terms of port competitiveness. For example, Slack (1985) explored the factors that contribute to the competitiveness of a port; Cullinane et al. (2005) analyzed the relative competitiveness of Shanghai and Ningbo, two adjacent container ports in the Yangtze River Delta in the east coast of Shanghai; Tongzon and Heng (2005) empirically identified the link between port privatization, efficiency and competitiveness, and Yap and Lam (2006) unveiled the competitive dynamics between the major container ports in East Asia. A few authors studied port competition explicitly. For example, Song (2002) described the possible competition and cooperation between the ports in Hong Kong and South China region; Tongzon (2007) studied the cooperation and competition between Singapore and Tanjung Pelepas; Veldman and Buckmann (2003) studied the competition for the hub position among European ports; and Anderson et al. (2008) studied the competition between Shanghai and Busan for transhipment cargoes. Compared with existing research, the two ports in our study are very close substitutes in both direct cargoes and transhipments.

Many studies adopt two-stage game in modeling strategic competition using both capacity investment and pricing for different purposes, including efficiency issues in oligopolistic competition (Acemoglu et al., 2009) and governmental investment (Takahashi, 2004), transportation network congestion and taxing strategies (De Borger et al., 2005), strategic capacity expansion and pricing in congested transport corridor (De Borger et al., 2007), airports and their accessing road networks (Dunkerley et al., 2009), and port competition (De Borger et al., 2008). Takahashi (2004) modeled the spatial competition of governments in investing public facilities in a linear economy to avoid coordination problems and to maximize the welfare of the citizens in each city. His main contribution is to identify possible inefficiencies in governmental capacity investment, while our paper is to study the port expansion strategy after a new entrant with better competitive condition entered the ex-monopoly market. In De Borger et al. (2008), the competing ports serve a common hinterland with separable transportation networks. It concerns optimal capacities in ports as well as in hinterland transportation networks. The objective for each port is to maximize its social welfare, including port surplus and the well-being for the users of the hinterland transportation network. The container traffic is allocated to each port according to the generalized user cost that includes port charges and road congestion costs. This allocation mechanism allows the study of mutual impacts between capacity development and congestion in ports and access roads. In our study, the two ports serve the same hinterland and use the same road network. Our purpose is to study the capacity development strategy when they have different competitive advantages. Therefore, congestion is not modeled explicitly in our study. Different user preferences for the attributes external to ports, including possible road congestion, are captured by the demand function. Congestion within a port is reflected implicitly by the nature of cost function.

Pricing and capacity investment are also two of the most common strategies used in the entry deterrence game. Most previous works in this area are ex-ante studies which analyze the possible strategies/threats that the incumbent can use to deter entry, or the credibility and effectiveness of such strategies/threats. For example, Spence (1977) studied the incumbent’s strategy facing an entry, for both homogeneous and differentiated products, and concluded that the entry can be deterred if the capacity of the incumbent is large enough to make the entry not profitable. Eaton and Lipsey (1979) described the possible results of the preemptive strategy for spatially located incumbents and new entrants in an increasing market. They demonstrated different results from
preemption by new entrants and monopoly preemption, and explained the persistence of excess capacity and monopoly in a growing spatial market. Reynolds (1987) explained the preemptive effect of reversible capacity investment using dynamic Nash equilibrium in a repeated game. Wilson (1992, p.2) summarized three main forms of entry-deterrence game (preemption, signaling and predation), and defined the credibility of the preemptive strategy as “part of an equilibrium satisfying selection criteria that exclude incredible threats of dire consequences”, which implies that any non-equilibrium threats are not credible.

While most of the analyses in market preemption focus on the decision for entry, there are a few *ex post facto* studies on post-entry strategic pricing and capacity investment. For example, Bresnahan (1985) described the market competition for plain paper copier after Xerox’s monopoly ended in 1972 when IBM and Litton entered the market. While rapid price falls were experienced by both the new entrants (IBM & Litton) and the incumbent (Xerox), the falling rate for the latter was much higher than the former until 1978. Since then, the price index for Xerox moved closely with the others. During this 5-year period, the market share for Xerox dropped from 100% to 55%. Although the price drop may not necessarily be a preemptive measure, the entrants secured almost half of the market share, and the monopoly market transited to competition. Recently, Simon (2005) studied the post-entry pricing strategy for the incumbent using the magazine subscription prices in US. The results are consistent with the general expectation that incumbents respond to entry more aggressively when the benefits to keep the new entrant out is higher. Compared with these two studies that only describe and test post-entry preemption, we model the post-entry capacity development using a two-state game, explore the conditions for the effectiveness of the preemptive price, and explain the change of market power between the new and the ex-monopoly ports.

For the price competition in a duopoly market, Baye and Kovenock (2008) summarized the Bertrand competition, described how different assumptions on demand, cost function, and product differentiation lead to different Nash equilibrium prices. He stated that with differentiable products, linear demand and product substitution, each firm could have a linear upward-slopped best response function; firms may charge different prices and earn positive profits. Similar results were also provided in Cheng (1985).

The purpose of this paper is to explain the growth of a new port in the ex-monopoly market in the PRD region, through analyzing the pricing and capacity expansion strategies between two ports with different competitive conditions. The study has three unique features. First, it considers a duopoly market where each player has different internal conditions (operating and investment cost differences) and external conditions (e.g. price sensitivity and location.). This can help the decision makers with different economic and business conditions to determine the most appropriate competition strategy in today’s increasingly integrated global economy. Secondly, we consider lumpy and irreversible capacity investment, and capacity is not binding. In many industries, the publicized capacity is not the physical limit of the production system. For example, container port throughput can be higher than its design capacity (Drewry, 2002). When a port handles close to its capacity, it incurs congestion cost, which makes capacity expansion beneficial. Finally, we apply a duopoly game to analyze not only duopoly strategies, but also the credibility and effectiveness of preemptive measures to reduce the market share of the new port. Our model not only explains market transition and evolution in the past, but also envisages possible capacity paths of the competitors when the demand increases.

We organize the rest of the paper as follows. We first present model basics in §2. In §3,
we investigate the competition game between the two ports, first the pricing subgame, then the capacity expansion subgame. In §4, we apply the model for competition between HKP and SZP. A summary of the paper and the findings are given in §5.

2. Model Basics

This section presents the basic assumptions for the two-stage pricing and capacity expansion game. Specifically, the model setup follows the competition between HKP and SZP, although it can be modified to apply in other transportation facilities where the new player and the existing one have different competitive advantages. The overall demand for two ports ($x$) is determined exogenously by the import/export of containerized cargoes in the common hinterland. The demand for each port is modeled by a linear demand function, which is commonly used in the literature (Gilbert and Harris, 1994; Alperovich and Weksler, 1996; Demichelis and Tarola, 2006),

$$x_k(p_k, p_l) = \alpha_k \bar{x} - \beta_k p_k + \beta_l p_l, \quad k \in \{1, 2\}, \quad l \in \{1, 2\}, \quad \text{and} \quad l \neq k.$$  \hspace{1cm} (1)

where $\alpha_k$ stands for the initial market share of port $k$ and $\alpha_1 + \alpha_2 = 1^3$, $\beta_k$ the price sensitivity which reflects users’ preferences over all the attributes external to ports, and $p_k$ the price at each port.

This demand specification enables us to concentrate on two aspects: the market share of each port over the same hinterland, and the price sensitivity of the two ports. The change of market share is an important indicator on the effectiveness of post-entry preemptive measures. If the market share of the new port increases, the preemptive measure is not effective. The price sensitivity ($\beta_1$ or $\beta_2$) captures the user preferences over all the attributes external to the port, which implicitly includes road congestion that is explicitly included in the general user cost in De Borger et al. (2008). Compared with the logit-preference specification (Dunkerley et al., 2009), the linear demand function allows us to obtain clearer analytical results because $\frac{\partial^2 x_k}{\partial p_k \partial p_l} = 0$. In addition, it also enables the direct application of Bertrand competition under linear demand with differentiated products (Baye and Kovenock, 2008) in the price competition.

On the cost side, we start from a general cost function for each port to demonstrate the general results in price competition, and then introduce the case for which the specific cost function is applied. We assume that each port has its own variable cost function $V_k(x_k, C_k, \theta_k)$, where $C_k$ is the capacity of the port and $\theta_k$ is the cost factor, reflecting the impact of economic conditions on the cost. This cost function is assumed to have following properties:

- It has a positive and convex marginal cost, i.e., $mc_k(x_k, C_k, \theta_k) = \frac{\partial V_k}{\partial x_k} > 0$ and $\frac{\partial^2 mc_k}{\partial x_k^2} > 0$;

- The impact of the capacity expansion on marginal cost depends on the slope of marginal cost curve $mc'_k (= \frac{\partial mc_k}{\partial C_k})$, i.e.,

$$\frac{\partial mc_k(x_k, C_k, \theta_k)}{\partial C_k} \begin{cases} < 0, & \text{if } mc'_k > 0 \\ = 0, & \text{if } mc'_k = 0 \\ > 0, & \text{if } mc'_k < 0 \end{cases} \hspace{1cm} (2)$$

In the model development, we use $k$ and $l$ to indicate any one of the two ports, e.g., if $k$ is 1, $l$ is 2.
This condition states that if there is congestion \((mc_k' > 0)\), an increase in capacity can reduce the marginal cost; if there is an increasing return-to-scale \((mc_k' < 0)\) in output, an increase in capacity will increase the marginal cost. If the slope of the marginal cost is constant, a small change in capacity will not change the marginal cost.

- The marginal cost and its slope increase with the cost factor, i.e., \(\frac{\partial mc_k}{\partial \theta_k} > 0\) and \(\frac{\partial mc_k'}{\partial \theta_k} > 0\).

In addition to the variable cost, a port also has to pay the annual capital cost \(\rho EC(C_k)\), where \(\rho\) is the capital cost rate, such as loan rate, and \(EC(C_k)\) is the cumulative expansion cost for the capacity \(C_k\).

The two-stage game for strategic pricing and capacity expansion follows the real-world decision-making process. In the first stage, each port decides whether to expand its capacity, knowing the capacity expansion behavior of the competitor and anticipating the pricing strategy of the two ports after this stage. In practice, port capacity expansion is for a known incremental size fixed prior to the decision process. To allow comparison, we assume that the capacity increments are the same in two ports. Capacity, once added, is not removable. In the second stage, having observed the realized capacities at the two ports and responding to the pricing strategy of the competitor, each port sets a price to maximize its profit.

Following backward induction, the analysis starts from the second stage. Suppose the available capacities at both ports are given, each port sets its best price in response to the price of the competitor. Then in the first stage, each port determines its best strategy in capacity development anticipating the impact of capacity developments on the pricing strategies in the second stage. In this stage, if a port chooses to develop, the new capacity will be \(C_{1k}\); otherwise, it will be \(C_k\). In the next section, we first present the price competition in the second stage, followed by the capacity investment game in the first stage.

### 3. Capacity Expansion and Pricing Game

This section presents the theoretical analysis for the two-stage game. In the pricing subgame, we analyze the nature of the best response functions (BRF) of the two ports for the existing capacities. Using comparative statistics with respect to capacity, we characterize the necessary condition for port expansion. Furthermore, by combining the demand with the best response functions, we discuss the credibility and effectiveness of preemptive measures, and show the condition for an effective preemptive price. In the capacity expansion game, we analyze the pure-strategy Nash equilibrium for each port.

#### 3.1. Pricing Subgame

As introduced in §2, we model the strategic pricing using Bertrand competition with differentiated products. Cheng (1985) showed that for a positive and constant marginal cost, there exists a unique Bertrand equilibrium; the port equilibrium price always exceeds its marginal cost, and the two ports can have different prices and earn positive profits. We relax the restriction on the constant marginal/unit cost (Cheng, 1985; Baye and Kovenock, 2008) and show that there are positive sloped Best Response Functions (BRFs) under constant slopped marginal cost.

Assuming that each port chooses a price to maximize its profit based on the existing capacity, i.e.,

\[
\max_{p_k} \Pi_k = p_k x_k - V_k(x_k, C_k, \theta_k) - \rho EC(C_k),
\]
the first order condition (FOC) for this profit maximization problem is

\[
\pi_k(p_k) := \frac{\partial \Pi_k}{\partial p_k} = -\beta_k p_k + x_k + \beta_k m_{ck} = 0,
\]

where \( m_{ck} \) is the marginal cost for port \( k \). The second order condition (SOC) requires

\[
\frac{\partial^2 \Pi_k}{\partial p_k^2} = -2\beta_k - \beta_k^2 m_{ck}' < 0, \text{ or }
\]

\[
m_{ck}' > -\frac{2}{\beta_k}. \tag{5}
\]

From equation (4), it is clear that the the optimal price \( p_k^* \) is larger than its marginal cost as long as it has a positive throughput. Furthermore, the slope of the BRF for port \( k \) can be obtained by differentiating its FOC function w.r.t. \( p_l \):

\[
\frac{\partial \pi_k(p_k^*(p_l))}{\partial p_l} = \frac{\partial \pi_k}{\partial p^*_k} \frac{dp^*_k}{dp_l} + \frac{\partial \pi_k}{\partial p_l} = 0.
\]

This gives

\[
\frac{dp^*_k}{dp_l} = -\frac{\frac{1}{\beta_k} + m_{ck}'}{\beta_k(\frac{1}{\beta_k} + m_{ck}')} = \begin{cases} 
< 0, & \text{if } -\frac{2}{\beta_k} < m_{ck}' < -\frac{1}{\beta_k}, \\
= 0, & \text{if } m_{ck}' = -\frac{1}{\beta_k}, \\
> 0, & \text{if } m_{ck}' > -\frac{1}{\beta_k}.
\end{cases}
\tag{7}
\]

The slope of the BRF for port \( k \) is a constant if the slope of marginal cost \( m_{ck}' \) is a constant. In addition, since

\[
\lim_{m_{ck}' \to \infty} \frac{\frac{1}{\beta_k} + m_{ck}'}{\frac{2}{\beta_k} + m_{ck}'} = 1,
\]

the slope of the BRF satisfies

\[
\frac{dp^*_k}{dp_l} \leq \frac{\beta_l}{\beta_k}, \tag{9}
\]

where the equality happens only when the marginal cost curve is vertical, i.e., \( m_{ck}' \to \infty \).

In addition to the slope, the intercept of the BRF is also necessary to depict the nature of the BRF. From equation (4), expanding the \( x_k \) using the demand function, the price of port \( k \) can be expressed as

\[
p_k^* = \frac{\alpha_k \bar{x} + \beta_l p_l + \beta_k m_{ck}^*}{2\beta_k}.
\]

Since \( p_k^* \geq m_{ck}^* \) from equation (4), substituting the marginal cost with the optimal price, we can obtain

\[
p_k^* \leq \frac{\alpha_k \bar{x} + \beta_l p_l + \beta_k p_k^*}{2\beta_k},
\]

or,

\[
p_k^* \leq \frac{\alpha_k \bar{x} + \beta_l}{\beta_k} p_l. \tag{11}
\]
From equation (11), we can see that the intercept of the BRF is always less than \( \frac{\alpha_k - \beta_k}{\beta_k} \). The equal sign is there only when the optimal price equals its marginal cost - a condition for perfect competition.

The BRFs for the two ports when one of the ports \((k=1)\) has negative, zero and positive slopes are shown in Figure 3. Part (a) is for \(-\frac{2}{\beta_1} < mc_1' < -\frac{1}{\beta_1}\). In this case, the huge marginal cost and the high increasing return-to-scale make it optimal for port 1 to attract more cargoes by reducing its price, in addition to the demand increase as a result of the competitor’s price increase. Therefore, the slope of the BRF for port 1 is negative. For part (b), the slope of the marginal cost is equal to that of the demand function, i.e., \( mc_1' = -\frac{1}{\beta_1} \). In this case, there is no incentive for port 1 to change its price for any price change in the other port, because the impact of price change just offset the marginal cost change. Lastly, part (c) depicts the case when \( mc_1' > -\frac{1}{\beta_1} \). In this case, for a price increase in port 2, port 1 also needs to increase its price to maximize the profit. This is the case where the slopes of the best response functions for both ports are positive (Baye and Kovenock, 2008). This is also the case from which the specific cost function is formulated. The Nash equilibrium prices \((p_2^*, p_1^*)\) for each case are the intersection of these two BRFs for a given capacity level of each port.

From the above discussion, we can conclude that (1) the BRF of the port with a higher initial market share and price sensitivity can have larger intercept; (2) the maximum slope of the BRF is the ratio of the price sensitivity between the competitor and its own; the higher the cost factor \(\theta_k\), the closer it is to the maximum value, as \( \frac{\partial mc}{\partial \theta} > 0 \) by assumption; and (3) a port with a lower initial market share and a higher own-price sensitivity can have a lower equilibrium price.

### 3.2. Results from comparative static analysis and the necessary condition for port expansion

Having explored the equilibrium pricing strategy in the pricing subgame, we applied the comparative static analysis to examine the changes in equilibrium price, throughput, and profit with respect to the changes in the important parameters such as capacity, demand, and price sensitivity. The mathematical derivation for the comparative statics is given in Appendix A. The results are summarized below.

First, the equilibrium price (throughput) of port \(k\) increases with \( \bar{x}, \alpha_k\), and \( \beta_l \), and decreases with \( \alpha_l \) and \( \beta_k \). In other words, the port with larger market share and lower price sensitivity could have a higher price and throughput (§Appendix A.1).

Secondly, if an increase in capacity can reduce its marginal cost, capacity expansion can increase its throughput (equation Appendix A.8), decrease the prices for both ports (equations Appendix §A.1).
A.6 and Appendix A.7) and reduce the competitor’s throughput and profit (equation Appendix A.9).

Thirdly, without considering the capacity expansion cost, the necessary condition for port \( k \) to gain (i.e., increase profit) through capacity expansion is \( \frac{\partial \Pi_k}{\partial C_k} > 0 \), which is equation (Appendix A.10) in §Appendix A.3. Divide both sides of this equation by \( x_k^* \), this condition can be rewritten as:

\[
\frac{\beta_l}{\beta_k} \frac{\partial p_l^*}{\partial C_k} \bigg|_{x_k^*=\text{constant}} - \frac{\partial V_k(x_k^*, C_k, \theta_k)}{x_k^*} \frac{\partial p_l^*}{\partial C_k} > 0. \tag{12}
\]

It is straightforward that the second term in equation (12) is the average cost saving from the capacity expansion at port \( k \) when \( x_k^* \) remains constant. To maintain market share, the competitor will reduce its price in responding to this capacity expansion, which will then trigger a corresponding price reduction by the expanding port. To examine the necessary price reduction for the expanding port, we differentiate the demand equation of port \( k \) with respect to the capacity increase \( C_k \) and set the derivative to zero:

\[
\frac{\partial x_k^*}{\partial C_k} = 0 - \beta_k \frac{\partial p_l^*}{\partial C_k} + \beta_l \frac{\partial p_l^*}{\partial C_k} = 0.
\]

It is clear from the above equation that the first term in equation (12) equals \( \frac{\partial p_l^*}{\partial C_k} \), the price reduction necessary for port \( k \) to keep \( x_k^* \) constant. From this, we can see that the necessary condition for capacity expansion requires the average cost saving to be larger than the price reduction necessary to offset the impact of the competitor’s price reduction. If the price reduction is higher than the savings in average cost, the capacity expansion will reduce the profit of the expansion port.

It is worth pointing out that although capacity expansion can support lower price at the expansion port and attract more cargoes, their impacts are canceled out because marginal revenue is always equal to marginal cost when profit is maximized. Therefore, they will not be involved in the necessary condition for capacity expansion.

Finally, from equation (12), if the competitor \( l \) has a higher price sensitivity (\( \beta_l \) is large) compared with \( \beta_k \), the capacity expansion of port \( k \) can reduce its own profit. On the other hand, if port \( k \) has higher price sensitivity (larger \( \beta_k \)), it may be easier for it to satisfy the necessary condition. In addition, from equation (2), if \( mc_k' > 0 \), it is easier for a smaller port to satisfy the necessary condition.

3.3. Credibility and effectiveness of the preemptive price.

This section examines price preemption where the ex-monopoly port \( 2 \) with higher operational cost and lower price sensitivity face a new port \( 1 \) with lower operational cost and higher price sensitivity. We adopt Wilson’s (1992) method in judging the credibility of the preemptive price\(^4\), and assess its effectiveness by combining BRF and the nature of the market demand function.

First, from Figure 3(c), if port \( 2 \) sets a preemptive price \( p_2^0 \) lower than the equilibrium price \( p_2^* \), for any best response price \( p_1^0 \) from port 1, the best response price of port 2 \( p_2^l \) is always higher than the preemptive price, i.e., \( p_2^l > p_2^0 \). Therefore, it is not credible for port 2 to use a

\(^4\)We follow the definition of credibility in Wilson (1992) for post-entry preemption. Simply put, credibility is the belief of the new port on the possibility that the ex-monopoly port will adopt a preemptive measure, while effectiveness refers to whether the preemptive measure can prevent the growth of the new port.
price lower than its equilibrium price as the preemptive price, as it is not to the best interest of port 2. The same reasoning can be made for Figures 3(a) and (b).

Second, we assess the effectiveness of preemptive pricing by examining the relationship of the BRF with the demand function. To do this, we first rewrite the demand function of the new port:

$$p_1 = \frac{\bar{x}\alpha_1 - x_1}{\beta_1} + \frac{\beta_2}{\beta_1}p_2. \quad (13)$$

From this, we can see that:

$$
\begin{cases}
    x_1 = 0, & \text{if } p_1 \geq \frac{\bar{x}\alpha_1}{\beta_1} + \frac{\beta_2}{\beta_1}p_2 \\
    0 < x_1 \leq \bar{x}\alpha_1, & \text{if } \frac{\bar{x}\alpha_1}{\beta_1} + \frac{\beta_2}{\beta_1}p_2 > p_1 \geq \frac{\beta_2}{\beta_1}p_2 \\
    x_1 > \bar{x}\alpha_1, & \text{if } p_1 < \frac{\beta_2}{\beta_1}p_2
\end{cases} \quad (14)
$$

Figure 4: Demand for new port 1 and the BRFs

The three regions in equation (14) are depicted in Figure 4. On or above the top line (BC), the demand for port 1 is zero. Between lines BC and OD, the combination of prices for both ports will reduce the market share of port 1. Below line OD, the market share of port 1 will increase. This is also the area where port 2 cannot use the equilibrium price to preempt the market, i.e., to prevent the growth of port 1.

Figure 4 also includes the BRFs with a positive slope, which corresponds to part (c) of Figure 3. Compared with parts (a) and (b) in Figure 3, the probability for port 2 to effectively prevent the growth of port 1 is the highest. If port 2 cannot reduce the market share of port 1 when port 1 has a positive BRF, it will fail to do so when port 1 has a negative or horizontal BRF.
Therefore, to facilitate the further discussion on the effective condition for effective preemptive price, we adopted a specific form for the variable cost function $V_k(x_k, C_k, \theta_k) = f(C_k, \theta_k)x_k^2$, where $f(\cdot) > 0$, $\partial f(\cdot)/\partial \theta_k < 0$ and $\partial f(\cdot)/\partial C_k < 0$. In this function, $mc'_k = 2f(\cdot) > 0$, which satisfies the condition for the slope of the BRF to be positive. Using this specific cost function, the BRF for port 1 can be written as:

$$p^*_k(p_l) = \varphi_k \frac{\alpha_k x^\alpha_k}{\beta_k} + \varphi_k \frac{\beta_l p_{l}}{\beta_k}, (k \in \{1,2\}, l \in \{1,2\}, \text{and } l \neq k)$$  \(15\)

where $\varphi_k = \frac{1 + 2\beta_k f(C_k, \theta_k)}{2 + 2\beta_k f(C_k, \theta_k)}$. Since $\beta_k \geq 0$ and $f(C_k, \theta_k) \geq 0$, we can see that $\frac{1}{2} \leq \varphi_k \leq 1$.

The mathematical derivation for the effectiveness of preemptive pricing is provided in Appendix B. The condition for port 2 to effectively prevent the growth of port 1 (equation Appendix B.9 of Appendix B) can be written as:

$$\varepsilon^*_2 < \frac{\alpha_1}{\alpha_2} \varepsilon^*_1,$$  \(16\)

which means that for the same 1% change in price at the equilibrium point, if the change in the output of port 2 is smaller than that of the new port by the ratio of the market share between ports 1 and 2, the price preemption can be effective. In other words, if the market share for port 1 is small, it is hard to use the equilibrium price to prevent the growth of port 1.

Figure 4 can also be used to discuss the impact of the cost factor $\theta_1$ and price sensitivity $\beta_1$ on the effectiveness of port 2 to use $p^*_2$ as a preemptive measure. The lower the BRF of 1 (line AF), the less effective the equilibrium price can reduce the equilibrium output of the new port. Two attributes from the new port determine the position of line AF. First, a larger $\beta_1$ can effectively reduce both the intercept and the slope of line AF. Second, a smaller cost factor ($\theta_1$) will also reduce both the intercept and the slope of line AF through reducing the value of $\varphi_1$. Therefore, a larger price sensitivity and a lower cost factor of the new port can reduce the effectiveness of price preemption for the ex-monopoly port.

We can therefore conclude that when the new port has a higher price sensitivity, and the marginal cost increasing rate is low, it is effective for the ex-monopoly to use the equilibrium price to protect its market share only when equation (16) holds. The higher the price sensitivity (the lower cost factor) of the new port, the less effective for the ex-monopoly to use the preemptive price to prevent the growth of the new port. Furthermore, port expansion can reduce the marginal cost, and thus increases the competitiveness by reducing the price. Because price is the only instrument that the two ports use to compete with each other, the credibility and effectiveness of preemptive capacity can also be checked using this condition.

The properties derived in these two sections have practical implications and provide insights into the decision process in market transition and evolution. First, to set a preemptive measure, the ex-monopoly should examine the relative conditions in cost factor, demand sensitivity, and market share to determine the effectiveness of the measure. Second, to make capacity expansion decision, it is necessary to check if the expansion can actually increase profit when there is competition. Finally, as optimal pricing and capacity expansion decisions are interdependent, it is necessary to consider the behavior in capacity expansion, in addition to the pricing of the competitor.

### 3.4. Capacity Expansion Game

This section explores the capacity expansion game where each port makes its capacity expansion decision knowing that the other port is doing the same. Denote the equilibrium profit and
annualized capital cost for port $k$ ($k \in \{1, 2\}$) by $\Pi^*_k(C_k, C_l)$, and $I_k$, where $C_k$ and $C_l$ are the original capacities for port $k$ and $l$ ($l \in \{1, 2\}$ and $l \neq k$) respectively. The *sufficient condition* for port $k$ to expand is that the gain from expansion should be larger than annualized capital cost for the expanded capacity, i.e.,

$$\Pi^*_k(C^1_k, C_l) - \Pi^*_k(C_k, C_l) > I_k,$$

(17)

where $C^1_k$ is the new capacity after expansion.

When two ports make investment decisions simultaneously, the gain from expansion for one port is contingent on the capacity development strategies of the competitor. To assist the analysis, we first define some notations for possible gains from expansion for each port, given the possible strategies of the other port:

$L_k$: the gain from expansion for port $k$ when port $l$ does not expand, i.e., $\Pi^*_k(C^1_k, C_l) - \Pi^*_k(C_k, C_l)$;

$M_k$: the gain from expansion for port $k$ when port $l$ expands, i.e., $\Pi^*_k(C^1_k, C^1_l) - \Pi^*_k(C_k, C_l)$.

Based on the relation of the annualized capital cost and the gain from expansion for each port, we have the following scenarios and their corresponding decision rules:

- $I_k < \min(L_k, M_k)$: The annualized capital cost is less than the gain, regardless of expansion decisions of the other port. It is optimal to expand;
- $M_k < I_k < L_k$: The annualized capital cost is less than the gain if the other port does not expand, and more than the gain if it does. It is optimal to select a strategy different from its competitor’s;
- $M_k > I_k > L_k$: The annualized capital cost is more than the gain if the other port does not expand and less than the gain if it does. This happens when the expansion of one port exerts a detrimental impact on the other. It is better for the other port to follow the strategy, and to counteract the impact of the expanding port.
- $I_k > \max(L_k, M_k)$: The annualized capital cost for expansion is larger than the gain regardless of the expansion strategy of the competitor. It is optimal not to expand.

These four decision rules at each port will generate 16 scenario combinations, since there can be four different responses to each decision rule from the competitor. Table 1 lists all the possible equilibrium strategies for each of the 16 combinations. The letters in each parenthesis are the expansion decisions for 1 and 2 respectively, and Y stands for ‘Yes expansion’, and N for ‘No expansion’. Unlike the pricing subgame that has a unique equilibrium, the capacity investment game may have multiple equilibria or no equilibrium. When there is no equilibrium, we cannot predict the strategy for the player with certainty. The 16 scenarios are analyzed in the following paragraphs.

When $M_1 > I_1 > L_1$ and $M_2 > I_2 > L_2$, i.e., expansion is only desirable when the other port also expands, there are two equilibrium points $(Y, Y)$ and $(N, N)$. This situation occurs when the cost of expansion is larger than the gain ($I_1 > L_1$ and $I_2 > L_2$). However, the expansion of the competitor will exert serious negative impact. Thus, the best response is also to expand, in order to counter-balance the impact from the competitor.

For the scenario $M_1 < I_1 < L_1$ and $M_2 < I_2 < L_2$, there are two equilibrium points $(Y, N)$ and $(N, Y)$. For each port, $M_k < L_k$ means that the gain from expansion will be weakened by the expansion of the competitor, thus the port will be reluctant to make the expansion decision if the
other port expands. By comparing the net profits of each port under the two equilibria, we found no dominating equilibrium.

For the scenarios \((M_1 < I_1 < L_1, M_2 > I_2 > L_2)\) and \((M_1 > I_1 > L_1, M_2 > I_2 > L_2)\), it is optimal for the first port to make a decision different from the second port, while the preferred decision for the second port is the same as the first port. Thus there is no equilibrium.

From Table 1, it is obvious that if one port has a clear indication of its strategy \([I_k < min(L_k, M_k)\) or \(I_k > max(L_k, M_k)\)], there will be a unique pure-strategy Nash equilibrium. For all cases of the border cells in the table, at least one port has a very clear choice for expansion strategy. However, when neither port can indicate a clear direction, the competition strategy will be more interactive and interdependent, such as the strategies in the middle cells of Table 1. In this case, two ports will take turns to expand, or take the same strategy, or their strategies may not be predictable.

### 3.4.1. Numerical Examples

The purpose of this section is to show the equilibrium expansion decisions under different parameter settings through numerical simulation. To enable the numerical simulation, we let \(V_k(x_k, C_k, \theta_k) = \frac{\theta}{k} x_k^2\). The parameter values used in this section are for illustration purposes, and they do not reflect the actual values in a container port. The index \(k\) in this section follows \(k \in \{1, 2\}\), where the set of values with index 1 are so assigned to represent the port with smaller capacity, lower cost factor, and higher price sensitivity comparing with those indexed 2.

First, we use an example to illustrate the use of the decision rules. The parameter values used in this example are: \(\bar{x}=1, \alpha_1=0.4, \beta_1=0.2, \beta_2=0.1, \theta_1=1, \theta_2=2, C_1=2, C_2=3, \Delta C=1\). \(I_1=0.01\), and \(I_2=0.014\), where \(\Delta C\) is the capacity increment due to the lumpy investment.

In this experiment, for port 1, when 2 does not expand, \(\Pi_1(C_1^1, C_2)=1.1751\) (the profit when port 1 expands), \(\Pi_1(C_1, C_2)=1.1638\) (the profit when port 1 expands); when 2 expands, \(\Pi_1(C_1^1, C_2^1)=1.1478\) (the profit when port 1 expands), and \(\Pi_1(C_1, C_2^1)=1.1364\) (the profit when port 1 does not expand). Then \(L_1=0.0113\) and \(M_1=0.0114\). For port 2, \(\Pi_2(C_1, C_2^1)=3.1240\), \(\Pi_2(C_1, C_2)=3.1104\), \(\Pi_2(C_1^1, C_2^1)=3.0175\), and \(\Pi_2(C_1^1, C_2)=3.0032\) (the profit when 2 does not expand). Hence \(L_2=0.0136\) and \(M_2=0.0143\). This corresponds to the scenario \(I_1<min(L_1, M_1)\) and \(L_2< I_2 < M_2\). Since port 1 always has an incentive to expand, port 2 will expand too. The pure-strategy Nash equilibrium is \((Y, Y)\).

Second, we designed four scenarios to show the impacts of different factors on equilibrium expansion strategies. The purposes, assumptions, simulation results and explanations are all listed in Table 2. The letters in the parenthesis indicate the equilibrium strategy for ports 1 and 2 respectively.

From the above analysis, we can conclude that:

1. The chance to expand increases with the base demand and market share;

<table>
<thead>
<tr>
<th>(I_1&lt;\text{min}(L_1, M_1))</th>
<th>(M_2&lt; I_2&lt; L_2)</th>
<th>(M_2&gt; I_2 &gt; L_2)</th>
<th>(I_2&gt;\text{max}(L_2, M_2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>((N,Y))</td>
<td>((Y,Y))</td>
<td>No Equilibrium</td>
<td>((Y, N))</td>
</tr>
<tr>
<td>(M_1 &lt; I_1 &lt; L_1)</td>
<td>((N,Y))</td>
<td>((Y,Y))</td>
<td>((Y, N))</td>
</tr>
<tr>
<td>(M_1 &gt; I_1 &gt; L_1)</td>
<td>((N,Y))</td>
<td>((Y,Y))</td>
<td>((N, N))</td>
</tr>
</tbody>
</table>

Table 1: Nash Equilibrium of the Capacity Investment Game
2. The chance to expand decreases with the price sensitivity of the competitor;
3. The player with large cost factor, ceteris paribus, are more likely to expand, because expansion can effectively reduce the congestion cost;
4. High investment cost reduces the likelihood to expand.

In §3.4, the sufficient conditions for port capacity expansion with different competitors are discussed when investment costs are considered. The decision rules are defined, and applied to the analysis of equilibrium strategy on capacity expansion. We found that pure-strategy Nash equilibrium exists whenever there is a clear indication of capacity expansion from either one of the ports; multiple equilibria or no equilibrium is possible when neither has a clear indication. The numerical example illustrates the change of expansion strategies with the change of competition conditions.

4. Model Applications to Competition between HKP and SZP

In this section, we apply the two-stage game model to explain the change of market power between HKP and SZP, and to predict the possible outcomes of competition when the demand for port services increases. As stated in the introduction, the last major container terminal development project (CT9) in HKP was planned long before the major port expansion project in Shenzhen. Therefore, when SZP was planning the port expansion, the decision-maker already knew both the existing and future capacities in HKP. Confronted with such a large port with a dominating market share in 1991, SZP successfully evolved from a small player with less than 1%
market share, to one of the busiest ports in the world serving half of the market in the region. Many factors contributed to the success of SZP. This transition of container market structure can be explained by the competition strategies of the two ports with different competitive conditions.

Due to different levels of economic development, significant differences exist between Hong Kong and Shenzhen in the container terminal construction cost, mainly in land price and labor cost. According to Yantian International Container Terminal (YICT, a terminal group in SZP), it costs about HK$6.6 billion to build a terminal of 4 berths with a total capacity of 2 million TEUs (YICT, 2004). The budget for CT9 in HKP is about HK$10 billion and its capacity is 2.6 million TEUs (HKPMB, 1998). Normalizing it to the same size (2 million TEUs), the total cost would be HK$7.7 billion for HKP. Assuming a 5% loan rate, the annualized capital costs are around HK$330 million and HK$385 for SZP and HKP respectively\(^5\). Therefore, in this model application, \(\Delta C = 2\) million TEUs, \(I_H = HK$385\) million, and \(I_S = HK$330\) million, where subscripts \(H\) and \(S\) stand for HKP and SZP respectively.

On the demand side, we assume that the price sensitivity of SZP is 1.5 times of that of HKP, considering its proximity to the manufacturing center in the PRD area, and the additional time and cost required for moving a container between PRD and HKP. The actual values used in the analysis are \(\beta_S = 150000\) TEUs/$, and \(\beta_H = 100000\) TEUs/$. We also set the cost factors \(\theta_H = 800\) and \(\theta_S = 400\), to allow for the cost differences between two ports.

Additional data, such as the capacity, initial market share for each port, and the base demand at the beginning of each simulation will be introduced later in each subsection.

4.1. Credibility and Effectiveness of Preemptive Pricing

We first check if it is possible for HKP to use preemptive pricing to prevent the growth of SZP. Most of the container terminals for SZP are added after 1997 when the total capacity of the port was around 3 million TEUs. The capacity of HKP has been 14 million TEUs after CT9. The total throughput at the two ports was over 15 million TEUs, with HKP taking 14.5 million TEUs and SZP 1.14 million TEUs. Therefore, we assume that the initial market shares for HKP and SZP are 90% and 10% respectively in our analysis.

The BRFs for the two ports are shown in Figure 5. It shows that for every possible price at HKP, the best price at SZP is always lower. In contrast, the best price for HKP is always higher than that of SZP. For example, if HKP charges a preemptive price of HK$600 (read from the horizontal axis), the best price for SZP (read from the vertical axis following the dotted line) is about HK$400. At this price by SZP, HKP would be better off if it could charge around HK$700.

To check the existence of a credible preemptive price, we use equation (Appendix B.9) developed in Appendix B. In this case, the condition requires

\[
\frac{\varepsilon^*_H}{\varepsilon^*_S} < \frac{\alpha_S}{\alpha_H} = \frac{1}{9}.
\]

In this analysis, \(\varepsilon^*_H = 1 + 2\beta_H \frac{\theta_H}{C_H} = 1 + 2 \times 100000 \times 800/14000000 = 12.42\), and \(\varepsilon^*_S = 1 + 2\beta_S \frac{\theta_S}{C_S} = 1 + 2 \times 150000 \times 400/3000000 = 41\). Therefore, \(\frac{\varepsilon^*_H}{\varepsilon^*_S} = 0.30 > \frac{1}{9}\). HKP cannot use the equilibrium price to effectively prevent the growth of SZP.

Next, we discuss whether it is possible for HKP to use a nonequilibrium price to preempt. The slope of line OD in Figure 4 in this case is \(2/3\). From Figure 5, we can see that when \(p_H > 600\), the

\(^5\)The terminal constructed is assumed not depreciable.
best response price of SZP is less than $\beta_H p_H$. Thus, for any preemptive price $p_H$ to be effective, it must be less than $600. However, if HKP adopts such a price, the loss to HKP would be much larger than that to SZP. Therefore, it is not credible for HKP to use a preemptive price that is lower than $600$. This also shows that in reality, it is a wise economic decision for HKP not to reduce the terminal charge in response to the competition from SZP. Our finding is also consistent with the empirical evidence observed in a recent study on the competition between SZP and HKP (Liu et al., 2009). Findings show that the container throughput increase in HKP does not Granger cause SZP’s throughput increase while the reverse is true for SZP on HKP. In other words, the competitive measures, such as competitive pricing, by HKP for market share would not have affected SZP’s growth in market share.

4.2. CT9 in HKP and its Impact on the Port Capacity Expansion in SZP

We now apply the model to explain the past capacity expansion of the two ports. Specifically, we want to see if adding CT9 is optimal for HKP, and what is the impact of CT9 on the capacity expansion of SZP. To achieve this, we perform two groups of simulations. In the first group, we simulate the expansion strategy as if CT9 was not added. Therefore, the base capacities are 11.4 and 3 million TEUs for HKP and SZP respectively. The purpose is to check which port should expand the capacity by 2 million TEUs. In the second group, we simulate the same problem assuming that CT9 has already been added to HKP. In this case, the starting capacity for HKP increased to 14 million TEUs.

For each group, we simulate the expansion strategy at two base demand levels, one at 15 million TEUs, corresponding to the total throughput of the two ports in 1997, and the other at 25 million TEUs, corresponding to the 2003 level. For each simulation, we calculate the gain for port $k$ ($k=\{H, S\}$) to expand when the other port also expands ($M_k$), or does not expand ($L_k$). The results are summarized in Table 3. The initial market shares in this simulation are 90% for HKP and 10% for SZP.
Table 3: Capacity Expansion Strategy for HKP and SZP with/without CT9

<table>
<thead>
<tr>
<th></th>
<th>Group 1: No CT9</th>
<th>Group 2: With CT9</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{x}$ (million TEU)</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>HKP (million)</td>
<td>$L_H$</td>
<td>-$614$</td>
</tr>
<tr>
<td></td>
<td>$M_H$</td>
<td>-$2,796$</td>
</tr>
<tr>
<td></td>
<td>$I_H$</td>
<td>$385$</td>
</tr>
<tr>
<td>HK$$</td>
<td>$L_S$</td>
<td>$435$</td>
</tr>
<tr>
<td>SZP (million)</td>
<td>$M_S$</td>
<td>-$30$</td>
</tr>
<tr>
<td></td>
<td>$I_S$</td>
<td>$330$</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>$L_S&gt;M_S$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$N,Y$</td>
<td></td>
</tr>
</tbody>
</table>

According to the results from the first group of simulation, HKP should not expand CT9, as the gains from expansion are all negative at both demand levels. The actual decision of building CT9 was made around 1997-98, when the demand was about 15 million TEUs. It is not clear whether CT9 was intended as a preemptive capacity, or just followed the “Trigger Point Policy”, the long-standing port development policy in Hong Kong, which totally ignored SZP because of its low market share. Nevertheless, it functioned as a de facto preemptive capacity at that time. Next, we explain whether it had any impact on the expansion decision of SZP.

In both groups, the results show that HKP would not expand since $L_H<0$ and $M_H<0$. Then, SZP should expand for both the low demand and the high demand cases, as the gains to SZP from expansions at both demand levels could offset their annualized capital cost ($L_S>I_S>M_S$). Therefore, CT9 did not change the expansion strategy of SZP.

After HKP built the CT9, while SZP has experienced fast expansion, HKP has not committed any major capacity expansion project. This can be explained by the simulation results in the second group. HKP would have no incentive to expand at both demand levels, while SZP can benefit from the expansion if HKP does not expand.

We can also demonstrate the above results by simulating the capacity expansion paths with the demand increased from 6 to 45 million TEUs between 1991 and 2008, as given in Figure 6. As can be seen from the actual capacity expansion paths of the two ports (Figure 2 on page 4), the only major terminal expansion project for HKP in this period was CT9, which first increased its capacity from 11.4 to 14 million TEUs, then to 19 million TEUs through productivity improvement in recent years. The actual capacity in SZP increased steadily, with most recent capacity around 11 million TEUs. In Figure 6, the solid lines are the simulated port expansion paths, with the base demand increased from the throughput level in 1991 to that in 2008. Table 3 shows that HKP should not increase its capacity. This is reflected in the simulated capacity expansion path for HKP, which does not show a capacity increase for HKP. To be comparable with the actual situation, we set the capacity of HKP in the simulation to the actual capacity after CT9 was added at approximately the same demand levels as shown in Figure 2. The simulation results (the dotted line) show that HKP will not add more capacity other than the forced capacity increase (Add CT9), while SZP’s capacity increased even faster than that without CT9. This is expected, as from the necessary condition for port expansion (equation (12)), the higher the capacity of the
HKP, the easier for SZP to obtain positive gain from port expansion.

The above analysis explains two important facts. First, even if CT9 was a *de facto* preemptive capacity, it had not been effective to deter the growth of SZP. Second, the contrast between the fast capacity development in SZP and no major expansion in HKP post CT9 demonstrates the rational behavior of both ports. Finally, our simulation can largely replicate the port expansion paths of both ports, especially the port expansion path of SZP.

### 4.3. Possibility of CT10 for HKP

The previous section explains different port capacity development strategies of the two ports, both before and after the construction of CT9. Such differences resulted in the convergence of SZP to HKP in terms of capacities (11 to 18-19 million TEUs), throughputs (21 to 24 TEUs), and market shares (47% to 53%) at the end of 2008.

The sum of the throughputs for the two ports is then already larger than the total available capacity, which reveals the need for further capacity expansion in the PRD region. There are existing plans in both ports to expand the capacity. SZP’s development plan will see 10 more berths be added to the existing container terminals by 2010, and Hong Kong has proposed CT10 to add 8 more berths. While the major part of the port development plan has been realized in SZP, the construction of CT10 has been discussed and delayed several times in Hong Kong, and still has not been decided.

The simulation results from §4.2 show that HKP cannot satisfy the necessary condition for port expansion, due to its low price sensitivity, and large existing capacity. For CT10 to be a profitable capacity investment, HKP needs to increase its attractiveness ($\beta_H$), or wait for SZP port to increase its capacity to a substantially higher level.

Next we use two simulation results to demonstrate the possible scenarios when CT10 is needed, and possible expansion paths of the two ports while demand is increasing, with different price sensitivities at HKP. These expansion paths are presented in Figure 7.

Figure 7(a) presents the capacity paths of the two ports when the price sensitivity of HKP is 100000 TEUs/HK$. It reveals that CT10 would benefit HKP only when SZP has more capacity.
than HKP. In other words, if HKP does not take measures to improve its market competitiveness, SZP will overtake HKP as the leading port in the PRD region.

Considering that HKP is adopting many measures to increase its market competitiveness, Figure 7(b) portrays the possible capacity paths for both ports if HKP can increase its price sensitivity. In this case, CT10 could be a profitable investment at an earlier stage when the base demand is smaller; SZP would not expand as faster as shown in Figure 7(a), and HKP could still keep its leading positions in the region.

From both figures, it is obvious that according to the duopoly model, the CT10 may not be necessary at present, as there are still big differences in construction and operation costs between the two ports. Considering the current economic slowdown in the PRD region, it might take a long time for the total demand to reach such a high level for new capacity to benefit HKP. Thus, from this simulation, we could conclude that the CT10 can be further postponed.

5. SUMMARY

Using container port competition between Hong Kong and Shenzhen as an example, this paper studies the port decision processes in a duopoly environment with a dominating port and a new port. We adopt Bertrand competition with differentiated products to study the competitive outcomes, when the market demand is increasing and the two ports have different competitive conditions. In addition to the short-run market competition measures such as pricing, the increasing market demand also provides opportunities for capacity expansion, which adds to the competitive game a long-term strategy for competition. For the given throughput, the capacity expansion of one port can reduce its marginal variable cost, which can lead to a lower price and a higher market share. To counterbalance this impact, the other port also needs to reduce its price(s) and maximize its overall profit. The competing ports need to consider these two measures side by side.

Based on the decision making process for capacity expansion and pricing, we construct a two-stage game theory model to analyze the market transition from monopoly to duopoly, the evolution of the market structure and the possible outcomes in the duopoly market. We first analyzed the
pricing strategy of the two competitors for given capacities. We showed the unique Nash equilibrium for the pricing subgame. Using the BRFs and the demand properties of the two ports, we explained the credibility and effectiveness of preemptive price and capacity. The equilibrium price of each competitor increases with its base market demand and market share, and decreases with price sensitivity. Capacity expansion can reduce equilibrium prices, which is beneficial to the consumers. We also analyzed the impact on equilibrium outputs and profits with the capacity change, and established the necessary condition for capacity expansion. In addition, we characterized the condition for the dominating port to effectively prevent the growth of the new port using preemptive pricing.

In the capacity investment game, we identified the pure-strategy Nash equilibrium between the two competitors for different scenarios characterized by the possible gains from capacity expansion and the investment cost. Using numerical examples, we show that both competitors will be more inclined to expand when the total market demand or market share is increasing. The new port with smaller capacity, lower investment cost and higher price sensitivity will be more likely to expand. To obtain positive gain in expansion, the cost savings should be larger than the net revenue loss for the capacity expansion.

We applied the theoretical model to explain the past container port market transition and evolution in the PRD region, and demonstrated possible future outcomes from port competition between the two ports. First, we showed that the equilibrium price of HKP cannot be an effective preemptive measure; and any preemptive price lower than the equilibrium price is not a credible preemptive price. The commission of CT9 in HKP, a de facto preemptive capacity measure, did not effectively prevent the expansion of SZP. Second, we replicated the capacity expansion paths of the two ports, analyzed the feasibility for a new container terminal (CT10), and the possible future capacity expansion paths for the two ports. Because of the cost and location advantage of SZP, it might be a better economic policy for the Hong Kong government to further postpone the construction of CT10. If HKP cannot improve its attractiveness to the shippers and carriers, its market leadership could be replaced by SZP in the future.

The main conclusion of this paper is that in the absence of non-market protective measures, when the new port has better competitive power, it is very important for the dominating port to check if the equilibrium condition can prevent the new port to grow. If not, then check whether it is possible to improve the condition through capacity development, so as to stop the growth of the new comer. The best strategy for the dominating port is to increase its market competitiveness, so as to reduce the possibility of being overtaken by the new player in the future market competition.

There are some directions for further research in port capacity investment decision. Firstly, in our paper, the common terminal operator in both ports has limited influence on the port development decision, because such a decision is made by the government and there is competition among the terminal operators in this area. However, it is worthwhile to examine the optimal pricing strategies for the two terminals that have different operating costs facing competition from other terminal operators serving the same hinterland. Secondly, the increased size in container ships has intensified the competition for the regional transshipment hub. Such competition may cover a larger geographical region, and involve more factors such as the change in global trade patterns, shipping route design and size of the local market. Considering the capitals involved in the construction of such a hub, and the impact of such a decision on both the port development policy and the shipping operation, studies on the capacity development strategies for transshipment ports are highly needed. Finally, this study focuses on the competitive strategies for two players.
in a non-cooperative environment. The social outcomes of such competition with pricing and capacity development when taking into account the impact on the local economy and environment, and possible cooperative outcomes could provide additional insights into the formation of public policies facing market transition and evolution.

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References


YICT, April 2004. Funding for the YICT phase III project. Company news.

Appendix

Appendix A. Comparative Static Analysis

Appendix A.1. The change of equilibrium price and quantity with price sensitivity

Let

$$
\pi_k(p^*_k, p^*_l, C_k, \theta_k) : = \frac{\partial \Pi_k(p^*_k, p^*_l, C_k, \theta_k)}{\partial p_k} = x^*_k - \beta_k[p^*_k - \frac{\partial V_k(x^*_k, C_k, \theta_k)}{\partial x_k}] = 0,
$$

where \( k \in \{1, 2\} \), \( l \in \{1, 2\} \), and \( l \neq k \), and

$$
\Pi_k(p^*_k, p^*_l, C_k, \theta_k) = x^*_k p^*_k - V_k(x^*_k, C_k, \theta_k) \quad \text{(Appendix A.1)}
$$

is the implicit profit function of port \( k \) at optimal price and quantity. We take derivatives of \( \pi_k(p^*_k, p^*_l, C_k, \theta_k) \) on \( \beta_i \) (note that \( p^*_k, p^*_l \) are functions of \( \beta_k \) and \( \beta_l \)),

$$
\frac{\partial \pi_k(p^*_k, p^*_l, C_k, \theta_k)}{\partial p_k} \frac{\partial p^*_k}{\partial \beta_1} + \frac{\partial \pi_k(p^*_k, p^*_l, C_k, \theta_k)}{\partial p_l} \frac{\partial p^*_l}{\partial \beta_1} + \frac{\partial \pi_k(p^*_k, p^*_l, C_k, \theta_k)}{\partial \beta_k} = 0.
$$

For \( k = \{1, 2\} \), we get

$$
-\beta_1(1 + \mu_1) \frac{\partial p^*_1}{\partial \beta_1} + \beta_2 \mu_1 \frac{\partial p^*_2}{\partial \beta_1} - (p^*_1 \mu_1 + \frac{x^*_1}{\beta_1}) = 0,
$$

$$
\beta_1 \mu_2 \frac{\partial p^*_1}{\partial \beta_1} - \beta_2 (1 + \mu_2) \frac{\partial p^*_2}{\partial \beta_1} + p^*_1 \mu_2 = 0,
$$

where \( \mu_k = 1 + \beta_k mc_k' \) and \( mc_k' = \frac{\partial^2 V_k}{\partial x_k^2} = \frac{\partial mc_k}{\partial x_k} \). Solving the above linear equations for \( \frac{\partial p^*_1}{\partial \beta_1} \) and \( \frac{\partial p^*_2}{\partial \beta_1} \), we get

$$
\frac{\partial p^*_1}{\partial \beta_1} = \frac{-\beta_1 p^*_1 \mu_1 - x^*_1 (1 + \mu_2)}{\beta_1 \lambda} < 0, \quad \text{if} \ mc_k' \geq 0, \quad \text{(Appendix A.2)}
$$

$$
\frac{\partial p^*_2}{\partial \beta_1} = \frac{mc_1 \mu_2}{\beta_2 \lambda} > 0, \quad \text{if} \ mc_k' \geq 0, \quad \text{(Appendix A.3)}
$$

where \( \lambda = 1 + \mu_1 + \mu_2 \). When \( mc_k' < 0 \), the signs of above equations are not decisive. Similarly, we can obtain \( \frac{\partial p^*_1}{\partial \alpha_1} > 0, \frac{\partial p^*_2}{\partial \alpha_1} < 0 \) when \( mc'_2 \geq 0 \). Using the same method, we can derive that

$$
\frac{\partial p^*_1}{\partial \alpha_1} = \frac{(\alpha_1 + \mu_2) \mu_1}{\beta_1 \lambda} > 0, \quad \text{(Appendix A.4)}
$$

$$
\frac{\partial p^*_2}{\partial \alpha_1} = \frac{(x^*_1 + \mu_2) \mu_1}{\beta_1 \lambda} > 0, \quad \text{(Appendix A.5)}
$$

and \( \frac{\partial p^*_1}{\partial \alpha_2} = -\frac{\partial p^*_2}{\partial \alpha_1} < 0. \) \[\square\]
Appendix A.2. The change of equilibrium price and quantity with capacity change

Using the same method above, the following linear equations can be derived,

\[-\beta_1 (1 + \mu_1) \frac{\partial p_1^*}{\partial C_1} + \beta_2 \mu_1 \frac{\partial p_2^*}{\partial C_1} + \beta_1 \frac{\partial mc_1}{\partial C_1} = 0,\]
\[\beta_1 \mu_2 \frac{\partial p_1^*}{\partial C_1} - \beta_2 (1 + \mu_2) \frac{\partial p_2^*}{\partial C_1} = 0.\]

When \(mc'_k > 0\) and \(\frac{\partial mc_k}{\partial C_k} < 0\), i.e., there is congestion, and expansion always decreases marginal cost, we get

\[\frac{\partial p_1^*}{\partial C_1} = (1 + \mu_2) \frac{\partial mc_1}{\partial C_1} \frac{1}{\lambda} < 0,\]  \hspace{1cm} (Appendix A.6)
\[\frac{\partial p_2^*}{\partial C_1} = \frac{\beta_1}{\beta_2} \mu_2 \frac{\partial mc_1}{\partial C_1} \frac{1}{\lambda} < 0,\]  \hspace{1cm} (Appendix A.7)

where \(\mu_k\) and \(\lambda\) are defined as in Appendix A.1. Similarly, we can prove \(\frac{\partial p_1^*}{\partial C_2} < 0\), \(\frac{\partial p_2^*}{\partial C_2} < 0\).

With the use of the expressions in (Appendix A.6) and (Appendix A.7), if \(\frac{\partial mc_k}{\partial C_k} < 0\) and \(mc'_k > 0\), it can be derived that

\[\frac{\partial x_1^*}{\partial C_1} = \frac{\partial x_1^*}{\partial p_1} \frac{\partial p_1^*}{\partial C_1} + \frac{\partial x_1^*}{\partial p_2} \frac{\partial p_2^*}{\partial C_1} \]
\[= -\beta_1 \frac{\partial mc_1}{\partial C_1} \frac{1}{\lambda} > 0.\]  \hspace{1cm} (Appendix A.8)

Then \(\frac{\partial x_1^*}{\partial C_1} = \frac{\partial (x_1 - x_1^*)}{\partial C_1} < 0\). By symmetry, \(\frac{\partial x_1^*}{\partial C_2} < 0\).

Appendix A.3. The change of equilibrium profit with capacity expansion

To check the change of the equilibrium profit with capacity expansion, we differentiate the equilibrium profit (equation Appendix A.1) w.r.t. \(C_2\) (recall that \(p_1^* - mc_1 = x_1^* / p_1\) from equation (4)):

\[\frac{\partial \Pi_1(p_1^*, p_2^*, C_1, \theta_1)}{\partial C_2} = \frac{\partial \Pi_1(p_1^*, p_2^*, C_1, \theta_1)}{\partial p_1} \frac{\partial p_1^*}{\partial C_2} + \frac{\partial \Pi_1(p_1^*, p_2^*, C_1, \theta_1)}{\partial p_2} \frac{\partial p_2^*}{\partial C_2} \]
\[= 0 + \frac{\partial \Pi_1(p_1^*, p_2^*, C_1, \theta_1)}{\partial x_1} \frac{\partial x_1^*}{\partial p_1} \frac{\partial p_1^*}{\partial C_2} \]
\[= \frac{\beta_2}{\beta_1} \frac{x_1^*}{\partial C_2} \frac{\partial p_2^*}{\partial C_2}.\]  \hspace{1cm} (Appendix A.9)

Combining the results from equation (Appendix A.6), we can see that if port 2’s expansion can reduce its marginal cost, \(\frac{\partial p_2^*}{\partial C_2} < 0\), and it can reduce the equilibrium profit of port 1.
To find out if port expansion can increase its own profit, we differentiate the equilibrium profit function w.r.t. $C_1$:

$$\frac{\partial \Pi_1(p_1^*, p_2^*, C_1, \theta_1)}{\partial C_1} = \frac{\partial (p_1^* x_1^*)}{\partial C_1} - \frac{\partial V_1(x_1^*, C_1, \theta_1)}{\partial C_1}$$

$$= x_1^* \frac{\partial p_1^*}{\partial C_1} + (p_1^* - mc_1) \frac{\partial x_1^*}{\partial C_1} - \frac{\partial V_1(x_1^*, C_1, \theta_1)}{\partial C_1} |_{x_1^* = \text{constant}}$$

$$= x_1^* \frac{\partial p_1^*}{\partial C_1} + x_1^* \left( \frac{\partial x_1^*}{\partial p_1^*} \frac{\partial p_1^*}{\partial C_1} + \frac{\partial x_1^*}{\partial p_2^*} \frac{\partial p_2^*}{\partial C_1} \right) - \frac{\partial V_1(x_1^*, C_1, \theta_1)}{\partial C_1} |_{x_1^* = \text{constant}}$$

$$= x_1^* \frac{\partial p_1^*}{\partial C_1} + x_1^* \left( -\beta_1 \frac{\partial p_1^*}{\partial C_1} + \beta_2 \frac{\partial p_2^*}{\partial C_1} \right) - \frac{\partial V_1(x_1^*, C_1, \theta_1)}{\partial C_1} |_{x_1^* = \text{constant}}$$

$$= \frac{\beta_2}{\beta_1} x_1^* \frac{\partial p_2^*}{\partial C_1} - \frac{\partial V_1(x_1^*, C_1, \theta_1)}{\partial C_1} |_{x_1^* = \text{constant}}. \tag{Appendix A.10}$$

From here, we can see that the sign of (Appendix A.10) is not certain. Even when the capacity expansion can reduce marginal cost, the cost savings (the second term) may be lower than the net revenue losses (the first term). If port 1 has higher price sensitivity, the equilibrium price decrease in both ports may lead to higher revenue loss than the gain in cost saving.

\[\square\]

**Appendix B. The condition for effective preemptive price**

When the cost function takes the specific form $V(\cdot) = f(C_k, \theta_k)x_k^2$, the first order condition and equilibrium price can be solved analytically:

$$p_k - \frac{x_k}{\beta_k} = 2f(C_k, \theta_k)x_k, \tag{Appendix B.1}$$

$$p_k^* = \frac{x_k^*}{\beta_k} \left( \alpha \right) \tag{Appendix B.2}$$

where $\lambda = 3 + 2f(C_k, \theta_k)\beta_k + 2f(C_l, \theta_l)\beta_l$, and $\mu_k = 1 + 2f(C_k, \theta_k)\beta_k$. Substituting the demand equation ($x_k$) into the first order equation (Appendix B.1), we obtain:

$$p_k = \frac{x_k^*}{\beta_k} \left( \alpha \right) \tag{Appendix B.3}$$

Then, solving equation (Appendix B.3) for $p_k$, we can get a specific BRF function for port $k$:

$$p_k = \frac{\alpha}{\beta_k} x_k + \phi_k \frac{\beta p_l}{\beta_k} \tag{Appendix B.4}$$

where $\phi_k = \frac{1 + 2f(C_k, \theta_k)}{1 + 2f(C_k, \theta_k)}$, $k, l \in \{1, 2\}$ and $k \neq l$.

To assess the effectiveness of the preemptive price, we need to analyze the relative position between the BRF for the new port and the line OD in Figure 4, according to the position of their intersection (point $G$ in Figure 4). Solving

\begin{equation*}
\begin{cases}
    p_1 = \varphi_1 \frac{x_1}{\beta_1} \quad \text{(The BRF for the new port)} \\
    p_1 = \frac{\beta_2}{\beta_1} p_2 \quad \text{(The OD line)}
\end{cases}
\end{equation*}

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for \( p_1 \) and \( p_2 \), we can get the coordinates of point \( G \):

\[
\begin{align*}
    p^G_1 &= (1 + 2\beta_1 f(C_1, \theta_1))\frac{\alpha_1 x}{\beta_1}, \\
    p^G_2 &= (1 + 2\beta_1 f(C_1, \theta_1))\frac{\alpha_2 x}{\beta_2}
\end{align*}
\]  

(Appendix B.5)

When \( G \) is above \( F \), i.e., \( p^G_1 > p^*_1 \) or \( p^G_2 > p^*_2 \), the equilibrium price itself will make the new port to lose its initial market share. In this case, \( p^*_2 \) is an effective preemptive price because it will gradually drive the new port out of the market. Although the new port can earn positive profit, its market share is reducing. In addition, for the new port, charging a lower price is inferior to the equilibrium price.

From the \( p^G_1 > p^*_1 \), equations Appendix B.5 and Appendix B.2 when \( k=1 \), we can see that:

\[
(1 + 2\beta_1 f(C_1, \theta_1))\frac{\alpha_1 x}{\beta_1} > \frac{x(1 + 2f(C_1, \theta_1)\beta_1)(\alpha_1 + \mu_2)}{\lambda\beta_1}, \text{ or}
\]

\[
\alpha_1 \lambda > (\alpha_1 + \mu_2). \quad (\text{Appendix B.6})
\]

Since \( \lambda = 1 + \mu_1 + \mu_2 \), we have:

\[
\begin{align*}
    \alpha_1(1 + \mu_2 + \mu_1) &> \alpha_1 + \mu_2, \\
    \alpha_1(\mu_2 + \mu_1) &> \mu_2, \\
    \alpha_1\mu_2 + \alpha_1\mu_1 &> \mu_2, \\
    \alpha_1\mu_1 &> (1 - \alpha_1)\mu_2, \text{ since } \alpha_2 = 1 - \alpha_1, \\
    \alpha_1\mu_1 &> \alpha_2\mu_2, \text{ or}
\end{align*}
\]

\[
\frac{\alpha_1}{\alpha_2} > \frac{\mu_2}{\mu_1}.
\]  

(Appendix B.7)

Now, multiplying the first order condition (Appendix B.1) by \( \frac{\beta_k}{x_k} \), we get:

\[
\beta_k \frac{p_k}{x_k} - 1 = 2\beta_k f(C_k, \theta_k), \\
-\frac{\partial x_k}{\partial p_k} \frac{p_k}{x_k} = \mu_k,
\]  

(Appendix B.8)

since \( \frac{\partial x_k}{\partial p_k} = -\beta_k \) and \( \mu_k = 1 + 2\beta_k f(C_k, \theta_k) \). The left-hand-side of equation (Appendix B.8) is the demand elasticity by definition. Denote the demand elasticity for port \( k \) at equilibrium as \( \varepsilon^*_k \), then the condition for effective preemptive price is:

\[
\frac{\varepsilon^*_2}{\varepsilon^*_1} < \frac{\alpha_1}{\alpha_2}.
\]  

(Appendix B.9)