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Is competition in the transport industry bad? A welfare analysis of R&D with inter-regional transportation^{*}

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Abstract

We consider the welfare effects of a higher number of carriers in a two-region reciprocal market model. While exporting firms engage in cost-reducing R&D and use transport services to export their products to the foreign market, carriers haul the exporting firms' products and compete in a Bertrand fashion in the inter-regional transport market. We demonstrate that if the degree of R&D spillover is large, an increase in the number of carriers harms consumers and social welfare. We further examine the case in which the exporting firm has monopsony power in the transportation service, and also reveal that if the spillover rate is sufficiently high, a higher number of carriers reduces consumer and social surplus. Hence, policies to restrict competition in the transport industry may be socially desirable.

Key words: Transport industry; Price competition; Cost-reducing R&D; Spillovers

JEL classification: L13; F12; R40

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1 Introduction

The idea that “Promoting competition will benefit consumers” is widely believed among practitioners and competition authorities. For example, Joaquín Almunia¹ stated: “[...] Our objective is to ensure that consumers enjoy the benefits of competition, a wider choice of goods, of better quality, and at lower prices. But competition not only delivers benefits for consumers, it also delivers benefits business and the economy as a whole.” (Almunia, 2010, p. 4). This idea is also accepted with regard to industry such as ocean shipping, which has been strongly regulated until now. Although, liner shipping industry has enjoyed an antitrust exemption until relatively recently, the U.S. government reformed shipping act to promote competition and deregulation in the industry through narrowing the scope of antitrust exemption.²

However, there are conflicting views on the relationship between competition and consumer benefit. While some empirical studies reveal that tougher competition due to an increased number of firms lowers price and improves consumer surplus (e.g., Busso and Galiani, 2019; Hausman and Leibtag, 2007),³ Other studies find that an entry can increase prices and may possibly make consumers worse off (e.g., Caves et al., 1991; Grabowski and Vernon, 1992; Thomadsen, 2007).⁴ Hence, it may be assumed that in reality, greater competition due to an entry may not always be beneficial to consumers.

This paper presents a new perspective on the relationship between the promotion of compe-

¹Vice-President and Commissioner for Competition, European Commission 2010-2014.

²In liner shipping industry, “*conference*” (also referred to as *shipping conference*) has traditionally been formed by shipping companies (i.e., carriers). The conference is a horizontal cartel that restricts competition among carriers and engages in price-fixing, and it was immune from the application of the antitrust laws in many developed nations (Stopford, 1988). However, from the mid-1980s, a competition promotion policy such as independent fee-setting by conference members was introduced in the U.S., and the function of the conference has therefore been weakened (Sagers, 2006).

³Using a field experiment, Busso and Galiani (2019) examine the effect of an entry of small retailers into a market and they find that entry reduces prices. Hausman and Leibtag (2007) empirically demonstrate that Wal-Mart’s entry lowered prices in traditional supermarkets and increased consumers’ benefit due to the increased competition.

⁴Caves et al. (1991) empirically demonstrate that market entry can lead to an increase in drug prices. Grabowski and Vernon (1992) also find that an entry causes an increase in the price of pharmaceuticals. Using a simulation, Thomadsen (2007) demonstrates that duopoly prices can be higher than monopoly prices in a first-food market.

tition and consumer welfare. By considering a market structure consisting of carriers (upstream agents) and innovative exporting firms (downstream firms), we demonstrate that if the degree of knowledge spillover among exporting firms is large enough, a higher number of carriers not only harms consumers but also reduces social surplus.

We base our model on a Brander (1981) and Brander and Krugman (1983)-type reciprocal market. While each region's exporting firm uses inter-regional transport services and pays a freight charge to export to the foreign market, it can freely supply its local market. To reduce their production costs, exporting firms engage in research and development (R&D) investment involving knowledge spillovers.⁵ Inter-regional transportation is a homogeneous service, and carriers compete on price *à la* Dastidar (1995).

We show that a higher number of carriers can reduce welfare. First, a rise in the number of carriers reduces consumers surplus if and only if the degree of R&D spillover is large. A higher number of carriers lowers transport prices, and its effect becomes stronger as the spillover rate increases. The transport price reduction increases the rival firm's exports and decreases domestic supply. Hence, when the transport price reduction begins to have a large impact on the extent to which domestic supply decreases, total outputs fall because the decline in the domestic supply exceeds the increase in the rival firm's exports. Second, a higher number of carriers reduces social surplus in each region through a sharp decline in the domestic supply. Exporting firms must pay a transport fee to export their products; thus, export activity is less efficient than supplying domestically. Although a higher number of carriers lowers transport prices and promotes exports, it is equivalent to "fostering inefficient production activity," and it worsens production efficiency, which worsens social surplus.⁶

⁵This model setting is reasonable because previous studies empirically establish the existence of positive international spillovers from R&D. For example, see Coe and Helpman (1995) and Keller (1998).

⁶In a different context to our analysis, some studies consider the welfare effects of the number of firms in an oligopoly market. Lahiri and Ono (1988) reveal that elimination of a high-cost firm (i.e., a firm with a low market share) increases welfare. Dinda and Mukherjee (2014) demonstrate that when the government offers optimal uniform subsidy/tax, a higher number of high-cost firms reduces welfare. These studies focus on the cost asymmetry among firms and they are quite different from our model. Furthermore, Mizuno (2009) examines the welfare effects of a change in the number of upstream and downstream firms in a vertically related market with

To avoid criticism of the assumption such that downstream firms are price takers in the upstream market and also examine the robustness of our results, we further consider the case in which exporting firms have *monopsony power* regarding the transport service. The negative effect of an increased number of carriers on the domestic supply is moderated by this extension. However, since the domestic supply drops sharply as the number of carriers increases if the spillover rate is sufficiently high, a higher number of carriers can reduce the social surplus even in this extended case.

Our study has an important policy implication. While competition authorities tend to regulate horizontal mergers rigorously in the real world, our results indicate that reducing the number of carriers can raise both consumer and social surplus. Therefore, by facilitating mergers in shipping industries through a revision of antitrust laws, competition authorities can increase welfare. We believe that our model provides a new insight into the context of competition policy and consumer protection.

This paper is most closely related to those of Takauchi (2015) and Takauchi and Mizuno (2019), who employ a similar market structure. In their inter-regional R&D rivalry setting, exporting firms must pay freight charges to ship their products to their rival's domestic market, but they freely supply to their local market. Takauchi (2015) examines the effect of improving the R&D efficiency on exporting firms' profits. Takauchi and Mizuno (2019) consider a hold-up problem resulting from carriers raising prices after observing an exporting firm's investment, and reveal that the solution to the hold-up problem, that is, adopting fixed-price contracts for transport prices, can harm all firms. By contrast, we incorporate price competition among carriers into a reciprocal market model and examine the effects of the number of carriers on welfare.

This paper is also related to research on the transport sector in the context of international trade (Behrens et al., 2009; Behrens and Picard, 2011; Francois and Wooton, 2001; Ishikawa and

divisionalization.

Tarui, 2018).⁷ Francois and Wooton (2001) incorporate an imperfectly competitive transport sector into a competitive trade model and examine the effect of tariff reductions. Behrens et al. (2009) and Behrens and Picard (2011) examine the effects of endogenous freight rates on the agglomeration of firms. While Behrens et al. (2009) focus on the role of the carrier's market power, Behrens and Picard (2011) focus on the logistics problem associated with round trips. Ishikawa and Tarui (2018) also examine the logistics problem and consider the role of trade policies in oligopolies. While all of these studies use different models to provide useful insights, they do not consider the price competition among carriers and the R&D activities of exporting firms.

In section 2, we present the baseline model and we derive our results in section 3. We extend the baseline model to the case in which exporting firms have monopsony power regarding the transportation service in Section 4. Concluding remarks are presented in section 5. We provide all proofs in the appendix.

2 Model

We consider two regions, the H (Home) and F (Foreign) regions, whose product market is segmented from each other. Each region has an exporting firm, *firm* i ($i = H, F$), that engages in cost-reducing R&D activity and supplies its product to the local and other markets. The inverse demand in region i is $p_i = a - Q_i$, where p_i is the product price, $Q_i = q_{ii} + q_{ji}$ is total output, q_{ii} is firm i 's domestic supply, q_{ji} is firm j 's exports, $i, j = H, F$, $i \neq j$, and $a > 0$. The region i 's consumers surplus is $CS_i = Q_i^2/2$.

As firms have no means of carrying out long haul transportation, they pay a per-unit transport price, t , and use a transportation service to export their products. The profit of firm i

⁷In addition, some studies treat transport prices (or costs) endogenously. Abe et al. (2014) examine trade and environmental policies in a two-way duopoly in which transportation generates pollution. Matsushima and Takauchi (2014) study port privatization and its effects on the port usage fee (i.e., trade cost) in a two-way oligopoly model.

is

$$\Pi_i \equiv (p_i - c_i)q_{ii} + (p_j - c_i - t)q_{ij} - x_i^2 \text{ for } i \neq j,$$

where x_i is firm i 's investment level and x_i^2 is the R&D cost. Firm i 's production cost after investment is $c_i \equiv c - x_i - \delta x_j$; that is, although firm i invests x_i to reduce the unit cost c , there is a knowledge spillover and the firm i enjoys some part of its rival's developed knowledge, δx_j , without any payments. $\delta \in [0, 1]$ is the spillover rate of R&D and $a - c > 0$.

In the transport industry, there are n (≥ 2) identical cargo transporters, which we refer to as *carriers*. For simplicity, we assume that carriers exist in regions besides the Home and Foreign regions. In our model, inter-regional transportation is a homogeneous service and carriers compete in a Bertrand fashion. Let the transport price offered by carrier k ($\in \{1, \dots, n\}$) be t_k , carrier k 's individual transport demand be q_k , and the aggregate demand be $q_{HF} + q_{FH}$. Each firm employs the carriers offering the lowest price, so the individual transport demand of carrier k is $q_k = [q_{HF}(t^l) + q_{FH}(t^l)]/m$ if the carrier offers the lowest price, $t_k = t^l$. Here, m denotes the number of carriers offering the lowest price. If carrier k offers a slightly higher price than t^l , then $q_k = 0$. To obtain explicit solutions, we assume that carrier k has a quadratic operation cost, $(\lambda/2)q_k^2$, where $\lambda > 0$ denotes the transport efficiency.⁸ The profit of carrier k is $\pi_k \equiv t_k q_k - (\lambda/2)q_k^2$.

The timing of the game is as follows. In the first stage, each firm independently and simultaneously decides its investment level. In the second stage, the transport price is determined through price competition among carriers. In the third stage, each firm independently and simultaneously decides its level of its domestic supply and exports. The timing structure corresponds to the difficulty of a change in each decision. R&D generally takes much more time, so its investment decision is in the first stage of the game. In contrast, since firms can frequently

⁸The quadratic cost is popular in this type of price competition. For example, see Dastidar (1995 pp. 27), Dastidar (2001 pp. 85), Delbono and Lambertini (2016a, 2016b), Gori et al. (2014), and Mizuno and Takauchi (2019).

adjust their outputs, the production decision occurs in the last stage. Since in the second stage the Nash equilibrium is not unique, we employ subgame perfect Nash equilibrium (SPNE) with payoff-dominance refinement as the equilibrium concept.⁹ We solve the game using backward induction. We provide all proofs in Appendix B.

3 Results

In the third stage of the game, the first-order conditions (FOCs) to maximize the profit of firm i are $0 = a - c - 2q_{ii} - q_{ji} + x_i + \delta x_j$ and $0 = a - c - q_{jj} - 2q_{ij} + x_i + \delta x_j - t$ ($i \neq j$). These FOCs yield the following third-stage outputs of $q_{ii}(t, x) = \frac{1}{3}[a - c + t + (2 - \delta)x_i + (2\delta - 1)x_j]$ and $q_{ij}(t, x) = \frac{1}{3}[a - c - 2t + (2 - \delta)x_i + (2\delta - 1)x_j]$, where $i, j = H, F$, $i \neq j$, and $x = (x_i, x_j)$.

In the second stage, the transport price t is determined by price competition among carriers. As Dastidar (1995) demonstrates, if oligopolists with a convex cost engage in a homogeneous price competition, the Nash equilibrium is not unique. In our model, the pure strategy Nash equilibria of transport price has a certain range of $[\underline{t}, \bar{t}]$ derived from the following two conditions: The first condition is given by

$$\pi_k(t, x, n) \equiv t \left(\frac{q_{HF}(t, x) + q_{FH}(t, x)}{n} \right) - \frac{\lambda}{2} \left(\frac{q_{HF}(t, x) + q_{FH}(t, x)}{n} \right)^2 \geq 0,$$

which implies that “carriers do not raise their prices.” The second condition is given by

$$\pi_k(t, x, n) \geq \pi_k(t, x, 1) \equiv t(q_{HF}(t, x) + q_{FH}(t, x)) - \frac{\lambda}{2}(q_{HF}(t, x) + q_{FH}(t, x))^2,$$

which implies that “carriers do not lower their prices.” The first condition yields the lower bound $\underline{t}$, and the second yields the upper bound $\bar{t}$:

$$\underline{t} = \frac{[2(a - c) + (x_H + x_F)(1 + \delta)]\lambda}{2(3n + 2\lambda)}, \quad \bar{t} = \frac{(n + 1)[2(a - c) + (x_H + x_F)(1 + \delta)]\lambda}{2[(3 + 2\lambda)n + 2\lambda]}.$$

To narrow the equilibria, we employ the *payoff-dominance criterion* that maximizes each

⁹For example, Cabon-Dhersin and Drouhin (2014) and Mizuno and Takauchi (2019) employ this concept.

carrier's profit. Since carriers are symmetric, the transport price is

$$t_P = \operatorname{argmax}_t \pi_k(t, \mathbf{x}) = \frac{[2(a - c) + (x_H + x_F)(1 + \delta)](3n + 4\lambda)}{8(3n + 2\lambda)}.$$

The prices $\underline{t}$, $\bar{t}$, and t_P ,¹⁰ yield Lemma 1.

Lemma 1 (i) $t_P > \underline{t}$. (ii) $t_P \leq \bar{t}$ if and only if $\lambda \geq \lambda_0 \equiv 3n/[2(n - 1)]$.

To ensure $t_P < \bar{t}$; that is, $t = t_P$,¹¹ we require Assumption 1.

Assumption 1 $\lambda > \lambda_0 \equiv 3n/[2(n - 1)]$.

We next define z to facilitate the analysis.

Definition 1 $z \equiv \lambda/n \in [3/2, \infty)$.¹²

Substituting the outcomes of the third and second stages into the profit of firm i and solving the FOC, we obtain the following.

$$x_i^* = \frac{(a - c)[48z^2 + 144z + 113 - (4z + 5)(4z + 11)\delta]}{E}, \quad (1)$$

$$q_{ii}^* = \frac{8(a - c)(2z + 3)(4z + 5)}{E}; \quad q_{ij}^* = \frac{16(a - c)(2z + 3)}{E}, \quad i \neq j, \quad (2)$$

$$t^* = \frac{8(a - c)(2z + 3)(4z + 3)}{E}, \quad (3)$$

where $E \equiv (4z + 5)(4z + 11)\delta^2 - 2(16z^2 + 40z + 29)\delta + 5(4z + 5)(4z + 7) > 0$. The variable “*” is the SPNE outcome.

The profits of carrier k and firm i are $\pi_k^* = \left(\frac{2z+3}{n}\right)(q_{ij}^*)^2$ and $\Pi_i^* = (q_{ii}^*)^2 + (q_{ij}^*)^2 - (x_i^*)^2$,

respectively.

¹⁰The price t_P is also known as *collusive-price* because it maximizes joint profit of carriers. To narrow the set of Nash equilibria, this collusive-price refinement is often employed. For example, see Dastidar (2001), Gori et al. (2014), and Mizuno and Takauchi (2019). The collusive-price refinement is identical to the payoff-dominance refinement if the Nash equilibria contain the interior maximizing point of each carrier's profit (i.e., the upper bound of the equilibria is strictly larger than the interior maximizer of each carrier's profit).

¹¹“ $t = t_P$ ” is partially consistent with the characteristics of the transport industry. For example, as indicated by Hummels et al. (2009), ocean shipping is an oligopoly market. Moreover, some studies report collusion in this industry (e.g., Sjoström, 2004; Sys, 2009; Sys et al., 2011). Among them, Sys (2009) empirically demonstrates that the containerized shipping industry is tacitly collusive.

¹²Although we need $z > (3/2)(1/(n - 1))$ from Assumption 1 because the maximum of $1/(n - 1)$ is 1, $\lambda > \lambda_0$ holds for all $z \geq 3/2$.

To ensure a positive unit production cost after investment, we require Assumption 2.

Assumption 2 $c/(a - c) > (1 + \delta)[48z^2 + 144z + 113 - (4z + 5)(4z + 11)\delta]/E$.

From (1)–(3), we establish Lemma 2.

Lemma 2 *I. If $\delta > (=, <)$ $\delta_t \equiv \frac{16z^2 + 40z + 29}{(4z + 5)(4z + 11)}$, $\partial t^*/\partial \delta$, $\partial q_{ii}^*/\partial \delta$, and $\partial q_{ij}^*/\partial \delta < (=, >) 0$.*

II. (i) Suppose $z < z_1 \simeq 5.90928$; then, $\partial x_i^/\partial \delta < 0$. (ii) Suppose $z > z_1$; then, if $\delta < \delta_x$, $\partial x_i^*/\partial \delta > 0$. Otherwise, $\partial x_i^*/\partial \delta \leq 0$. (The threshold δ_x is defined in Appendix B1.)*

Similarly, (1)–(3) yield the following result.

Proposition 1 *(i) Keener competition in the transport industry (i.e., a rise in n) and higher transport efficiency (i.e., a fall in λ) decreases transport prices and domestic supply, but these increase exports. (ii) Keener competition in the transport industry and higher transport efficiency increases the firm's investment if and only if $\delta < 5/(8z + 7)$.*

We first consider part (i) of Proposition 1. A higher n and a smaller λ (i.e., a decrease in z) have a similar effect. A higher n lowers transport prices by intensifying competition among carriers and it therefore increases exports. A smaller λ flattens the slope of the carriers' cost curve, which induces a lower transport price, and thereby promotes exports. Because both a higher n and a lower λ expand imports and makes competition in the local market tougher, firm i 's domestic supply falls.

Second, we examine the logic behind Lemma 2. A higher δ lowers production costs, facilitates production activities, and thus increases both domestic supply and exports. That is, in our model, δ has exactly the same effect on both domestic supply and exports. Since a higher δ leads to an expansion in transport demand, it encourages carriers to set higher prices. (A lower δ yields the inverse result.) Hence, if a higher (lower) δ increases (decreases) transport demand, both outputs and transport prices increase (decrease) as δ goes up (down) because

it also raises (lowers) transport price. On the one hand, an increase in transport prices raises the trade barrier, which impedes exports. If δ rises when its level is low enough, because the transport price is low and the positive effects of a reduction in production costs exceeds the export impeding effect of rising transport prices, the firm's exports increase. Conversely, when both δ and transport prices are high, a rise in δ reduces exports because the export impeding effect becomes large. Transport demand then falls and carriers lower their prices as δ rises.¹³

A rise in δ has positive and negative effects on the R&D motive. A higher δ encourages investment because it reduces the unit production cost and facilitates production (positive effect). If δ increases, because each firm enjoys its rivals developed knowledge without cost, the R&D motive weakens (negative effect). Investment usually decreases as δ rises because the negative effect is dominant. This is a well-known result illustrated by d'Aspremont and Jacquemin (1988).

Different from the standard result, in our model, the positive effect can be dominant. When λ is large, that is, z is large, transportation is inefficient and its price is high. A high transport price impedes cross-hauling and strengthens the monopolization of the local firm in its market. Suppose that the R&D spillover arises, that is, δ slightly increases from 0 in this case; the unit production cost then falls and outputs increase, but it also raises transport prices and the domestic supply increases more rapidly than exports. This strengthens the degree of the local firm's relative monopoly in its market. Because such enlargement in the domestic supply promotes investment and the positive effect becomes dominant, R&D investment increases as δ rises. However, if δ goes above a certain level, the negative effect is dominant since an inflow of the rival firm's developed knowledge becomes large.

We next consider part (ii) of Proposition 1, which indicates that to raise investment by

¹³ Additionally, $\partial x_i^* / \partial \delta$ can explain why the transport prices and the firm's outputs have the same change for δ . From the third-stage outputs and $t = t_P$, noting that $x_i = x_j$ in equilibrium, the total differentiation of $q_{ii} = q_{ii}(x, t, \delta)$, $q_{ij} = q_{ij}(x, t, \delta)$, and $t = t(x, \delta)$ yields $dt/d\delta = \frac{3n+4\lambda}{4(3n+2\lambda)} [x_i + (1+\delta) \frac{dx_i}{d\delta}]$, $dq_{ii}/d\delta = \frac{5n+4\lambda}{4(3n+2\lambda)} [x_i + (1+\delta) \frac{dx_i}{d\delta}]$, and $dq_{ij}/d\delta = \frac{n}{2(3n+2\lambda)} [x_i + (1+\delta) \frac{dx_i}{d\delta}]$.

lowering transport prices, δ should be sufficiently small. The intuition is as follows. As we show in Lemma 2, when δ is sufficiently small, the transport price is also low and the degree of export restriction is weak. Although a higher n and a smaller λ commonly reduce transport prices and increase exports, they decrease the domestic supply. If δ is sufficiently small, because the transport price reduction leads to an increase in exports in excess of the decrease in the domestic supply, a higher n and a smaller λ can encourage investment. In contrast, if δ is large, a higher n and a smaller λ can never encourage investment because the degree of the reduction in domestic supply becomes larger.

Does an increase in the number of carriers and improved transport efficiency enhance welfare? We next focus on the welfare effects of n and λ . To examine their effects on consumer benefit, we use (2) and obtain the following result.

Proposition 2 *Keener competition in the transport industry and higher transport efficiency reduces consumer welfare if and only if the R&D spillover rate is sufficiently high; that is, $\partial Q_i^*/\partial z > 0$ if and only if $\delta > \delta_{cs}$. (The threshold δ_{cs} is defined in Appendix B1.)*

[Fig. 1 around here]

Panel (a) of Fig. 1 depicts Proposition 2. As long as the R&D spillover is not too high, the trade promotion due to the transport price reduction increases total output, $Q_i = q_{ii} + q_{ji}$, and lowers the product price and consumer surplus therefore increases. However, Proposition 2 indicates that this promotion of inter-regional trade is not always desirable for consumers. A key to this result is the role of $\partial t^*/\partial z$.

A higher δ lowers the production costs of firms and increases aggregate transport demand. When the aggregate transport demand is high, each carrier's individual demand is also high because carriers are symmetric. Then, suppose that the number of carriers n increases; that is, $z (\equiv \lambda/n)$ decreases. Tougher competition among them reduces each carrier's demand, and the

size of the demand that the carrier loses increases as the aggregate transport demand increases. Although each carrier lowers its price if there is a reduction in its demand, carriers sharply lower their prices compared to the case of low aggregate transport demand because the size of the lost demand increases as the aggregate transport demand increases. Hence, a higher δ strengthens $\partial t^*/\partial z$.¹⁴

Although a higher δ facilitates production, it can raise transport prices (Lemma 2). A higher δ has both export promotion and restriction effects and a higher δ therefore strengthens $\partial q_{ji}^*/\partial z$ in some cases, but it weakens $\partial q_{ji}^*/\partial z$ in the other cases. On the one hand, as we show in Proposition 1, a higher n (or lower z) reduces domestic supply because transport prices (i.e., the rival firm's trade barrier) fall. If δ is high, the degree of reduction in domestic supply for an increase in n is also large because the degree of the reduction in transport prices for an increase in n is large. That is, when δ rises, the “ $\partial t^*/\partial z$ ” effect becomes stronger, which strengthens the “ $\partial q_{ii}^*/\partial z$ ” effect.

We illustrate $\partial q_{ii}^*/\partial z$ and $-(\partial q_{ji}^*/\partial z)$ as functions of δ in Panel (b) of Fig. 1. (Since $\partial q_{ji}^*/\partial z$ has a negative value, we multiply it by -1 .) As δ increases above a certain level, $\partial q_{ii}^*/\partial z$ (the increasing curve) exceeds $-(\partial q_{ji}^*/\partial z)$ (the inverted U-shaped curve). Hence, if δ is sufficiently high, $\partial Q_i^*/\partial z$ has a positive value. When δ is high, a higher n (lower z) reduces total output.

z ($\equiv \lambda/n$) and δ have the following effects on the profits of firms and carriers.

Lemma 3 *I. $\partial \Pi_i^*/\partial z > 0$ and $\partial \Pi_i^*/\partial \delta > 0$. II. (i) $\partial \pi_k^*/\partial n < 0$, $\partial \pi_k^*/\partial \lambda < 0$, and $\partial(\sum_{k=1}^n \pi_k^*)/\partial z < 0$. (ii) If $\delta > (=, <) \delta_t \equiv \frac{16\lambda^2 + 40\lambda n + 29n^2}{(4\lambda + 5n)(4\lambda + 11n)}$, $\partial \pi_k^*/\partial \delta < (=, >) 0$.*

Lemma 3 is intuitive. Since a larger n and a smaller λ promote less efficient production activity, that is, exports, they reduce the firm's profit. In contrast, a higher δ decreases production costs, and thus increases the firm's profit. The carrier's profit depends on the transport price, so $\partial \pi_k^*/\partial n$ and $\partial \pi_k^*/\partial \delta$ correspond to the changes in the transport price. A smaller λ implies an

¹⁴ $\forall z \geq 3/2$, $(\partial/\partial \delta)(\partial t^*/\partial z) > 0$ holds.

efficiency improvement in transportation, and it hence increases the carrier's profit. A larger n , that is, fall in z , makes competition among carriers tougher and reduces each existing carrier's profit. However, the aggregate number of carriers increases and the total amount of their profits increases.

Subsequently, we examine the effects of a change in the number of carriers on each region's social surplus and the entire world. The social surplus in region i ($i = H, F$) is defined by the sum of consumers surplus and profit of firm i , which is given by

$$SW_i^* = \frac{(a-c)^2}{E^2} \left[\begin{aligned} &3840z^4 + 22016z^3 + 48160z^2 + 47712z + 18047 \\ &+ 2(4z+5)(4z+11)(48z^2+144z+113)\delta - (4z+5)^2(4z+11)^2\delta^2 \end{aligned} \right]. \quad (4)$$

World welfare, WW , is comprised of two countries' social surplus and all profits of carriers, that is, $WW^* \equiv \sum_{i=H,F} SW_i^* + \sum_{k=1}^n \pi_k^*$. The π_k^* and (4) yield

$$WW^* = \frac{2(a-c)^2}{E^2} \left[\begin{aligned} &3840z^4 + 23040z^3 + 52768z^2 + 54624z + 21503 \\ &+ (4z+5)(4z+11)(48z^2+144z+113)\delta - (16z^2+64z+55)^2\delta^2 \end{aligned} \right]. \quad (5)$$

From (4) and (5), we establish Proposition 3.

Proposition 3 *Suppose that all carriers belong to other than both two regions H and F . Then, keener competition in the transport industry and higher transport efficiency (i) always reduce each region's social surplus (i.e., $\partial SW_i^* / \partial z > 0$); (ii) reduce the world welfare if and only if the R&D spillover rate is sufficiently high, that is, $\partial WW^* / \partial z > 0$ if and only if $\delta > \delta_{ww}$. (The threshold $\delta_{ww} \in (0, 1)$ is defined in Appendix B1.)*

We first consider part (i). From the definition of social surplus, the symmetric outcomes ($x_i = x_j$, $q_{ii} = q_{jj}$, $q_{ij} = q_{ji}$, and $p_i = p_j$), and $p'_i = -1$, we can decompose the effects of a

change in z (e.g., a change in n or λ) on welfare as follows:

$$\begin{aligned} \frac{\partial SW_i}{\partial z} = & \underbrace{[p_i - (c - (1 + \delta)x_i)] \frac{\partial q_{ii}}{\partial z}}_{\text{(i) Domestic supply effect (+)}} + \underbrace{[(1 + \delta)Q_i - 2x_i] \frac{\partial x_i}{\partial z}}_{\text{(ii) Investment effect (+)/(-)}} \\ & + \underbrace{[p_j - (c - (1 + \delta)x_i) - t] \frac{\partial q_{ij}}{\partial z}}_{\text{(iii) Export effect (-)}} + \underbrace{\left(-q_{ij} \frac{\partial t}{\partial z}\right)}_{\text{(iv) Transport price effect (-)}}. \end{aligned} \quad (6)$$

There are four effects (terms (i)–(iv)) in (6).¹⁵ The domestic supply effect, term (i), is positive because a decrease in z (i.e., an increase in n and a decrease in λ) raises the rival firm's exports and makes the competition in the domestic market tougher. The investment effect, term (ii), depends on a change in investment $\partial x_i^*/\partial z$ and the effect can therefore be positive when the R&D spillover is low; otherwise, it is negative. Both the export and transport price effects, which correspond to terms (iii) and (iv), respectively, are negative. Since a decrease in z promotes exports, the export effect is negative. A fall in transport prices curtails the inefficiency of cross-hauling; this effect is therefore also negative.

In our model, the domestic supply effect (term (i)) dominates any other effects because the production of domestic supply is more efficient than export activities. The difference in supply efficiencies makes the domestic supply larger than that of exports, and hence, the domestic supply sharply decreases when competition in the local market increases due to the promotion of the rival firm's exports. A fall in z , that is, a rise in n , reduces welfare.

We illustrate this result in Fig. 2. If the spillover rate of R&D is low, the investment effect can be negative. Thus, all terms can be negative except for (i) if the spillover rate is low. Fig. 2 depicts each term when $\delta = 1/4$. Even in such a case, we can immediately see that (i) (the curve (i) in Fig. 2) is extremely large compared with the other terms.

[Fig. 2 around here]

In contrast, the industry profit of the transport sector is added in the world welfare and

¹⁵For more detail, see Appendix A2.

it may therefore be improved due to competition among carriers. As shown in Lemma 3, the industry profit of the transport sector, $\sum_{k=1}^n \pi_i^*$, increases as z decreases. To understand part (ii), it is enough to incorporate this negative effect into the argument of part (i). As illustrated in the logic behind Proposition 2, a higher (lower) spillover rate strengthens (weakens) the effect of a change in the domestic supply due to a change in z (i.e., $\partial q_{ii}^*/\partial z$). Hence, when the spillover rate is small, the effect of term (i) in (6) is not sufficiently strong. Then, because the effect of “ $\partial(\sum_{k=1}^n \pi_i^*)/\partial z$ ” and other negative effects (terms (iii) and (iv) in (6)) can be dominant, a fall in z improves the world welfare.

There is an important policy implication. Suppose that the spillover rate of R&D is sufficiently high. Then, tougher competition due to an increase in the number of carriers worsens consumers surplus, each region’s social surplus, and world welfare (Propositions 2 and 3). This implies that promotion of competition in the transport industry through strengthening of mergers regulation or lowering barriers to entry can work negatively for economies. It may be desirable for the competition authorities to recommend horizontal mergers within the transport industry or to raise barriers to entry in that industry.

4 An Extension

Duopsony in the transport market

In Section 3, we assumed that firms are price takers in relation to the transport service, that is, firms have monopoly power in the downstream product market, whereas they do not have monopsony power in the upstream transport market. Although this assumption is frequently employed in the study of vertically related markets, there is also a criticism that “while downstream firms recognize their monopoly power and strategically behave as sellers in the downstream market, they do not strategically behave as buyers and are price takers in the upstream market.”¹⁶ To

¹⁶For this criticism see, for example, Ishikawa and Spencer (1999). They offer some arguments to justify the assumption such that downstream firms are price takers in the upstream market.

avoid such criticism, we further examine the situation in which firms have *monopsony power* in the transport service market.

To examine the situation in which the export decision of each firm directly affects to the transport supply, we consider the following timing of the game.

- *First stage:* The firm i ($i = H, F$) chooses its investment level, x_i .
- *Second stage:* Given the transport price t , each carrier k ($k = 1, \dots, n$) chooses its freight traffic, q_k . Then, the shape of the inverse transport supply function, $t = T(q_{HF} + q_{FH})$, is fixed.
- *Third stage:* Given the inverse transport supply function, firm i decides its exports, q_{ij} , and domestic supply q_{ii} ($i, j = H, F$ and $i \neq j$).
- *Fourth stage:* The transport market is cleared by the equilibrium price, t .

The game is solved using backward induction. In Appendix A, we report the detailed procedure used to obtain the SPNE of this game and the necessary equilibrium outcomes.

When firms have monopsony power regarding the transport service, they can lower the transport price by decreasing their export volume because their exports (i.e., volume of traffic) influences to the inverse transport supply. Hence, in the duopsony case, the equilibrium transport price, t^{d*} , is lower compared to the case in which they are price takers, that is, $t^* > t^{d*}$.¹⁷

From (A1), we establish the following proposition.

Proposition 4 (i) If $z < z_2 \simeq 2.58114$ or $[\delta < \delta_{cs}^d$ and $z > z_2]$, keener competition in the transport industry and higher transport efficiency increase consumer welfare.

(ii) If $\delta > \delta_{cs}^d$ and $z > z_2$, keener competition in the transport industry and higher transport efficiency reduce consumer welfare. (The threshold $\delta_{cs}^d > 0$ is defined in Appendix B1.)

¹⁷We summarize this result as “Lemma 4” in Supplementary Material.

[Fig. 3 around here]

A rise in the spillover rate, δ , strengthens the degree of a change in the transport price due to a change in z (i.e., the “ $\partial t/\partial z$ ” effect), and also strengthens the degree of change in the domestic supply due to a change in z (i.e., the “ $\partial q_{ii}/\partial z$ ” effect). Hence, when δ is sufficiently high, the “ $\partial q_{ii}/\partial z$ ” effect is dominant, and thus, the area such that $\partial Q/\partial z > 0$ appears (see Fig. 1). On the one hand, in the duopsony case, the equilibrium transport price is lower than that in the price-taker case. Because the decline in the transport price makes the “ $\partial t/\partial z$ ” effect weaker, the “ $\partial t/\partial z$ ” effect in the duopsony case becomes weaker than that in the price-taker case.¹⁸ As shown in the logic behind Proposition 2, if the “ $\partial t/\partial z$ ” effect becomes weaker, the “ $\partial q_{ii}/\partial z$ ” effect also becomes weaker. Hence, in the duopsony case, the “ $\partial q_{ii}/\partial z$ ” effect is weaker than that in the price-taker case. Therefore, in the duopsony, the value of the spillover rate that makes the “ $\partial q_{ii}/\partial z$ ” effect dominant (i.e., the threshold δ_{cs}^d) is higher than that in the price-taker case. Panels (a) and (b) in Fig. 3 illustrate this relationship.

In addition, from (A2), we establish the following proposition.

Proposition 5 *Suppose that all carriers belong to other than both two regions H and F . Then, keener competition in the transport industry and higher transport efficiency reduce each region’s social surplus if and only if the R&D spillover rate is sufficiently high. That is, $\partial SW_i^{d*}/\partial z > 0$ if and only if $\delta > \delta_{sw}^d$. (The threshold $\delta_{sw}^d \in (0, 1)$ is defined in Appendix B1.)*

The logic behind Proposition 5 is intuitive. A fall in z reduces the transport price and promotes less efficient production activity, that is, exports, and it therefore decreases the profit of firms, as is the case for price takers.¹⁹ However, as shown in Proposition 4, the area in which the total output (or consumers surplus) rises due to a decline in z expands, and hence, the area in which the social surplus increases due to a decline in z can appear. Different from the

¹⁸Using Mathematica plotting, we find that $\partial t^*/\partial z > \partial t^{d*}/\partial z > 0$.

¹⁹This result is reported in Supplementary Material.

price-taker case, in a duopsony case, even if there is no carrier within the region, an increase in the number of carriers can enhance the social surplus of that region.

5 Conclusion

Many argue that promoting competition, such as by increasing the number of firms in a market, weakens each firm's market power and lowers prices, which makes consumers better off. However, this standard perspective on the relationship between competition and consumer welfare is not necessarily robust and may not hold when we consider the inter-regional transportation.

We demonstrate that in a market structure consisting of carriers (or shipping firms) and innovative exporting firms, a higher number of carriers sharply reduces the exporting firms' domestic supply and therefore reduces total outputs and consumer surplus if the degree of R&D spillover is large. We also reveal that a higher number of carriers promotes less efficient production activity, that is, exports, which can reduce social surplus.

We further extend our model to the case in which exporting firm has monopsony power regarding the transportation service. This extension moderates the negative effect of domestic supply reduction due to an increased competition. On the other hand, because a higher number of carriers sharply reduces the domestic supply when the rate of R&D spillover is sufficiently high, a higher number of carriers can also decrease consumer surplus in a duopsony case.

We do not consider different forms of innovation activities among exporting firms, such as product R&D and quality improving innovation. Although whether our main findings hold may be interesting when exporting firms conduct these other R&D activities, this aspect is beyond the scope of our analysis. It may be fruitful for future research to examine this relationship.

Appendix

A. The SPNE outcomes in duopsony of exporting firms

We present the calculation to derive the equilibrium outcomes in the game in which firms have monopsony power in the transport market.

In the fourth stage of the game, the equilibrium transport price is decided so as to equalize transport supply with its demand. However, the transport demand, total exports of two firms, is chosen in the third stage. Thus, to solve the game correctly, we assume an inverse transport-supply function, $t = T(q_{HF} + q_{FH})$ and consider this in the third stage.

• **The third stage.** From the profit of firm i and $t = T(q_{HF} + q_{FH})$, the FOCs for profit maximization of firms are $\partial \Pi_i / \partial q_{ii} = 0 \Leftrightarrow a - c - 2q_{ii} - q_{ji} + x_i + \delta x_j = 0$ and $\partial \Pi_i / \partial q_{ij} = 0 \Leftrightarrow a - c - 2q_{ij} - q_{jj} + x_i + \delta x_j - t - T'(q_{HF} + q_{FH})q_{ij} = 0$ ($i \neq j$). Let “ r ” be the first derivative and $T' = T'(\cdot)$. The FOCs yield the third-stage outputs: $q_{ii}(t, x; T') = [a - c + (2 - \delta)x_i + (2\delta - 1)x_j + t + (a - c + x_i + \delta x_j)T'] / (3 + 2T')$ and $q_{ij}(t, x; T') = [a - c + (2 - \delta)x_i + (2\delta - 1)x_j - 2t] / (3 + 2T')$.

• **The second stage.** The carrier k 's maximization problem, $\max_{q_k} \pi_k$, yields $q_k = t/\lambda$. Because the transport demand is $q_{HF} + q_{FH}$, the market clearing condition is $q_{HF} + q_{FH} = \sum_{k=1}^n q_k = nt/\lambda$. From this, the inverse transport supply in this subgame is $t = T(q_{HF} + q_{FH}) = (q_{HF} + q_{FH})\lambda/n$, and hence, $T' = \lambda/n$ holds. Plugging $t = (q_{HF} + q_{FH})\lambda/n$ and $T' = \lambda/n$ into the third-stage outputs and solving these for outputs again, we obtain the second-stage outputs:

$$q_{ii}(x) = \frac{(a - c)(3n + 2\lambda)(n + 3\lambda) + u_i x_i + u_j x_j}{3(n + 2\lambda)(3n + 2\lambda)},$$

$$q_{ij}(x) = \frac{n[(a - c)(3n + 2\lambda) + v_i x_i + v_j x_j]}{3(n + 2\lambda)(3n + 2\lambda)},$$

where $u_i \equiv 2(3n^2 + 8n\lambda + 3\lambda^2) - n(3n + 5\lambda)\delta$, $u_j \equiv 2(3n^2 + 8n\lambda + 3\lambda^2)\delta - n(3n + 5\lambda)$, $v_i \equiv 2(3n + 5\lambda) - (3n + 8\lambda)\delta$, and $v_j \equiv 2(3n + 5\lambda)\delta - (3n + 8\lambda)$.

The above $q_{ij}(x)$ yields the second-stage transport price: $t(x) = \frac{(2(a-c)+(1+\delta)(x_H+x_F))\lambda}{3(n+2\lambda)}$.

• **The first stage.** In this stage, each firm decides its investment level, x_i . The objective

function of firm i , $\Pi_i(x)$, is derived from $q_{ii}(x)$, $q_{ij}(x)$, and $t(x)$. Solving the FOCs, $\partial \Pi_i(x)/\partial x_i = 0$ ($i = H, F$), with respect to x_i , we obtain the following SPNE investment level:

$$x_i^{d*} = \frac{(a-c)[2(9z^3+32z^2+25z+6)-(23z^2+25z+6)\delta]}{K},$$

where

$$K \equiv 54z^3+116z^2+76z+15 - (2z+3)(9z^2+7z+2)\delta + (23z^2+25z+6)\delta^2 > 0.$$

The SNPE outputs and transport price are

$$q_{ii}^{d*} = \frac{3(a-c)(2z+1)(2z+3)(3z+1)}{K}; \quad q_{ij}^{d*} = \frac{3(a-c)(2z+1)(2z+3)}{K},$$

$$t^{d*} = \frac{6(a-c)z(2z+1)(2z+3)}{K}.$$

The profit of carrier k and firm i are $\pi_k^{d*} = \frac{1}{n}t^{d*}q_{ij}^{d*}$ and $\Pi_i^{d*} = (q_{ii}^{d*})^2 + (q_{ij}^{d*})^2 - (x_i^{d*})^2$.

The equilibrium outputs yield the total output in region i :

$$Q_i^{d*} = q_{ii}^{d*} + q_{ji}^{d*} = \frac{3(a-c)(2z+1)(2z+3)(3z+2)}{K}, \quad j \neq i. \quad (\text{A1})$$

The social surplus in region i , $SW_i^{d*} = \frac{1}{2}(Q_i^{d*})^2 + \Pi_i^{d*}$, is

$$SW_i^{d*} = \frac{(a-c)^2}{2K^2} \left[\begin{aligned} &3240z^6+14688z^5+25720z^4+23200z^3+11683z^2+3162z+360 \\ &+ 8(23z^2+25z+6)(9z^3+32z^2+25z+6)\delta - 2(23z^2+25z+6)^2\delta^2 \end{aligned} \right]. \quad (\text{A2})$$

The world welfare, $WW^{d*} = \sum_{i=H,F} SW_i^{d*} + \sum_{k=1}^n \pi_k^{d*}$, is

$$WW^{d*} = \frac{(a-c)^2}{K^2} \left[\begin{aligned} &3240z^6+14976z^5+26872z^4+24784z^3+12547z^2+3324z+360 \\ &+ 8(23z^2+25z+6)(9z^3+32z^2+25z+6)\delta - 2(23z^2+25z+6)^2\delta^2 \end{aligned} \right].$$

B. Proofs and supporting calculations

B1. Proofs

Proof of Lemma 1. (i) A simple algebra yields $t_P - \underline{t} = \frac{3n[2(a-c)+(x_H+x_F)(1+\delta)]}{8(3n+2\lambda)} > 0$.

(ii) Since $\bar{t} - t_P = \frac{3n[2(a-c)+(x_H+x_F)(1+\delta)][2\lambda(n-1)-3n]}{8(3n+2\lambda)[(3+2\lambda)n+2\lambda]}$, $t_P \leq \bar{t}$ iff $\lambda \geq \frac{3n}{2(n-1)}$. Q.E.D.

Proof of Lemma 2. I. Differentiating (2) and (3) with respect to δ yields $\partial t^*/\partial\delta = (16(a - c)(2z + 3)(4z + 3)/E^2)L_1$, $\partial q_{ii}^*/\partial\delta = (16(a - c)(2z + 3)(4z + 5)/E^2)L_1$, and $\partial q_{ij}^*/\partial\delta = (32(a - c)(2z + 3)/E^2)L_1$, where $L_1 \equiv 16z^2 + 40z + 29 - (4z + 5)(4z + 11)\delta$. These yield part I.

II. Differentiating (1) with respect to δ yields $\partial x_i^*/\partial\delta = ((a - c)/E^2)L_2$, where $L_2 \equiv 256z^4 - 512z^3 - 4640z^2 - 7008z - 3071 - 2\delta(4z + 5)(4z + 11)(48z^2 + 144z + 113) + \delta^2(4z + 5)^2(4z + 11)^2$.

Solving $L_2 \geq 0$ for δ , we obtain $\delta \leq \delta_x \equiv \frac{48z^2 + 144z + 113 - 4\sqrt{2}\sqrt{(2z+3)^2(4z+5)(4z+11)}}{(4z+5)(4z+11)}$; δ_x is increasing

for z , $\lim_{z \rightarrow \infty} \delta_x = (3 - 2\sqrt{2}) \simeq 0.171573$, and $\delta_x = 0$ for $z = z_1 \simeq 5.90928$. Q.E.D.

Proof of Proposition 1. (i) Differentiating (2) and (3) with respect to z yields

$$\begin{aligned}\frac{\partial t^*}{\partial z} &= \frac{16(a-c)[9(23\delta^2 - 18\delta + 55) + 16(7\delta^2 - 2\delta + 15)z^2 + 8(37\delta^2 - 22\delta + 85)z]}{E^2} > 0, \\ \frac{\partial q_{ii}^*}{\partial z} &= \frac{16(a-c)[125\delta^2 - 38\delta + 125 + 16(5\delta^2 + 2\delta + 5)z^2 + 8(25\delta^2 + 2\delta + 25)z]}{E^2} > 0, \\ \frac{\partial q_{ij}^*}{\partial z} &= -\frac{32(a-c)[41\delta^2 - 62\delta + 185 + 16(\delta^2 - 2\delta + 5)z(3+z)]}{E^2} < 0.\end{aligned}$$

(ii) Differentiating (1) with respect to z yields $\partial x_i^*/\partial z = [128(a - c)(2z + 3)/E^2][\delta(8z + 7) - 5]$, which implies part (ii). Q.E.D.

Proof of Proposition 2. Since $CS_i^* = (Q_i^*)^2/2$, $\text{sign}\{\partial CS_i^*/\partial z\} = \text{sign}\{\partial Q_i^*/\partial z\}$. The differentiation of total output yields $\partial Q_i^*/\partial z = \frac{16(a-c)}{E^2}[(48z^2 + 104z + 43)(\delta^2 + 2\delta) - 5(4z + 7)^2]$. Thus, $\partial Q_i^*/\partial z \geq 0$ for $\delta \geq \delta_{cs} \equiv -1 + \frac{4\sqrt{2}\sqrt{(2z+3)^2(48z^2+104z+43)}}{48z^2+104z+43}$ (> 0); δ_{cs} is decreasing for z and $\delta_{cs} = 1$ for $z = (\sqrt{30} - 1)/4 \simeq 1.11931$. Q.E.D.

Proof of Lemma 3. I. From Π_i^* , we obtain $\partial \Pi_i^*/\partial z = [512(a - c)^2(2z + 3)^2/E^3][3(47\delta^2 - 56\delta + 25) + 16(7\delta^2 - 4\delta + 5)z^2 + 16(17\delta^2 - 13\delta + 10)z] > 0$ and

$$\frac{\partial \Pi_i^*}{\partial \delta} = \frac{2(a - c)^2(4z + 5)}{E^3} \left[\begin{aligned} &29696z^5 + 221952z^4 + 678272z^3 + 1054112z^2 + 829172z + 263171 \\ &+ \delta^3(4z+5)^2(4z+11)^3 - 3\delta^2(4z+5)(4z+11)^2(48z^2+144z+113) \\ &- \delta(4z+7)(4z+11)(832z^3 + 3024z^2 + 3756z + 1563) \end{aligned} \right] > 0.$$

II. (i) From π_k^* and $\sum_{k=1}^n \pi_k^* = n\pi_k^*$, we obtain

$$\begin{aligned}\frac{\partial \pi_k^*}{\partial n} &= -\frac{256(a-c)^2(2z+3)^2[3(55\delta^2-58\delta+175)+16(7\delta^2-2\delta+15)z^2+8(31\delta^2-28\delta+85)z]}{n^2 E^3} < 0, \\ \frac{\partial \pi_k^*}{\partial \lambda} &= -\frac{512(a-c)^2(2z+3)^2[3(9\delta^2-22\delta+65)+16(\delta^2-2\delta+5)z^2+16(2\delta^2-7\delta+15)z]}{n^2 E^3} < 0. \\ \frac{\partial (\sum_{k=1}^n \pi_k^*)}{\partial z} &= n^2 \left(\frac{\partial \pi_k^*}{\partial \lambda} \right) < 0.\end{aligned}$$

(ii) From π_k^* ,

$$\frac{\partial \pi_k^*}{\partial \delta} = \frac{1024(a-c)^2(2z+3)^3}{nE^3} [16z^2 + 40z + 29 - (4z+5)(4z+11)\delta],$$

which implies part (ii). Q.E.D.

Proof of Proposition 3. (i) Differentiating (4) with respect to z yields $\partial SW_i^*/\partial z = [128(a-c)^2(2z+3)/E^3]N$, where $N \equiv (1088z^3 + 4272z^2 + 5292z + 1993)\delta^2 - 2(4z+7)(16z^2 + 88z + 101)\delta + 5(64z^3 + 112z^2 - 84z - 163)$. $N > 0$ if $z > 1.37301$, therefore $\partial SW_i^*/\partial z > 0 \quad \forall z \geq 3/2$.

(ii) Differentiating (5) with respect to z yields

$$\frac{\partial WW^*}{\partial z} = \frac{256(a-c)^2(2z+3)}{E^3} \left[\begin{aligned} &(1024z^3 + 4048z^2 + 4992z + 1831)\delta^2 \\ &- 2(144z^2 + 552z + 509)\delta - 5(176z^2 + 528z + 397) \end{aligned} \right].$$

Thus, $\partial WW^*/\partial z \geq 0$ iff $\delta \geq \delta_{ww} \equiv \frac{509+552z+144z^2+4\sqrt{(3+2z)^2(27039+70232z+55984z^2+14080z^3)}}{1831+4992z+4048z^2+1024z^3}$. Since δ_{ww} is monotonically decreasing for z , $\lim_{z \rightarrow \infty} \delta_{ww} = 0$, and $\delta_{ww}|_{z=3/2} = \frac{1661+24\sqrt{305871}}{21883} \simeq 0.682463$, $\delta_{ww} \in \left(0, \frac{1661+24\sqrt{305871}}{21883}\right] \quad \forall z \geq 3/2$. Q.E.D.

Proof of Proposition 4. Differentiating (7) with respect to z yields

$$\frac{\partial Q_i^{d*}}{\partial z} = \frac{9(a-c)}{K^2} \left[\begin{aligned} &z(92z^3 + 200z^2 + 147z + 36)\delta^2 + z(7z+4)(2z+3)^2\delta \\ &- (4z+3)(28z^3 + 52z^2 + 36z + 9) \end{aligned} \right].$$

Thus, $\partial Q_i^{d*}/\partial z \geq 0$ if $\delta \geq \delta_{cs}^d$, where $\delta_{cs}^d \equiv \frac{\sqrt{3}\sqrt{z(2z+1)^2 M_1 - z(7z+4)(2z+3)^2}}{2z(92z^3 + 200z^2 + 147z + 36)}$ and $M_1 \equiv 3500z^5 + 13388z^4 + 21243z^3 + 17496z^2 + 7452z + 1296$. From the equation of δ_{cs}^d ,

$$\begin{aligned} &\left(\sqrt{3}\sqrt{z(2z+1)^2 M_1} \right)^2 - [z(2z+3)^2(7z+4)]^2 \\ &= 4z(4z+3)(28z^3 + 52z^2 + 36z + 9)(92z^3 + 200z^2 + 147z + 36) > 0, \end{aligned}$$

so $\delta_{cs}^d > 0$. We find that $\delta_{cs}^d \rightarrow \frac{5\sqrt{105}-7}{46} \simeq 0.961625$ as $z \rightarrow \infty$, and $\delta_{cs}^d - 1 \leq 0$ for $z \geq z_2 \simeq 2.58114$. Q.E.D.

Proof of Proposition 5. Differentiating SW_i^{d*} with respect to z yields

$$\frac{\partial SW_i^{d*}}{\partial z} = \frac{27(a-c)^2(2z+1)}{K^3} \times \begin{bmatrix} (1656z^6+8292z^5+15150z^4+13471z^3+5985z^2+1161z+54) \delta^2 \\ - (840z^6+5492z^5+10586z^4+9687z^3+4833z^2+1323z+162) \delta \\ -384z^6-632z^5-776z^4-1498z^3-1638z^2-783z-135 \end{bmatrix}.$$

Solving $\partial SW_i^{d*}/\partial z \geq 0$ for δ , we obtain $\delta \geq \delta_{sw}^d$, where

$$\delta_{sw}^d \equiv \frac{M_2 + (2z+1)(2z+3)\sqrt{M_3}}{2(1656z^6+8292z^5+15150z^4+13471z^3+5985z^2+1161z+54)},$$

$M_2 \equiv 840z^6 + 5492z^5 + 10586z^4 + 9687z^3 + 4833z^2 + 1323z + 162$, and $M_3 \equiv 203076z^8 + 822036z^7 + 1677397z^6 + 2360146z^5 + 2340511z^4 + 1501530z^3 + 560061z^2 + 103248z + 6156$. We find that $\delta_{sw}^d \rightarrow \frac{35+\sqrt{5641}}{138} \simeq 0.797874$ as $z \rightarrow \infty$, and $\delta_{sw}^d - 1 \leq 0$ for $z \geq \hat{z} \simeq 0.569$. Hence, $\delta_{sw}^d \in (0, 1) \quad \forall z \geq 3/2$. Q.E.D.

B2. The four effects in (6)

(i) Domestic supply effect (term (i)) is

$$[p_i - (c - (1+\delta)x_i)] \frac{\partial q_{ii}}{\partial z} = \frac{128(a-c)^2(2z+3)(4z+5)}{E^3} \begin{bmatrix} 125\delta^2 - 38\delta + 125 + 16(5\delta^2 + 2\delta + 5)z^2 \\ + 8(25\delta^2 + 2\delta + 25)z \end{bmatrix} > 0.$$

(ii) Investment effect (term (ii)) is

$$[(1+\delta)Q_i - 2x_i] \frac{\partial x_i}{\partial z} = \frac{256(a-c)^2(2z+3)[\delta(8z+7)-5]}{E^3} [139\delta - 29 + 16(3\delta - 1)z^2 + 8(21\delta - 5)z] \gtrless 0.$$

(iii) Export effect (term (iii)) is

$$[p_j - (c - (1+\delta)x_i) - t] \frac{\partial q_{ij}}{\partial z} = -\frac{512(a-c)^2(2z+3)}{E^3} \begin{bmatrix} 41\delta^2 - 62\delta + 185 + 16(\delta^2 - 2\delta + 5)z^2 \\ + 48(\delta^2 - 2\delta + 5)z \end{bmatrix} < 0.$$

(iv) Transport price effect (term (iv)) is

$$-q_{ij} \frac{\partial t}{\partial z} = -\frac{256(a-c)^2(2z+3)}{E^3} \begin{bmatrix} 9(23\delta^2 - 18\delta + 55) + 16(7\delta^2 - 2\delta + 15)z^2 \\ + 8(37\delta^2 - 22\delta + 85)z \end{bmatrix} < 0.$$

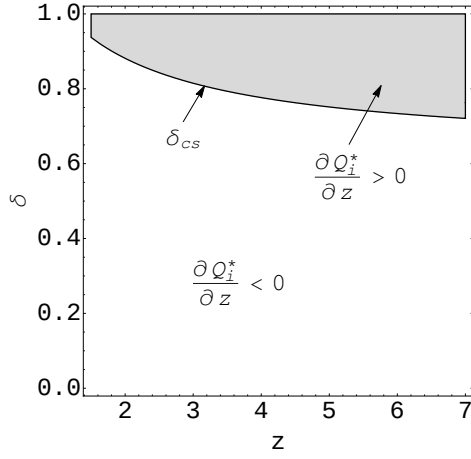
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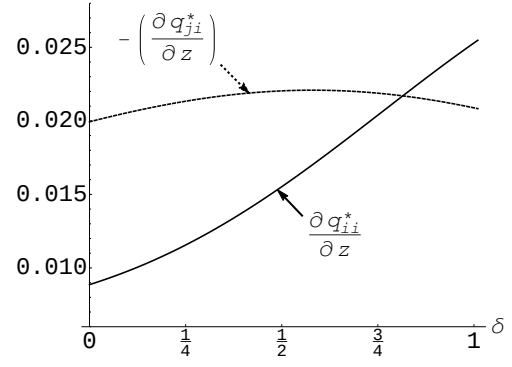
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Panel (a): The area “ $\partial Q_i^* / \partial z > 0$.”



Panel (b): $\partial q_{ii}^* / \partial z$ and $-(\partial q_{ji}^* / \partial z)$
($z = 3$; $a - c = 1$).

Figure 1: Illustration of Proposition 2.

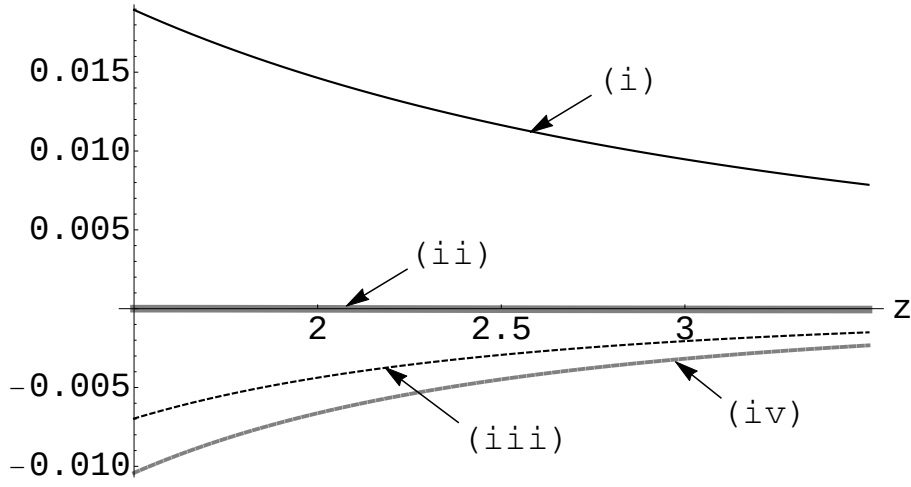
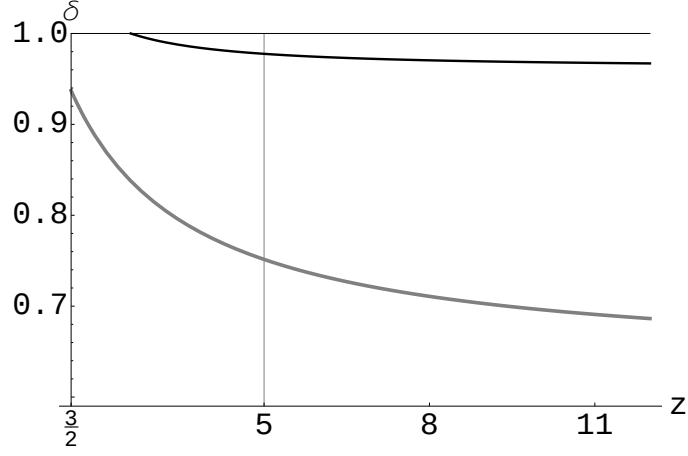
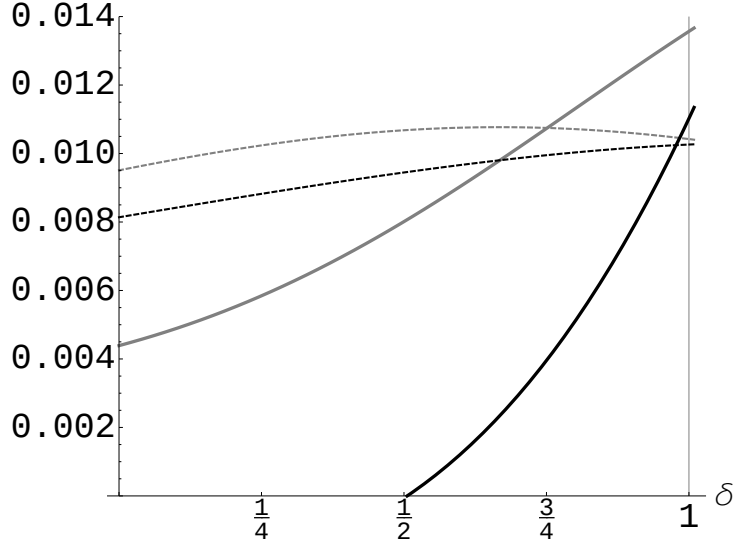


Figure 2: Graph of “(each term)/($a - c$)².” ($\delta = 1/4$)



Panel (a): Two thresholds: δ_{cs}^d (black curve) and δ_{cs} (gray curve).



Panel (b): $\partial q_{ii}^* / \partial z$ (gray curve), $-(\partial q_{ji}^* / \partial z)$ (dashed gray curve), $\partial q_{ii}^{d*} / \partial z$ (black curve), and $-(\partial q_{ji}^{d*} / \partial z)$ (dashed black curve).
Note: These four curves are illustrated where $z = 5$; $a - c = 1$.

Figure 3: Comparison of two cases: price-taker and duopsony.

Supplementary Material (Not for publication)

This supplement provides two additional results (Lemmas 4 and 5) in section 4.

Lemma 4 $t^* > t^{d*} \forall z \geq 3/2$.

Proof. The difference between t^* and t^{d*} is equal to

$$t^* - t^{d*} = \frac{2(a-c)(2z+3)}{EK} [\varphi(\delta)],$$

where

$$\begin{aligned} \varphi(\delta) \equiv & 180 + 627z + 838z^2 + 824z^3 + 384z^4 - 2(36 + 111z + 152z^2 + 148z^3 + 48z^4) \delta \\ & + (72 + 231z + 154z^2 - 64z^3 - 96z^4) \delta^2. \end{aligned}$$

Thus, $\text{sign}\{t^* - t^{d*}\} = \text{sign}\{\varphi(\delta)\}$.

Let $A \equiv 72 + 231z + 154z^2 - 64z^3 - 96z^4$ in $\varphi(\delta)$. Then, from numerical calculation, $A > (=, <) 0$ for $z < (=, >) z_A \simeq 1.55637$. To show that $\varphi(\delta) > 0 \forall z \geq 3/2$, we need to consider the sign of $\varphi(\delta)$ in the following three cases: (i) $A = 0$, (ii) $A > 0$, and (iii) $A < 0$.

Case (i) $A = 0$. When $z = z_A$, $\varphi(\delta)|_{z=z_A}$ is monotonically decreasing with respect to δ . Since $\varphi(\delta = 1)|_{z=z_A} = 5712.19 > 0$, $t^* > t^{d*}$.

Case (ii) $A > 0$. In this case, $\varphi(\delta)$ is downward convex. Solving $\varphi(\delta) = 0$ for δ , we obtain

$$\delta^+, \delta^- = \frac{(36 + 111z + 152z^2 + 148z^3 + 48z^4) \pm 2\sqrt{3}\sqrt{(2z+1)\Gamma}}{72 + 231z + 154z^2 - 64z^3 - 96z^4}$$

and $\Gamma \equiv 1632z^7 + 4096z^6 + 2558z^5 - 3201z^4 - 7992z^3 - 8235z^2 - 4617z - 972$. From numerical calculation, $\Gamma \leq 0$ for $z \leq \tilde{z} \simeq 1.37274$, so $\Gamma > 0$ for all $z \geq 3/2$.

δ^+ and δ^- yield

$$\begin{aligned} \delta^+ - 1 &= \frac{2\{(72z^4 + 106z^3 - z^2 - 60z - 18) + \sqrt{3}\sqrt{(2z+1)\Gamma}\}}{A}, \\ \delta^- - 1 &= \frac{2\{(72z^4 + 106z^3 - z^2 - 60z - 18) - \sqrt{3}\sqrt{(2z+1)\Gamma}\}}{A}. \end{aligned}$$

$72z^4 + 106z^3 - z^2 - 60z - 18 > 0$ for all $z \geq 3/2$, so $\delta^+ - 1 > 0$. Further,

$$\begin{aligned} & (72z^4 + 106z^3 - z^2 - 60z - 18)^2 - \left(\sqrt{3}\sqrt{(2z+1)\Gamma} \right)^2 \\ & = (45 + 159z + 172z^2 + 116z^3 + 48z^4) A > 0. \quad (\text{S1}) \end{aligned}$$

Thus, (S1) yields $\delta^- - 1 > 0$, which implies that $t^* > t^{d*}$ for all $3/2 \leq z < z_A$.

Case (iii) $A < 0$. Since its numerator is positive, $\delta^+ < 0$. By contrast, from the numerator of δ^- , we obtain

$$\begin{aligned} & (48z^4 + 148z^3 + 152z^2 + 111z + 36)^2 - \left(\sqrt{3}\sqrt{(2z+1)\Gamma} \right)^2 \\ & = (384z^4 + 824z^3 + 838z^2 + 627z + 180) A < 0. \end{aligned}$$

Hence, $\delta^- > 0$. On the one hand, from (S1), the numerator of $\delta^- - 1$ is negative, and its denominator, A , is also negative, so $\delta^- - 1 > 0$. Therefore, $t^* > t^{d*}$ for all $z > z_A$. Q.E.D.

Lemma 5 $\partial \Pi_i^{d*} / \partial z > 0 \quad \forall z \geq 3/2$.

Proof. Differentiating Π_i^{d*} with respect to z , we obtain

$$\frac{\partial \Pi_i^{d*}}{\partial z} = \frac{27(a-c)^2(2z+1)^2}{K^3} [\xi(\delta)],$$

where

$$\begin{aligned} \xi(\delta) \equiv & 144z^5 + 1216z^4 + 2138z^3 + 1440z^2 + 378z + 27 \\ & - 3(2z+1)(3z^2+13z+6)(28z^2+30z+9)\delta \\ & + (552z^5 + 2672z^4 + 4222z^3 + 2961z^2 + 837z + 54)\delta^2. \end{aligned}$$

The $\xi(\delta)$ is downward convex. The discriminant of " $\xi(\delta) = 0$ " is $(2z+3)^2(-15984z^8 - 258096z^7 - 785156z^6 - 990908z^5 - 561419z^4 - 82110z^3 + 50841z^2 + 21600z + 2268)$ and it has a negative value for any $z > 0.332382$, so $\xi(\delta) = 0$ does not have real roots and $\xi(\delta) > 0 \quad \forall z \geq 3/2$. This implies $\partial \Pi_i^{d*} / \partial z > 0$. Q.E.D.