ABSTRACT

The demand for door-to-door services including liner services is fast growing while public funds are often insufficient to finance new port capacity. The main question that I address in this paper is whether transportation firms that are prepared to invest in new capacity should make cooperative or individual use of it. Two cases are considered: i) two integrated firms that provide inland and seaside services and ii) two firms that provide inland services and a monopolistic seaside firm. The results indicate that specialized firms tend to favor the cooperative use of capacity compared to integrated firms. Since the number of integrated firms is growing, this indicates that smaller ports could benefit from this development.

INTRODUCTION

The global economy is underlying an integration process that drastically increases the importance of international freight transport. Most freight is based on intermodal transportation chains that combine inland modes of transport (e.g., road and rail) with seaside modes of transport (e.g. liner shipping). As essential parts of the intermodal transportation chain, maritime ports are crucial for the future development of freight transport. However, port throughput is often limited by the capacity of container terminals and inland infrastructure such as road and rail networks (UNCTAD 2006). On the other hand, public funds are often insufficient to finance new capacity. In the case of Europe public funds are also critically considered because they can affect inter-port competition (European Commission 1997 and 2001). Consequently, in many cases private investments in container terminals and inland infrastructure are needed.

Another development that has a large impact on freight markets is the growing demand for door-to-door services where logistics firms manage the entire transportation chain from the origin to the destination of products. It was in the
late 1980s when US shipping firms started to provide integrated logistics services that included different modes of transport (Notteboom and Winkelmans 2001). Today shipping lines are frequently involved in terminal operations and hinterland transportation and the share of inland costs from shipping lines can add up to 70% of total costs. This indicates the high relevance of logistics services and inland costs for liners. To share costs liners frequently form partnerships (e.g., alliances or consortia) and agree on a cooperative use of capacity including terminal capacity (Global Insight, TU Berlin and ISL 2005).

In this paper I focus on door-to-door services where individuals (e.g., manufacturers) wish to send freight from their location to an overseas destination. The question is whether transportation firms that are prepared to invest in container terminal capacity should make cooperative or individual use of capacity. The advantage of agreeing on a cooperative use of capacity is that due to economies of scale cost reductions can be achieved. However, notice that firms can save inland transportation costs by serving individuals that are located nearby their ports and terminals. I use a Hotelling-like model where firms have to carry transportation costs to demonstrate that the disadvantage of a cooperative capacity use is that it increases competition for individuals who are located nearby the port and who can be served with little cost. Thus, if firms build up individual capacity and make use of individual ports they give up scale economies but can benefit from reduced competition.

The analysis includes two basic cases: i) two firms that provide integrated logistics services including inland and seaside modes of transport and ii) specialized firms that serve only one mode of transport. In the first case individuals who demand door-to-door services pay a single price. In the second case individuals need to combine the services of two different firms and will have to pay two prices to receive a door-to-door service. Furthermore, I assume that in this case there is only one monopolistic seaside firm. For instance, observe that it is common international practice to exempt liners from competition law such that they are allowed to cooperatively fix prices and act as if they were one monopoly liner (Global Insight, TU Berlin and ISL 2005; OECD 2002).

The possible investment strategies (individual or cooperative use of capacity) and firm types (integrated or specialized) lead to four different constellations:

- two integrated firms, individual ports and no capacity sharing,
- two integrated firms that, one port and capacity sharing,
- two inland firms that use individual ports, a monopoly seaside firm and no capacity sharing and
- two inland firms, a monopoly seaside firm, one port and capacity sharing.

Observe that in cases 3 and 4 it is an open question whether inland firms or the seaside firm would invest in capacity. Port and capacity choice will crucially depend on the level of scale economies and the average capacity costs per capacity unit. As a measure for scale economies I

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† A notable exception is the EU, which repealed the liners' block exemption from competition law (Regulation 4056/86). The repeal will enter into effect in October 2008.
use the elasticity of capacity costs. Moreover, I use a capacity cost function that implies a constant elasticity of capacity costs. However, with this function it is difficult to derive a closed form expression for capacity choice. Furthermore, the effect of scale economies on average capacity costs is ambiguous. For these reasons I use two different numerical examples to explore capacity choice. One is chosen such that increasing economies of scale reduce average capacity costs and the other one is chosen such that increasing economies of scale lead to increasing average capacity costs.

The numerical examples show that high economies of scale (i.e. a low elasticity of capacity costs) can favor the use of individual ports and capacities if they imply low average capacity costs. The reason for this is that low average capacity costs imply low total capacity costs and, therefore, total savings in capacity costs due to scale economies are rather low although relative cost savings are high. The examples also show that the capacity of individual ports is smaller than the capacity under cooperative use but that the total capacity (= sum of individual capacities) tends to be larger if firms use individual ports and capacities. Furthermore, they show that integrated firms tend to favor individual ports and capacities in comparison to specified firms that tend to favor the cooperative use of capacity. This result indicates that logistics firms that provide integrated transportation services can be better off with a more individualized use capacities and ports.

Since my focus in this paper is on transportation firms and private investments in supplemental port capacity and not in the strategic behavior of ports, I use the simplifying assumption that port charges are constant and given. Several other authors explored the strategic behavior of ports including H. Meersman, E. Van de Voorde and T. Vaneislander (2002), B. De Borger and K. Van Dender (2006), Basso and Zhang (2007) and B. De Borger, F. Dunkerley and S. Proost (2007). See Zhang et al. (2007) for an analysis of intermodal alliances in the air cargo market.

The next section presents the basic model for two integrated transportation firms. Section 2 explores integrated firms and their charge and capacity choices. In section 3 numerical examples are used to analyze the port choices of integrated firms. Section 4 analyzes the behavior of specialized firms. Finally, section 5 provides conclusions.

THE BASIC MODEL

Assume that three ports exist and that they are distributed over the [0,2]-interval. Two ports are located at the border positions 0 and 2 and one port is located at the central position 1. Transportation firms that make use of ports are charged with a given and constant price per unit of freight.

Moreover, assume that a set of individuals with mass 2 exists. Every individual wishes to send one piece of freight from its location to one and the same overseas destination, which is a door-to-door service. Individuals are uniformly distributed over the [0,2]-interval and have a constant reservation price of 1. Door-to-door-services require inland and seaside services (think of trucking and liner services) that are connected to each other at one port. Assume that two firms exist that provide integrated services including inland and seaside services. Firms
charge a unit price $p_i \geq 0$ for door-to-door services with $i \in \{1,2\}$. The firms' freight masses are limited by capacities $k_i \in [0,2]$ (think of terminal capacities). For $p_i \geq 1$ freight demand is

$$D_i(p_1, p_2) = \begin{cases} 
2 & \text{for } p_i < p_j \\
\max\{1, 2 - k_j\} & \text{for } p_i = p_j \\
2 - k_j & \text{for } p_i > p_j 
\end{cases}$$

(1)

and 0 otherwise. In (1) and the remainder $j \neq i$ holds.

Regarding inland transportation assume that every individual has to be served separately (say that each individual's freight fills exactly one truck). Hence, the inland part of a door-to-door service includes a round-trip between the port and the individual's location. The respective inland transportation costs depend on the distance between the port used by the firm to transfer freight from inland to seaside modes of transport and the individual's location. Assume that transportation costs per marginal distance unit are constant and equal to 1. With regard to seaside transportation assume that all individuals can be served by a single trip that connects the port and the overseas destination (no capacity limits for seaside services).

‡ Observe that freight flows between Asia and the rest of the world are characterized by massive trade imbalances such that many liner connections experience excess capacity (Global Insight, TU Berlin and ISL 2005).

Figure 1

In case $B1$ border ports are used as individual ports by firms 1 and 2. In case $C1$ the central port is used as a common port by firms 1 and 2. Landside transportation patterns and, thus, transportation costs will depend on the location of the ports that are used by the firms. For this reason, before I turn to the transportation costs as functions of locations and freight I previously provide the
details of the considered game and the possible port and capacity constellations. The game includes three stages:

**Stage 1:** Firms 1 and 2 cooperatively decide upon ports. They have two choices. First, they can use the border ports located at positions 0 and 2 as individual ports (this case will be referred by index $B1$). Without loss of generality assume that in case $B1$ firm 1 uses the port located at position 0 and firm 2 uses the port located at position 2. In this case the central port located at position 1 is unused. Second, firms 1 and 2 can make cooperative use of the central port (this case will be referred by index $C1$). In this case the two border ports remain unused by the firms. Figure 1 illustrates the two different cases.

**Stage 2:** If firms 1 and 2 make use of a common hub, then they cooperatively choose total capacity $k \in [0,4]$ and share costs as well as capacity evenly, i.e. in this case $k_1 = k_2 = k/2$. If firms use individual ports, then they choose capacities $k_1$ and $k_2$ independently.

**Stage 3:** Firms simultaneously and independently choose prices $p_1$ and $p_2$ for door-to-door services.

Omitting the dependency on capacities $k_1$ and $k_2$ I denote firm i’s freight mass by

$$q_i(p_1, p_2) = \min\{k_i, D_i(p_1, p_2)\}.$$

To minimize transportation costs firms first serve individuals located nearby the used ports. In case $B1$ individual ports are used and variable transportation costs are

$$C_i^{B1}(q_i) = \frac{q_i^2}{2}. \quad (2)$$

In case $C1$ the central port is used by firms 1 and 2. If firms charge different prices the low price firm serves individuals that are located nearby the common port. If both firms charge the same price than total transportation costs are divided according to market shares. In case $C1$ the variable transportation costs are

$$C_i^{C1}(q_1, q_2) = \begin{cases} 
q_i^2 / 4 & \text{for } p_i < p_j \\
q_i / (q_1 + q_2) \cdot (q_1 + q_2)^2 / 4 & \text{for } p_i = p_j \\
[(q_1 + q_2)^2 - q_j^2] / 4 & \text{for } p_i > p_j.
\end{cases}$$

In stage two of the game firms choose capacities. Assume that capacity costs are

$$\frac{k_i^\beta}{\gamma \alpha^{1-\beta}}$$

with $\alpha$, $\beta$ and $\gamma > 0$. Notice that $\beta$ determines the constant elasticity of capacity costs and that economies of scale are increasing for all $\beta < 1$. However, the effect of $\beta$ on average capacity costs
is ambiguous. It is straightforward to show that there is a positive relationship between the average capacity costs and $\beta$ if and only if $\alpha k > 1$. Furthermore, $\alpha$ can be used to adjust the level of total capacity costs.

I obtain the following expressions for profits. In case $B1$ profits are

$$\Pi_i^{B1}(p_1, p_2, k_1, k_2) = p_i q_i(p_1, p_2) - C_i^{B1}(q_i(p_1, p_2)) - \frac{k_i^\beta}{\gamma \alpha^{1-\beta}}$$

and in case $C1$ they are

$$\Pi_i^{C1}(p_1, p_2, k_1, k_2) = \Pi_i^{C1}(p_1, p_2, k/2, k/2)$$

$$= p_i q_i(p_1, p_2) - C_i^{C1}(q_i(p_1, p_2), q_2(p_1, p_2)) - \frac{k_i^\beta}{2\gamma \alpha^{1-\beta}}.$$

PRICES, CAPACITIES AND PORTS

In this section I start to explore price and capacity choices when individual ports are used (case $B1$). Then I turn to the situation of the cooperative use of the central port (case $C1$). However, it turns out to be difficult to derive closed form expressions for capacity choices. Therefore, the analysis of capacity and port choice is based on numerical examples, which I will present in the following section.

Prices and capacities when individual ports are chosen

Assume that firms 1 and 2 use individual ports. In this case the price reactions in stage three of the game are

$$p_i^{B1}(p_j) = \arg \max_{p_i} \Pi_i^{B1}(p_1, p_2, k_1, k_2).$$

Without loss of generality assume $k_1 < k_2$ and denote critical prices

$$\tilde{p}_i(k_i) = \frac{1}{2} \cdot (1 + (2 - k_i)k_i)$$

which implies $\tilde{p}_i(k_i) \leq 1$.

Proposition 1

When firms 1 and 2 use individual ports (case $B1$) the following holds:
If $0 < k_1 \neq 1$, $p_1^{B1} = p_2^{B1} = 1$ is the unique Nash equilibrium.

If $1 < k_1 < 2$, all pairs of prices with $p_1^{B1} = p_2^{B1} \in [\tilde{p}_1(k_1), 1]$ are Nash equilibria.

If $k_1 = 2$, $p_1^{B1} = p_2^{B1} = 1$ is a Nash equilibrium and all pairs of prices $(p_1^{B1}, p_2^{B1}) > 1$ are Nash equilibria.

Nash equilibrium $p_1^{B1} = p_2^{B1} = 1$ is Pareto-dominant for all $k_1 > 0$.

**Proof:** See Appendix A.1.

If firms charge the same price, then each firm attracts a minimum freight mass that is equal to 1 (due to (1)) and firms cannot benefit from undercutting the rival's price. This is because marginal transportation costs are greater than 1 if the individual freight mass exceeds 1 (see the first derivative of $C_i^{B1}(q_i)$), which is higher than the reservation price of 1. Consequently, the use of individual ports prevents a downward pressure on prices in this particular case. Reducing the distance between individual ports, reducing marginal transportation costs or increasing reservation prices could change this result and gradually increase competition or, respectively, reduce equilibrium prices. However, in this paper it is my intention to simplify the analysis and to compare the extreme cases of individual ports with no competition and a central port with full competition for individuals located nearby the port.

Since the Nash equilibrium $p_1^{B1} = p_2^{B1} = 1$ is Pareto-dominant for all $k_1 > 0$, I will use it as a focal point. This leads to capacity reactions

$$k_i^{B1}(k_j) = \arg \max_{k_i} k_i - \frac{k_i^2}{2} - \frac{k_j^{B1}}{\gamma \alpha^{1-\beta}}$$

and implies a dominant strategy $k_i^{B1} = k_i^{B1}(k_j) \leq 1$. Observe, equilibrium prices are equal to the reservation prices of 1 and, therefore, firms fully internalize the benefits of door-to-door services, which implies that $k_i^{B1}$ is welfare optimal. However, it is difficult to derive the closed form expression for $k_i^{B1}$ and the comparative statics results based on the first-order conditions are ambiguous.

**Prices and capacity when the central portal is chosen**

Assume that firms 1 and 2 agree on a cooperative use of the central port (case $C1$). Then, total gateway capacity is $k$ and each firm’s capacity is $k/2$. In this case price reactions in stage three of the game are

$$p_i^{C1}(p_j) = \arg \max_{p_i} \Pi_i^{C1}(p_1, p_2, k/2, k/2).$$

**Lemma 1** When firms 1 and 2 use the same (central) port and share capacity the following holds:
If \( k = 4 \), \( p_1^{C1} = p_2^{C1} = 1/2 \) is the unique Nash equilibrium.
If \( 0 < k < 4 \), a Nash equilibrium in pure price strategies not exists.

**Proof:** see Appendix A.2.

Notice, if firms use the same port and share capacity then firms can benefit from undercutting the rival’s price. This is so because the firm with the lower price increases freight demand and serves individuals located nearby the port, which reduces transportation costs. For capacity choice \( k^{C1} \) it holds:

**Lemma 2** \( k^{C1} < 4 \).

**Proof** If \( k = 4 \), \( p_1^{C1} = p_2^{C1} = 1/2 \) is the unique Nash equilibrium, revenues net of variable costs are 0 and profits are negative because of fixed capacity costs.

Lemma 1 shows that a Nash equilibrium in pure price strategies not exists for all \( k \in (0,4) \), which is the relevant range for capacity, due to Lemma 2. To explore capacity choice \( I \), therefore, take resort to the concept of Nash equilibria in *mixed* price strategies.⁶ A mixed price strategy is determined by a probability function \( F_i(p) = \Pr(p_i \leq p) \in [0,1] \) which is the probability that firm \( i \) charges a price \( p \) or less. Assume that firm \( j \) mixes prices and that it chooses the rival’s price with zero probability. Then, for \( p_i + 1 \) firm \( i \)’s expected profits are

\[
E[\Pi_i^{C1}(p_i, F_j(p), k/2, k/2)]
= F_j(p_i) \cdot (p_i \cdot \min\{k/2, 2 - k/2\} - \min\{3k^2/16, 1 - k^2/16\})
+ (1 - F_j(p_i)) \cdot (p_i \cdot k/2 - k^2/16) - \frac{k^6}{2 \gamma \alpha^{1 - \beta}}.
\]

(4)

The second row of definition (4) shows the product of the probability that \( p_j < p_i \) and the respective revenues minus transportation costs of firm \( i \). The third row shows the product of the probability that \( p_j > p_i \) and respective revenues minus transportation costs and minus firm \( i \)’s share of capacity costs.

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⁶ D.M. Kreps and J.A. Sheinkman (1983) also make use of mixed price strategies to analyze capacity choice.
Proposition 2

When firms 1 and 2 use the same (central) port and share capacity the following holds:

\[ F^C_1(p) = F^C_2(p) = \begin{cases} 
\min \left\{ 1, \max \left\{ 0, \frac{k + 4 + 4p - 4}{k} \right\} \right\} & \text{for } 0 < k \leq 2 \\
\min \left\{ 1, \max \left\{ 0, \frac{k^2 - 4k(1 + p) + 8}{k^2 + 8p(2 - k) - 8} \right\} \right\} & \text{for } 2 < k < 4 
\end{cases} \]

is the unique Nash equilibrium in mixed price strategies and \( k^C \equiv 2 \).

Proof: Due to Lemma 2, \( k < 4 \) is the relevant range for capacity choice. In this case \( \Pi^C_i > 0 \) for all \( p_i \in (0,1] \) and for all \( p_j \equiv 0 \). Thus, prices \( p_i > 1 \) are strictly dominated by prices \( p_i \leq 1 \) and, consequently, a Nash equilibrium in mixed price strategies \( F^C_j \) must satisfy \( F^C_j(l) = 1 \) for all \( j \in \{1,2\} \).

Denote profits of firm 1 for \( p_i > 1 \) and for all \( p_j < p_i \) by \( \Pi^C_1(p_i, p_j) \). Furthermore, observe that \( 1 = \arg \max_{p_i} \Pi^C_1(p_i, p_j) \) and that

\[ \Pi^C_i(1, < 1, k/2, k/2) = \frac{1}{6} \max \left\{ (8 - 3k)k, 16 - (8 - k)k \right\} - \frac{k^\beta}{2\gamma \alpha^{1-\beta}}. \tag{5} \]

In a mixed price strategies equilibrium firms cannot be strictly better off by changing price strategies (including a switch from mixed to pure strategies). Hence, condition

\[ E[\Pi^C_i(p_j, F_j(p), k/2, k/2)] = \Pi^C_i(1, < 1, k/2, k/2) \tag{6} \]

must be satisfied for all \( i \in \{1,2\} \). Denote a critical price by

\[ \bar{p}(k) = \begin{cases} 
1 - \frac{k}{4} & \text{for } 0 < k \leq 2 \\
\frac{2 - k}{k} + 1 & \text{for } 2 < k < 4 
\end{cases} \]

that implies \( 0 < \bar{p}(k) < 1 \).

If \( k \in (0,2] \): \( \min(k/2, 1 - k/2) = k/2 \), \( \min(3, k^2/16, 1 - k^2/16) = 3k^2/16 \) and \( \max((8 - 3k)k, 16 - (8 - k)k) = (8 - 3k)k \). If \( k \in (2,4] \): \( \min(k/2, 2 - k/2) = 2 - k/2 \), \( \min(3k^2/16, 1 - k^2/16) = 3k^2/16 \) and \( \max((8 - 3k)k, 16 - (8 - k)k) = (8 - 3k)k \).
1 − \(k^2/16\) = 1 − \(k^2/16\), and max\{(8 − 3k)k, 16 − (8 − k)k\} = 16 − (8 − k)k. Now, solving (6) for mixed price strategies we obtain the unique Nash equilibrium in mixed price strategies \(F_1^{ci}(p) = F_2^{ci}(p)\) for \(k \in (0, 4]\) with support \([\bar{p}(k), 1]\).

In stage 2 capacity choice is

\[k^{ci} = \arg \max_k E[\Pi_1^{ci}(p_1, F_2^{ci}(p), k/2, k/2)].\]

Equations (5) and (6) imply

\[E[\Pi_1^{ci}(p_1, F_2^{ci}(p), k/2, k/2)] = \frac{1}{16} \cdot \max\{(8 − 3k)k, 16 − (8 − k)k\} − \frac{k^\beta}{2\gamma \alpha^{1-\beta}} \quad (7)\]

for all \(p_1 \in [\bar{p}(k), 1]\). Since \(\frac{\partial}{\partial k} E[\Pi_1^{ci}(p_1, F_2^{ci}(p), k/2, k/2)] < 0\) for all \(k \in (2, 4]\), it follows \(k^{ci} = 2\). ♦

It is difficult to derive a closed form expression for \(k^{ci}\) and the comparative statics results based on the first-order conditions are ambiguous (similar to case \(B_1\)).

Using (3), (7) and \(k^{ci} = 2\) and assuming that firms maximize expected welfare, firms 1 and 2 will use the central port and share capacity if in stage three of the game condition

\[\frac{k^{ci}}{2} − \frac{(3k^{ci})^2}{16} − \frac{(k^{ci})^\beta}{2\gamma \alpha^{1-\beta}} \geq k_1B_{1} − \frac{(k_1B_1)^2}{2} − \frac{(k_1B_1)^\beta}{\gamma \alpha^{1-\beta}}\]

is satisfied. Otherwise, they are assumed to choose individual ports and capacities.

In the next section I present two different numerical examples to analyze capacity and port choice.

**Numerical analysis of the capacity and port choice**

The numerical analysis is based on two examples: \((\alpha, \gamma) = (4, 1)\) and \((\alpha, \gamma) = (1, 2)\). Observe, the examples are such that capacity costs are identical for \(\beta = 1/2\).

Figure 2 depicts the total capacity of a central port \(k^{ci}\), individual capacity of a central port \(k^{ci}/2\) and capacities of individual ports \(k_iB_1\) as functions of \(\gamma \in [0, 1]\) (solid lines: \((\alpha, \gamma) = (4, 1)\); dashed lines: \((\alpha, \gamma) = (1, 2)\)). Notice, if \((\alpha, \gamma) = (4, 1)\), there is a positive relationship between the average capacity costs and \(\gamma \alpha\) in equilibrium. If \((\alpha, \gamma) = (1, 2)\), the reverse holds.

Figure 2 indicates that there is a negative relationship between capacities and \(\beta\). This demonstrates the intuitive result that capacity is expanded if economies of scale are high or, respectively, \(\beta\) is small. The figure also indicates that the capacity of a central port is larger than the capacity of individual ports, i.e. \(k^{ci} > k_iB_1\) for most parts of \(\beta\) (or \(k^{ci} = k_iB_1 = 0\)). In contrast, total individual capacity is normally higher.
than the capacity of a central port, i.e. $k_i^B + k_2^B > k^C$ if $k_i^B > 0$. If $(\alpha, \gamma) = (4, 1)$, $k^C > 0$ and $k_i^B = 0$ is also possible. This is so because capacity sharing better exploits scale economies, which can lead to a positive supply of capacity even if total costs are high (and if $(\alpha, \gamma) = (4, 1)$ there is a positive relationship between average and total capacity costs and $\beta$).

Figure 3 depicts profits $i^B$ for $p_i = p_i^B$ and $k_i = k_i^B$ and expected profits $E[i^C]$ for $F_i(p) = F_2(p) = F_1^C(p)$ and $k = k^C$ as functions of $\in [0, 1]$. If $(\alpha, \gamma) = (4, 1)$, there is a positive relationship between $\beta$ and the average capacity costs which implies a negative relationship between profits and $\beta$ which holds for cases $B1$ and $C1$. If $(\alpha, \gamma) = (1, 2)$, there is a negative relationship between average capacity costs and which implies a positive relationship between profits and $\beta$ in the case of $B1$. In contrast, the same example leads to an ambiguous relationship between profits and $\beta$ in the case of $C1$. The reason for this is that there is a negative relationship between $\beta$ and $k^C$ (see Figure 2) and a negative relationship between $\overline{p}$ and $k^C$. Recall that $\overline{p}$ is the lower limit of the support of the mixed strategy $F_1^C(p)$. Thus, there is a positive relationship between $\beta$ and prices and, since capacity and price effects are contrary, the effect of $\beta$ on expected profits can be ambiguous.

I now turn to the strategic choice of ports. The examples demonstrate the surprising result that the effect of economies of scale on port choice is not clear-cut. If $(\alpha, \gamma) = (4, 1)$, the central port is chosen for high values of $\beta$ or, respectively, if economies of scale are less significant. In this example less significant economies of scale imply high average and total capacity costs. Therefore, the absolute cost savings that can be realized by sharing capacity are important and lead to the choice of the central port although the relative cost savings are low. On the other hand, if $(\alpha, \gamma) = (1, 2)$, the central port is chosen for low values of $\beta$ or, respectively, if economies of scale are significant (which is the expected result).

In the next section I analyze the behavior of specialized firms and compare the results with the findings of this section.

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$\alpha = 4, \gamma = 1$

$\alpha = 1, \gamma = 2$

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**Figure 2:** Total capacity of a central port $k^C$, individual capacity of a central port $k^C/2$ and capacities of individual ports $k_i^B$ as functions of the constant elasticity of capacity costs $\in [0, 1]$. 
Assume that three specialized firms exist. Two firms provide inland services and one firm provides seaside services. Furthermore, suppose that capacity investments are sunk. In this situation individuals who make use of door-to-door services are charged twice, one price is charged by an inland firm and one by the seaside firm. I will first consider a case where inland firms use individual (border) ports and where each border port is also served by the monopoly seaside firm (this case will be referred by index $B2$). Second, I consider a case where inland firms use the same (central) port that is also served by the monopoly seaside firm (this case will be referred by index $C2$).

Prices and capacities when individual ports are chosen and firms are disintegrated

If individual ports are used assume that inland firms and the seaside firm charge prices such that, first, sum of prices is equal to 1 at each port and, second, total revenues net of variable costs are evenly shared. Hence, individuals are indifferent between inland firms. However, inland firms will first serve individuals that are located nearby their port (which is consistent with the case of integrated firms). Capacity investments of inland firm $i$ at its port are $k_i^{B2}$ and observe that there is a hold-up problem, since prices are not affected by capacity investments (this is so because they are sunk). This leads to

$$k_i^{B2} < k_i^{B1}$$

for all $k_i^{B1} > 0$. Notice that capacity choice will not depend on whether the inland or the seaside firm undertakes the investment, which is due to the pricing rule applied (share evenly total revenues net of variable costs). Furthermore, examples $(\alpha, \gamma) =$
(4, 1) and \((\alpha, \gamma) = (1, 2)\) lead to \(k_i^{B2} = 0\), since under the given pricing rule prices cannot raise sufficient revenues to cover the investment costs which holds for all \(\in [0, 1]\). Hence, for the given examples and with specialized firms the use of individual ports is not a relevant option.

Observe that the game structure for the case of specialized firms and individual ports is similar to the game structure used for integrated firms. The port choice is followed by capacity choices that are followed by simultaneous price choices. However, the outcome of price choices follows a specific pricing rule, which evenly shares total revenues net of variable costs between the inland and the seaside firm. The rational behind this pricing rule is that the seaside firm is a monopoly provider and in this situation the inland firm is a monopoly provider for the individuals located nearby its port as well (this follows from \(k_i^{B2} < k_i^{B1} \leq 1\)).

**Prices and capacities when the central port is chosen and firms are disintegrated**

If the central port is used I, first, assume that the seaside firm invests in capacity \(k + 2\) (which is the relevant case as I will argue below) and charges a price \(p_s \neq 0\) for seaside services. Inland firms charge prices \(p_i\). Observe, under seaside firm investments inland firms can make full use of capacity (this is in contrast to case \(C_1\) where capacity is shared between the firms). Therefore, I substitute \(k_i\) by \(k\), use \(D(p, p_2)\) and denote freight mass of inland firm \(i\) by

\[
Q_i(p_1, p_2) = \begin{cases} 
\min\{k, D_i(p_1, p_2)\} & \text{for } p_i \leq p_j \\
0 & \text{for } p_i > p_j
\end{cases}
\]

for \(p_s \neq 1 - p_i\) and \(Q(p, p_2) = 0\) otherwise. The difference between \(q_i\) and \(Q_i\) is that the freight mass of the high price firm is always zero (since the inland firm that charges the low price uses total capacity). Furthermore, notice that the inland firm's freight mass also depends on \(p_s\). Now, substitute \(q_i(p_1, p_2)\) by \(Q_i(p_1, p_2)\) and use \(C_i^{C1}\), which leads to inland firm profits

\[
\Pi_i^{C2}(p_1, p_2, p_s) = p_i Q_i(p_1, p_2) - C_i^{C1}(Q_i(p_1, p_2), Q_2(p_1, p_2)).
\]

Seaside firm profits are

\[
\Pi_s^{C2}(p_1, p_2, p_s) = p_s (Q_i(p_1, p_2) + Q_2(p_1, p_2)) - \frac{k^\beta}{\gamma \alpha^{1-\beta}}.
\]

**Proposition 3**

*When inland firms 1 and 2 use the same (central) port and the seaside firm provides capacity \(k + 2\), \((p_1^{C2}, p_2^{C2}, p_s^{C2}) = (k/4, k/4, 1 - k/4)\) is the unique Nash equilibrium.*
Proof: For inland firms the standard Bertrand result applies, i.e. equilibrium prices are determined by unit costs $k/4$, $p_s^{C_2} = 1 - k/4$ directly follows. ♦

Now, equilibrium profits of inland firms are 0, seaside firm profits are

$$\Pi_s^{C_2}(k/4,k/4,1-k/4) = (1-k/4)(Q_1(k/4,k/4) + Q_2(k/4,k/4)) - \frac{k^\beta}{\gamma \alpha_1^{-\beta}}$$

$$= (1-k/4)k - \frac{k^\beta}{\gamma \alpha_1^{-\beta}}$$

and capacity choice is

$$k^{C_2} = \arg \max_k (1-k/4)k - \frac{k^\beta}{\gamma \alpha_1^{-\beta}}.$$

Dividing (8) by 2 and comparison with the right hand side of (7) for $k \neq 2$ shows that

$$k^{C_2} > k^{C_1}$$

for all $k^{C_2} > 0$. Figure 4 illustrates this result and depicts capacities of the central port $k^{C_1}$ and $k^{C_2}$ as functions of the constant elasticity of capacity costs $\in [0, 1]$ for $(\alpha_1, \gamma) = (4, 1)$ and $(\alpha_1, \gamma) = (1, 2)$. Notice that $k^{C_2}$ is welfare maximizing because $p_s^{C_2}$ internalizes total surplus. However, it is difficult to derive a closed form expression for $k^{C_2}$ and the comparative statics results based on the first-order conditions are ambiguous (similar to cases $B_1$ and $C_1$).

Figure 4: Capacities of the central port $kC_1$ (integrated firms) and $kC_2$ (specialized firms) as functions of the constant elasticity of capacity costs $\in [0, 1]$.

Observe that Proposition 3 is based on a simultaneous price choice of inland firms and the seaside firm (which is similar to the pricing sequence applied before). However, if the central port is chosen it is likely that the monopoly seaside firm becomes a price leader (which has no affect on Proposition 3). Furthermore, under these conditions inland firms would not undertake capacity investments. This is so
because in this situation the seaside firm would charge a price equal to 1 minus the variable unit costs of inland firms, i.e. inland firms would stay with prices that could just cover variable costs. Therefore, in this situation a massive hold-up problem shows up and, as a consequence, inland firms would not invest.

What about the port choice of specialized firms? Specialized firms tend to favor the use of a central port. The reason is that the hold-up problem significantly reduces capacity investments when individual ports are used. In contrast, the hold-up problem can be avoided if a central port is used and (welfare optimal) investments are undertaken by the monopolistic seaside firm. Notice that in this setting a central port is also welfare optimal because it saves capacity costs due to scale economies.

Another possibility that solves the hold-up problem and increases the relative profitability of individual ports is the merger of specialized firms into integrated firms. Since the importance of integrated firms in logistics markets is growing, this result indicates that individualized port use will become more important in the future.

CONCLUSIONS

The demand for international freight transport and door-to-door services is fast growing. The number of integrated firms that serve the entire transportation chain and provide global logistic packages is also growing. On the other hand, public funds are often insufficient to finance needed capacity investments (e.g., in terminal capacity). The main question that I address in this paper is whether private transportation firms that are prepared to make capacity investments should make cooperative or individual use of ports and capacity.

I consider four different constellations including i) two integrated firms and individual ports, ii) two integrated firms that share capacity, iii) three specialized firms and individual ports and iv) three specialized firms that share capacity. Furthermore, I use a capacity cost function that implies a constant elasticity of capacity costs. With this function it is difficult to obtain closed form expressions for capacity choice and, therefore, I refer to two numerical examples to explore port and capacity choice in detail.

The numerical examples demonstrate that high economies of scale (i.e. a low elasticity of capacity costs) can favor the use of individual ports if they imply low average capacity costs. Notice that there is a positive relationship between the level of economies of scale and the possible relative savings of capacity costs. Now, if high economies of scale imply low average capacity costs then the total costs savings from cooperation can be small although relative costs savings are high. In contrast, if high economies of scale imply high average capacity costs relative and total costs savings are high which can favor the cooperative use of port capacity.

The examples also show that the capacity of individual ports is usually smaller than the capacity of one port under cooperative use. In contrast, the capacity of one port is smaller than total capacity of individual ports. However, it is possible that the capacity of one port is positive while individual capacity is zero. This is because the cooperative use of ports and capacity better exploits economies of scale.
The port choice affects the use of scale economies but it also affects competition between firms. They can save transportation costs by serving individuals that are located nearby the ports they use. Therefore, if firms share capacity and use the same port, then they compete for the individuals that are located nearby this port. However, my examples indicate that specialized firms would still favor the use of one port. This is for two reasons. First, with specialization firms create a hold-up problem, which reduces investments and profits in the case of individual ports. Second, seaside firm investments stimulate competition between inland firms in the case of one port, which reduces the hold-up problem and increases seaside firm profits. Notice that firms, which provide integrated services, can solve the hold-up problem in the case of individual ports and increase the relative benefits (reduction of competition) of choosing individual ports. Since the number of integrated firms is currently growing, my results indicate that smaller ports are likely to benefit from this development.

A. PROOFS

A.1. Proof of Proposition 1

Revenues of firm \( i \) are 0 for all \( p_i > 1 \). If firms 1 and 2 choose individual ports (case \( B_1 \)), for \( p_i + 1 \) revenues net of variable costs are

\[
\Pi_i^{B_1}(p_1, p_2, k_1, k_2) + \frac{k_i^\beta}{\gamma \alpha^{1-\beta}} = \begin{cases} 
  p_i (k_i - q_i^2) / 2 & \text{for } p_i < p_j \\
  p_i \min \{k_i, \max \{1, 2 - k_j\}\} - (\min \{k_i, \max \{1, 2 - k_j\}\})^2 / 2 & \text{for } p_i = p_j \\
  p_i \min \{k_i, 2 - k_j\} - (\min \{k_i, 2 - k_j\})^2 / 2 & \text{for } p_i > p_j.
\end{cases}
\]

If \( 0 < k_1, k_2 < 1 \), I shall distinguish between two cases including i) \( k_1 + k_2 > 2 \) and ii) \( k_1 + k_2 \)

\[> 2 \text{ and } 1 < k_2 \text{.} \]

In the first case, \( \Pi_i^{B_1}(p_1, p_2, k_1, k_2) + k_1 / (\gamma \alpha^{1-\beta}) = p_1 (k_1 - k_2^2) / 2 \text{ for all } p_i + 1 \text{ and all } p_i \text{ which implies the strictly dominant strategies } p_i^{B_1}(p) = 1 \text{ and the unique Nash equilibrium } p_1^{B_1} = p_2^{B_1} \text{.} \]

In the second case,

\[
\Pi_2^{B_1}(p_1, p_2, k_1, k_2) + \frac{k_2^\beta}{\gamma \alpha^{1-\beta}} = \begin{cases} 
  p_2 k_2 - q_2^2 / 2 & \text{for } p_2 < p_1 \\
  p_2 - 1 / 2 & \text{for } p_2 = p_1 \\
  p_2 (2 - k_1) - (2 - k_1)^2 / 2 & \text{for } p_2 > p_1.
\end{cases}
\]

for all pairs of prices \( (p_1, p_2) \text{ } + 1 \text{.} \text{} \text{Observe that } p_2 = 1 \text{ maximizes firms' 2 profits for all } p, \text{ } + 0 \text{. Furthermore, for } k_2 \text{ 2 profits net of variable costs are strictly positive at their maximum which implies the strictly dominant strategy } p_2^{B_1}(p) = 1 \text{. For } k_2 = 2 \text{ price reactions are}
which implies the dominant strategy $p_z = 1$. Before turning to firm 1 denote

$$\tilde{p}(k_1, k_2) = \frac{k_1^2 + (2 - k_2) k_2}{2 k_1}.$$ 

Now, profits of firm 1 are

$$\Pi_1^{p_1}(p_1, p_2, k_1, k_2) + \frac{k^\alpha}{\gamma \alpha^{1-\beta}} = \begin{cases} p_1 k_1 - k_1^2 / 2 & \text{for } p_1 \leq p_2 \\ p_1 (2 - k_2) - (2 - k_2)^2 / 2 & \text{for } p_1 > p_2 \end{cases}$$

for all pairs of prices $(p_i, p_j) \neq 1$. From comparison of profits for $p_i = p_1$ and $p_j = p_2$ it follows that $p_1 k_1 - k_1^2 / 2 \neq 2 - k_2$ for all $p_i \in [\tilde{p}(k_1, k_2), 1]$ which implies the reaction function

$$p_i^{p_1}(p_2) = \begin{cases} p_2 & \text{for } p_2 \in [\tilde{p}(k_1, k_2), 1] \\ 1 & \text{for } p_2 < \tilde{p}(k_1, k_2). \end{cases}$$

There is exactly one intersection between the reaction functions of firms 1 and 2 at $p_1^{p_1} = p_2^{p_2} = 1$. Hence, in the first and in the second case the unique Nash equilibrium is $p_1^{p_1} = p_2^{p_2} = 1$.

If $1 < k_1 < 2$ and $1 < k_2$,

$$\Pi_1^{p_1}(p_1, p_2, k_1, k_2) + \frac{k^\alpha}{\gamma \alpha^{1-\beta}} = \begin{cases} p_1 k_1 - q_1^2 / 2 & \text{for } p_i < p_j \\ p_1 - 1/2 & \text{for } p_i = p_j \\ p_i (2 - k_j) - (2 - k_j)^2 / 2 & \text{for } p_i > p_j \end{cases}$$

for all pairs of prices $(p_i, p_j) \neq 1$. From comparison of profits for $p_i = p_1$ and $p_j = p_2$ it follows that $p_i - 1/2 \neq 2 - k_j$ for all $p_i \in [\tilde{p}_j(k_j), 1]$ which implies reactions

$$p_i^{p_1}(p_j) = \begin{cases} p_j & \text{for } p_j \in [\tilde{p}_j(k_j), 1] \\ 1 & \text{for } p_j < \tilde{p}_j(k_j). \end{cases}$$
Notice that $k_1 < k_2 \Rightarrow \bar{p}_1(k_1) > \bar{p}_2(k_2)$. Thus, all pairs of prices with $p_1 = p_2 \in [\bar{p}_1(k_1),1]$ are Nash equilibria (including $p_1 = p_2 = 1$). Observe that $p_1 = p_2 = 1$ is Nash equilibrium for all pairs of capacities $(k_1, k_2) > 0$. It is Pareto-dominant for all $(k_1, k_2) > 0$ if and only if the firms strictly prefer this equilibrium over all other existing Nash equilibria. If $0 < k_1 + k_2$, this holds because $p_1 = p_2 = 1$ is the unique Nash equilibrium. If $1 < k_1 < 2$ and $1 < k_2 < 2$, this holds because $1/2 > p_i - 1/2$ for all $p_i \in [\bar{p}_1(k_1),1]$.

A.2. Proof of Proposition 2

If firms 1 and 2 use the central port (case Cl) for $p_i < 1$ revenues net of variable costs are

$$\Pi_i^{Cl}(p_1, p_2, k/2, k/2) + \frac{k^\beta}{2 \gamma \alpha^{1-\beta}}$$

$$= \begin{cases} 
  p_i \frac{k/2 - k^2}{16} & \text{for } p_i < p_j \\
  p_i \min\{1, k/2\} - (\min\{2, k\})^2 / 8 & \text{for } p_i = p_j \\
  p_i \min\{k/2, 2 - k^2 / 2\} - (\min\{1, k^2 / 4\} - k^2 / 16) & \text{for } p_i > p_j, 
\end{cases}$$

Notice that revenues are not affected by the port choice. In contrast, variable costs are different because port locations affect the transportation patterns of door-to-door service. To analyze the existence of Nash equilibria we shall distinguish between two different cases including $k = 4$ and $0 < k < 4$. If $k = 4$, the standard Bertrand result applies, i.e. equilibrium prices are determined by unit costs 1/2. If $0 < k < 4$, reaction functions are

$$p_i^{Cl}(p_j) = \begin{cases} 
  1 & \text{for } p_j < 1 \\
  p_j - \epsilon & \text{for } \bar{p}(k) < p_j \leq 1 \\
  1 & \text{for } p_j \leq \bar{p}(k), 
\end{cases}$$

Observe that reaction functions not intersect. Hence, a Nash equilibrium in pure price strategies not exists.

REFERENCES

