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Backfiring with Backhaul Problems: Trade and Industrial Policies with Endogenous Transport Costs (Revised Version of HIAS-E-12)

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Backfiring with Backhaul Problems*

Trade and Industrial Policies with Endogenous Transport Costs

Jota Ishikawa† and Nori Tarui‡

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Abstract

Trade barriers due to transport costs are as large as those due to tariffs. This paper incorporates the transport sector into a standard model of international trade and studies the effects of trade and industrial policies. Transport firms need to commit to a shipping capacity sufficient for a round trip, with a possible imbalance of shipping volumes in two directions. This imbalance is known as the "backhaul problem." As transport firms attempt to avoid this problem, a tariff in one sector may affect other independent import and/or export sectors. In particular, domestic tariffs may backfire: domestic exports may also decrease, harming domestic export sectors and the domestic economy. This finding contributes to the literature on how import liberalization may generate a positive effect on the liberalizing country's exports by identifying a new channel through endogenous changes in transport costs given the backhaul problem.

JEL Codes: F12, F13, R40

Key words: Transport sector; transport cost; backhaul problems; international shipping; tariffs

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1 Introduction

The recent literature on international trade documents the important role of transport costs in terms of both magnitude and economic significance (Estevadeordal et al., 2003; Anderson and van Wincoop, 2004; Hummels, 2007). According to Hummels (2007), studies examining customs data consistently find that transport costs pose a barrier to trade at least as large as, and frequently larger than, tariffs.[1] Hummels (2007) also argues that, "[a]s tariffs become a less important barrier to trade, the contribution of transportation to total trade costs—shipping plus tariffs—is rising."

Despite such clear presence in international trade, the analytical treatment of transport costs tends to be ad hoc. The standard way to incorporate transport costs is to apply the iceberg specification (Samuelson, 1952): the cost of transporting a good is a fraction of the good, where the fraction is given exogenously. Thus this specification implicitly assumes that transport costs are exogenous and symmetric across countries. However, several trade facts indicate that such assumptions are not ideal when studying the impacts of transport costs on international trade. In particular, market power in the transport sector and the asymmetry of trade costs are key characteristics of international transport, as detailed below.

Among the various modes of transport, maritime (sea) transport is the most dominant.[2] Liner shipping, which accounts for about two-thirds of U.S. waterborne foreign trade by value (Fink et al., 2002), is oligopolistic. The top three firms account for more than 40% of the global liner fleet capacity.[3] Liner shipping firms form "conferences," where they agree on the freight rates to be charged on any given route.[4] An empirical investigation by Hummels et al. (2009) find that ocean cargo carriers charge higher prices when transporting goods with higher product prices, lower import demand elasticities, and higher tariffs, and when facing fewer competitors on a trade route—all indicating market power in the shipping industry.[5] Air cargo, whose share in the value of global trade has been increasing, is also oligopolistic (Weiher et al., 2002).[6] The prediction of standard trade theory without a transport sector,

[1] Anderson and van Wincoop (2004) estimate that the ad-valorem tax equivalent of freight costs for industrialized countries is 10.7 percent while that of tariffs and nontariffs is 7.7 percent.

[2] For example, waterborne transport accounted for more than 75% in volume (46% in value) of U.S. international merchandise trade in 2011 (U.S. Department of Transportation, 2013, Figure 3-4). Globally, maritime transport handles over 80% (70%) of the total volume (value) of global trade (United Nations, 2012, p.44).

[3] Based on the Alphaliner Top 100, `www.alphaliner.com/top100/`.

[4] De Palma et al. (2011) provide evidence of market power in various transportation sectors.

[5] Regulations may also be responsible for enhancing transport firms' market power. Under the Merchant Marine Act (also known as the Jones Act) of 1920 in the United States, for example, vessels that transport cargo or passengers between two U.S. ports must be U.S. flagged, U.S. crewed, U.S. owned and U.S. built. Debates exist over the impact of the Act on the U.S. ocean shipping costs.

[6] Top 25 air cargo carriers are found in http://www.aircargonews.net/news/airlines/single-view/news/top-

with exogenous transport costs, may be altered once we consider the markets for transportation explicitly by taking into account the market power of transport firms in influencing shipping costs.[7]

Trade costs exhibit asymmetry in several dimensions. First, developing countries pay substantially higher transport costs than developed nations (Hummels et al., 2009; Waugh, 2010). Second, depending on the direction of shipments, freight charges differ on the same route. For example, the market average freight rates for shipping from Asia to the United States was about 1.5 times the rates for shipping from the United States to Asia in 2009 (United Nations Conference on Trade and Development, 2010).[8] This fact is also at odds with the assumption of iceberg transport costs in the standard trade theory.

Such asymmetry of transport costs may have substantial economic consequences. For example, Waugh's (2010) empirical analysis suggests that "[t]he systematic asymmetry in trade costs is so punitive that removing it takes the economy from basically autarky to over 50 percent of the way relative to frictionless trade" (p.2095). Asymmetric transport costs are associated with the "backhaul problem," a widely known issue regarding transportation: shipping is constrained by the capacity (e.g., the number of containers) of each transport firm, and hence firms need to commit to the capacity necessary for the maximum load of a round-trip. This implies an opportunity cost associated with a trip (the backhaul trip) with cargo that is under-capacity.[9] To avoid the backhaul problem, that is, to have the balance in shipping volume in both directions, transport firms adjust shipping capacities and freight rates.

Attempts to incorporate transportation in general equilibrium trade models show the challenges associated with defining simultaneous market clearing for the goods to be traded and the transport services to be required (Kemp, 1964; Wegge, 1993; Woodland, 1968). They assume a competitive transport sector without explicit attention to shipping capacity constraints. Thus, neither the market power in the transport sector nor the backhaul problems are considered.

Several recent studies have developed trade models that incorporate an explicit transport sector in a tractable manner. Behrens and Picard (2011) apply a new economic geography model to show that, because a region that is a net exporter of manufactured goods faces a higher transportation costs due to the backhaul problem, the agglomeration forces are

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[7]Deardorff (2014) demonstrates that, even without an explicit transport sector, considering transport costs may alter the pattern of trade.

[8]Takahashi (2011) and Behrens and Picard (2011) provide several examples where freight costs exhibit asymmetry.

[9]Dejax and Crainic (1987) provide an early survey of the research on backhaul problems in transportation studies.

weakened given endogenous transport costs. While they assume a perfectly competitive transport sector with explicit shipping capacity, several other studies consider market power in the transport sector (without taking into account the constraint on the shipping capacity). Behrens et al. (2009), Takahashi (2011) and Forslid and Okubo (2015) address the implication of endogenous transport costs on agglomeration and dispersion forces. Abe et al. (2014) focus on pollution from international shipping and analyze the optimal pollution regulation. Takauchi (2015) examines the relationship between freight rates and R&D efficiency.

Existing studies have not investigated the impacts of trade and industrial policies in the presence of a transport sector with backhaul problems (or with its capacity constraint). Our point of departure is an investigation of how the effects of trade and industrial policies change once the transport sector and its decision making are considered explicitly.

For this purpose, we incorporate a transport sector into a standard model of international trade with perfectly competitive markets of traded goods. In the basic model, we assume a monopolistic transport firm to capture market power in a simple manner.[10] We investigate the effects of tariffs and a tax on the transport firm on trade and welfare. We do so by taking into account how each policy influences the volume of trade and the freight rates endogenously, with the backhaul problem being considered explicitly.[11]

Our model with an explicit transport sector with market power illustrates how transport costs are determined endogenously, with possible asymmetry between domestic and foreign countries. In particular, when a gap in the demand size exists between the two countries, the country with the lower demand faces higher freight costs on shipping (provided the price elasticity of shipping demand is not too different between the two countries). This theoretical prediction is consistent with Waugh's (2010) finding that countries with lower income tend to face higher export costs. Furthermore, when a gap in the price elasticity of shipping demand exists between the two countries, the country with the higher elasticity faces higher freight costs on shipping (provided the demand for shipping is not too different between the two countries).

Our analysis demonstrates that an explicit consideration of a transport sector changes

[10]In fact, a monopolistic transport firm can be justified by Hummels et al. (2009). They report: "In the fourth quarter 2006 one in six importer–exporter pairs world-wide was served by a single direct liner "service", meaning that only one ship was operating on that route. Over half of importer–exporter pairs were served by three or fewer ships, and in many cases all of the ships on a route were owned by a single carrier".

[11]As Demirel et al. (2010) argue, most studies that consider the backhaul problem assume that the transportation sector is competitive and hence predict that the equilibrium backhaul price is zero when there is imbalance in shipping volume in both directions over a given route. This is the case for Behrens and Picard (2011). Demirel et al. (2010) offer a matching model to generate equilibrium transport prices that may differ but are positive for both directions. Our model, with the transportation firms having market power, also supports positive equilibrium transport prices.

the prediction of the effects of trade policies based on standard trade models. In particular, a country's trade policy may backfire: domestic import restrictions may also decrease domestic exports and harm the domestic export sectors while benefiting the foreign import sectors. These results are due to transport firm's endogenous response to trade policy. A transport firm with market power makes decisions on two margins: the freight rate to be charged for each direction and the capacity for transport. With changes in trade restrictions, the transport firm makes adjustments only in the freight rates, or in both the freight rates and the capacity, depending on the stringency of the trade policy. When the transport firm avoids the backhaul problem, a policy that affects one trip may influence the return trip through a linkage due to endogenous transport. Thus an increase in a country's import tariff can reduce its exports, thereby generating the backfiring effect described above. We also demonstrate such policy linkages when the transport sector's shipping capacity is taxed.

The backfiring effects of tariffs also imply that a country that reduces its import tariffs may enhance not only its imports but its exports. Thus this paper contributes to the literature on how import liberalization may generate a positive effect on the liberalizing country's exports (e.g., Cruz and Bussolo 2015) by identifying a new route, i.e., via endogenous changes in the transport costs given backhaul problems.

Our basic model consists of a monopolistic transport firm, a single export sector and a single import sector in each country. Investigating this simple case allows us to explain the economic intuitions of our main results (Propositions 2-3) in a transparent manner. We then consider extensions and check the robustness of our results. In one extension, we investigate a case with multiple transport firms. In another extension, we consider multiple exportable goods. In these extensions, besides the backfiring effects, we obtain a few additional results.

Most importantly, we confirm that the main backfiring results that we find with a monopolistic transport firm hold with oligopolistic transport firms. Indeed, the result is more generalized: as long as one of the transport firms avoids the backhaul problem, an increased tariff by a trading partner could decrease both exports and imports. The basic welfare impacts remain the same as in the base case because the total shipping volume (instead of shipping by individual transport firms) matters for computing changes in consumer and producer surpluses. The effect of taxes on shipping capacity is also the same qualitatively when there are multiple shipping firms. In the case of multiple exportable goods, a tariff in one sector may affect other sectors even when the goods are independent (i.e., neither substitutes nor complements). In particular, a domestic tariff in one sector could hurt the other domestic import sectors and benefit the other foreign export sectors.

In what follows, Section 2 describes our trade model with an endogenous transport sector. Section 3 studies the impacts of tariffs and taxes on shipping capacity on trade volume and welfare. We provide extensions of our analysis when there are multiple carriers (Section 4) and when there are multiple exportable goods (Section 5). Section 6 discusses alternative international product market structures and the case of India's trade liberalization in the 1990s to see whether our theoretical results are consistent with it. Section 7 concludes the paper with a discussion on further research.

2 A trade model with a transport sector

There are two countries A and B. A single transport firm (firm T) supplies transport services between the two countries.[12] Firm T faces the following inverse demand:

$$T_{AB} = \Omega_B - \mu_B x_{AB},\ T_{BA} = \Omega_A - \mu_A x_{BA}, \tag{1}$$

where T_{ij} and x_{ij} are respectively the freight rate when shipping goods from country i to country j and the quantity demanded for transport services from country i to country j. The parameters $\Omega_A, \Omega_B, \mu_A$,and μ_B are all positive scalars. We assume that both Ω_A and Ω_B are large enough to have both $x_{AB} > 0$ and $x_{BA} > 0$ in the rest of the analysis. We assume that the freight rate is linear and additive by following the empirical findings supporting this specification.[13]

The costs of firm T, C, are given by

$$C = f + r\kappa,$$

where r, f, and κ are, respectively, the marginal cost (MC) of operating a means of transport such as vessels or containers, the fixed cost (FC), and the capacity (or, the maximum load, i.e., $\max\{x_{AB}, x_{BA}\} = \kappa$). In the following analysis, the MC plays a crucial role while the FC does not. Thus, we assume $r > 0$ and $f = 0$ for simplicity. Firm T chooses the shipping capacity κ and the freight rates T_{AB} and T_{BA} in order to maximize its profit:

$$\Pi_T = T_{AB}x_{AB} + T_{BA}x_{BA} - r\kappa.$$

The profit maximization generates three cases. First, if $x_{AB} > x_{BA}$ holds in equilibrium

[12]Firm T may be located in country A, country B, or a third country. The location becomes crucial when analyzing welfare.

[13]Using multi-country bilateral trade data at the 6-digit HS classification, Hummels and Skiba (2004) find that shipping technology for a single homogeneous shipment more closely resembles per unit, rather than ad-valorem, transport costs. Using Norwegian data on quantities and prices for exports at the firm/product/destination level, Irarrazabal et al. (2015) find the presence of additive (as opposed to ice-berg) trade costs for a large majority of product-destination pairs.

(this case is referred to as type 1 in the following), then we have

$$\Pi_T = T_{AB}x_{AB} + T_{BA}x_{BA} - rx_{AB} = (\Omega_B - \mu_B x_{AB})x_{AB} + (\Omega_A - \mu_A x_{BA})x_{BA} - rx_{AB}.$$

The equilibrium (type-1 equilibrium) under free trade is given by

$$T_{AB}^{F1} = \frac{\Omega_B + r}{2},\ T_{BA}^{F1} = \frac{\Omega_A}{2},\ x_{AB}^{F1} = \frac{\Omega_B - r}{2\mu_B},\ x_{BA}^{F1} = \frac{\Omega_A}{2\mu_A}.$$

The condition for type 1 is $x_{AB}^{F1} > x_{BA}^{F1}$, which is $\mu_A(\Omega_B - r) > \mu_B\Omega_A$. Both X_{BA} and the freight rate from country B to country A, T_{BA}, are independent of the MC of operating a means of transport, r, in this case.

Second, if $x_{AB} < x_{BA}$ holds in equilibrium (this case is referred to as type 3 in the following), then we have

$$\Pi_T = T_{AB}x_{AB} + T_{BA}x_{BA} - rx_{BA}.$$

Type-3 equilibrium is

$$T_{AB}^{F3} = \frac{\Omega_B}{2},\ T_{BA}^{F3} = \frac{\Omega_A + r}{2},\ x_{AB}^{F3} = \frac{\Omega_B}{2\mu_B},\ x_{BA}^{F3} = \frac{\Omega_A - r}{2\mu_A}.$$

The condition for type 3 is $\mu_B(\Omega_A - r) > \mu_A\Omega_B$. In this case, both X_{AB} and T_{AB} are independent of r.

Lastly, if $x_{AB} = x_{BA}$ holds in equilibrium (this case is referred to as type 2 in the following), which arises when both $\mu_A(\Omega_B - r) \leq \mu_B\Omega_A$ and $\mu_B(\Omega_A - r) \leq \mu_A\Omega_B$ hold (i.e., $\mu_A\Omega_B - \mu_A r \leq \mu_B\Omega_A \leq \mu_A\Omega_B + \mu_B r$ holds), then we have

$$\Pi_T = T_{AB}x_{AB} + T_{BA}x_{AB} - rx_{AB}.$$

Type-2 equilibrium is given by

$$\begin{aligned}
T_{AB}^{F2} &= \frac{1}{2(\mu_A + \mu_B)}\left(r\mu_B - \Omega_A\mu_B + 2\Omega_B\mu_A + \Omega_B\mu_B\right), \\
T_{BA}^{F2} &= \frac{1}{2(\mu_A + \mu_B)}\left(r\mu_A + \Omega_A\mu_A + 2\Omega_A\mu_B - \Omega_B\mu_A\right), \\
x_{AB}^{F2} &= x_{BA}^{F2} = \frac{\Omega_A + \Omega_B - r}{2(\mu_A + \mu_B)}.
\end{aligned}$$

In contrast to type-1 and type-3 equilibria, both T_{AB} and T_{BA} depend on r. However, they are not equal in general.

In the following analysis, we assume $x_{AB} \geq x_{BA}$ without loss of generality. There are two types of equilibrium with $x_{AB} \geq x_{BA}$. In type 1, there is a large demand gap between the two countries, implying an excess shipping capacity from country B to country A. That is, a full load is not realized for shipping from country B to country A. In type 2, the demand gap is relatively small. Thus, firm T adjusts its freight rates so that it does not have an excess shipping capacity, i.e., it realizes a full load in both directions. Obviously, type-2 equilibrium arises if the two markets are identical. Firm T faces the backhaul problem in the type-1 equilibrium but avoids the problem in the type-2 equilibrium.

Our result is consistent with Hummels et al. (2009), who find that freight rates are higher as the market size of importing countries becomes larger and as the price elasticity of import demand becomes lower. Observe from the type-1 equilibrium that a larger Ω_i ($i = A, B$) means a larger market, indicating that the freight rate for shipping to a country with a larger Ω_i tends to be higher. However, $T_{AB}^{F1} < T_{BA}^{F1}$ could arise even if $x_{AB}^{F1} > x_{BA}^{F1}$, that is, the freight rate could be higher even with excess shipping capacity. This stems from the difference in the price elasticities of the demand for shipping (which are characterized by μ_i, $i = A, B$, and are positively correlated with the price elasticity of import demand). Even if the demand for shipping is relatively large, firm T may set a low freight rate when its price elasticity is relatively large.

Figure 1 here

Since we started with the derived demand for transportation, the above result holds regardless of product market competition. Figure 1 specifically depicts the case of perfect competition.[14] Suppose that country i exports good i ($i = A, B$). For simplicity, we assume that goods are neither substitutes nor complements and that shipping one unit of good i requires one unit of shipping capacity. In Figure 1, the upper panel shows the export supply curve of good A, EX_A, which is excess supply of good A in country A, and the import demand curve of good A, IM_A, which is excess demand for good A in country B. With these two curves, noting one unit of shipping capacity is required to export one unit of good A from country A to country B, we can draw the demand for transportation services from country A to country B, DD_{AB}, which is a gap between IM_A and EX_A (see the lower panel). Facing this demand curve (i.e., (1)), firm T determines the freight rate, T_{AB}^F, and the shipping load, x_{AB}^F.[15] The prices of good A in country A and in country B are, respectively, given by P_{AA}^F and P_{AB}^F. The gap between the two prices is T_{AB}^F, i.e., $T_{AB}^F = P_{AB}^F - P_{AA}^F$.

[14] We analyze the case of an international oligopoly in the product market in detail elsewhere (Ishikawa and Tarui, 2015). See Section 6.1.

[15] In type-1 equilibrium, point F_B is the midpoint on the demand curve, because T_{BA}^{F1} does not depend on the MC, r. Point F_A is located to the upper left of the midpoint.

Recalling shipping one unit of good requires one unit of shipping capacity, we can easily verify who gains or loses from free trade by checking how producer surplus and consumer surplus change. In country i ($i = A, B$), free trade benefits producers of good i but harms consumers of good i. In Figure 1, the net gain in the product market of good A in country A is given by dcP_{AA}^F. In country B, free trade harms producers of good A but benefits consumers of good A. The net gain in the product market of good A in country B is given by abP_{AB}^F. The revenue of firm T from shipping good A from country A to country B is given by $bcP_{AA}^F P_{AB}^F$.

Figure 2 here

Type-2 equilibrium is shown in Figure 2. The upper panel and the lower panel show trade in good A and trade in good B, respectively. Firm T adjusts freight rates, T_{AB} and T_{BA} so as to have a full load in both directions (i.e., $x_{AB}^F = x_{BA}^F$). We can easily confirm the net gains from free trade in goods A and B and the revenue of firm T in the figures.

3 Trade and Industrial Policies

In this section, we first explore the effects of import tariffs on the freight rates and the equilibrium welfare of the trading countries.[16] Then we examine taxes on shipping capacity as an example of industrial policies because taxing imports and shipping capacity exhibit similar performance. Without loss of generality, we still assume that $x_{AB} \geq x_{BA}$ holds under free trade.

3.1 Tariffs

We begin with import tariffs on goods. We assume that product markets are perfectly competitive and that country i exports good i ($i = A, B$). Suppose that a specific tariff, the rate of which is τ_i ($i = A, B$), is imposed by country i. Then the inverse demand curve shifts downward by τ_i:

$$\begin{aligned} T_{AB} &= (\Omega_B - \tau_B) - \mu_B x_{AB} = \Omega_B^\tau - \mu_B x_{AB}, \\ T_{BA} &= (\Omega_A - \tau_A) - \mu_A x_{BA} = \Omega_A^\tau - \mu_A x_{BA}, \end{aligned}$$

where $\Omega_B^\tau \equiv \Omega_B - \tau_B$ and $\Omega_A^\tau \equiv \Omega_A - \tau_A$.

[16] The effects of import quotas are similar to those of tariffs. See Ishikawa and Tarui (2015).

Type-1 equilibrium with tariffs is given by

$$\begin{aligned} T_{AB}^{\tau 1} &= \frac{(\Omega_B - \tau_B) + r}{2} = \frac{\Omega_B^\tau + r}{2},\ T_{BA}^{\tau 1} = \frac{(\Omega_A - \tau_A)}{2} = \frac{\Omega_A^\tau}{2}, \\ x_{AB}^{\tau 1} &= \frac{(\Omega_B - \tau_B) - r}{2\mu_B} = \frac{\Omega_B^\tau - r}{2\mu_B},\ x_{BA}^{\tau 1} = \frac{(\Omega_A - \tau_A)}{2\mu_A} = \frac{\Omega_A^\tau}{2\mu_A}. \end{aligned}$$

An increase in τ_i decreases x_{ji} and increases x_{ii} $(i, j = A, B, i \neq j)$, but affects neither x_{ij} nor x_{jj}. This is the conventional effects of tariffs when goods A and B are neither substitutes nor complements. An increase in τ_i decreases T_{ji} but the total trade costs from country j to country i, which equal $T_{ji} + \tau_i$, increase.

Type-2 equilibrium with tariffs is given by

$$T_{AB}^{\tau 2} = \frac{1}{2(\mu_A + \mu_B)} \left(r\mu_B - \Omega_A^\tau \mu_B + 2\Omega_B^\tau \mu_A + \Omega_B^\tau \mu_B \right), \tag{2}$$

$$T_{BA}^{\tau 2} = \frac{1}{2(\mu_A + \mu_B)} \left(r\mu_A + \Omega_A^\tau \mu_A + 2\Omega_A^\tau \mu_B - \Omega_B^\tau \mu_A \right), \tag{3}$$

$$x_{AB}^{\tau 2} = x_{BA}^{\tau 2} = \frac{\Omega_A^\tau + \Omega_B^\tau - r}{2(\mu_A + \mu_B)}. \tag{4}$$

In this equilibrium, the shipping capacity is binding in both directions. We can easily verify that an increase in τ_i increases the trade costs not only from country j to country i, $T_{ji} + \tau_i$, but also from country i to country j, T_{ij}. Thus, both x_{ji} and x_{ij} decrease and both x_{ii} and x_{jj} increase $(i, j = A, B, i \neq j)$. This is in contrast to type-1 equilibrium, in which an increase in τ_i affects the supplies only in country i, that is, an increase in τ_i decreases x_{ji} and increases x_{ii}. An increase in τ_i decreases x_{ji} in both types of equilibrium. In type-2 equilibrium, however, the shipping capacity is reduced to be equal to x_{ji} and hence x_{ij} also decreases. Thus an increase in the import tariff generates a "backfiring effect" on the export quantity.

Even if $x_{AB} \geq x_{BA}$ holds under free trade, $x_{AB} < x_{BA}$ may arise with tariffs. That is, tariffs may shift the equilibrium from type 1 to type 3 or from type 2 to type 3. Type-3 equilibrium with tariffs is given by

$$T_{AB}^{\tau 3} = \frac{\Omega_B^\tau}{2}, T_{BA}^{\tau 3} = \frac{\Omega_A^\tau + r}{2},\ x_{AB}^{\tau 3} = \frac{\Omega_B^\tau}{2\mu_B},\ x_{BA}^{\tau 3} = \frac{\Omega_A^\tau - r}{2\mu_A}.$$

As in type-1 equilibrium, an increase in τ_i in type-3 equilibrium decreases x_{ji} and increases x_{ii} $(i, j = A, B, i \neq j)$, but affects neither x_{ij} nor x_{jj}.

Figure 3 here

The above cases are illustrated in Figure 3. The figure shows the relationship between

τ_B and the volumes of trade, i.e. x_{AB} and x_{BA}, with $\tau_A = 0$.[17] The free trade equilibrium is given by F_A and F_B in Figure 3 (a) and by F in Figure 3 (b). In Figure 3 (a), as τ_B increases, only x_{AB} decreases with $0 \leq \tau_B < \frac{1}{\mu_A}(\Omega_B\mu_A - \Omega_A\mu_B - r\mu_A)$. Both with $0 \leq \tau_B < \frac{1}{\mu_A}(\Omega_B\mu_A - \Omega_A\mu_B - r\mu_A)$ and with $\frac{1}{\mu_A}(\Omega_B\mu_A - \Omega_A\mu_B + r\mu_A) < \tau_B < \Omega_B$, x_{BA} is independent of τ_B. With $\frac{1}{\mu_A}(\Omega_B\mu_A - \Omega_A\mu_B - r\mu_A) \leq \tau_B \leq \frac{1}{\mu_A}(\Omega_B\mu_A - \Omega_A\mu_B + r\mu_A)$, $x_{AB} = x_{BA}$ holds and an increase in τ_B reduces both x_{AB} and x_{BA}. In Figure 3 (b), with $0 \leq \tau_B \leq \frac{1}{\mu_A}(\Omega_B\mu_A - \Omega_A\mu_B + r\mu_A)$, both x_{AB} and x_{BA} decrease together as τ_B increases. With $\frac{1}{\mu_A}(\Omega_B\mu_A - \Omega_A\mu_B + r\mu_A) < \tau_B < \Omega_B$, when τ_B rises, x_{AB} falls but x_{BA} is constant.

In Figure 3, the equilibrium shifts from type 1 to type 2 and then to type 3 or from type 2 to type 3. Type-1 equilibrium arises if $0 < \tau_B < \frac{1}{\mu_A}(\Omega_B\mu_A - \Omega_A\mu_B - r\mu_A)$, type-2 equilibrium arises if $\max\{0, \frac{1}{\mu_A}(\Omega_B\mu_A - \Omega_A\mu_B - r\mu_A)\} \leq \tau_B \leq \frac{1}{\mu_A}(\Omega_B\mu_A - \Omega_A\mu_B + r\mu_A)$, and type-3 equilibrium arises if $\frac{1}{\mu_A}(\Omega_B\mu_A - \Omega_A\mu_B + r\mu_A) < \tau_B < \Omega_B$.

The above results are summarized in the following proposition.

Proposition 1 *If country i imposes a tariff, τ_i, firm T lowers the freight rate from country j to country i, T_{ji} $(i, j = A, B, i \neq j)$ and mitigates the effects of the tariff. However, the trade costs, $\tau_i + T_{ji}$, increase and country j's shipping quantity decreases.*

Proposition 2 *Suppose $x_{AB} > x_{BA}$ holds under the free-trade equilibrium. Any tariff of country B, which leads to $x_{AB} \leq x_{BA}$, increases the freight rate from country B to country A and decreases not only country B's imports but also country B's exports. Suppose $x_{AB} = x_{BA}$ holds under the free-trade equilibrium. Then any tariff of country $B(A)$ increases the freight rate from country $B(A)$ to country $A(B)$ and decreases country $B(A)$'s exports as well as country $B(A)$'s imports.*

It should be pointed out that linear demands are not crucial for the above propositions. Appendix A shows (i) $\frac{dT_{ji}}{d\tau_i} < 0$ holds if demand for shipping from country j to country i is not very convex, (ii) $\frac{d(T_{ji}+d\tau_i)}{d\tau_i} > 0$ necessarily holds, and (iii) $\frac{dT_{ij}}{d\tau_i} = 0$ holds in type-1 and type-3 equilibria while $\frac{dT_{ij}}{d\tau_i} > 0$ holds in type-2 equilibrium. Thus, regardless of demand specifications, the backfiring effect of a tariff (i.e., $\frac{dT_{ij}}{d\tau_i} > 0$) necessarily arises in type-2 equilibrium.

The effects of country B's tariff are shown in Figure 1. When a specific tariff, τ_B, is imposed, the import demand curve of good A, IM_A, and hence the demand curve of transport services from country A to country B, DD_{AB}, shift down by τ_B. Then the freight rate and the capacity are now given by point τ in the lower panel. The freight rate decreases.

[17] If $x_{AB} = x_{BA}$ holds with free trade, the relationship between τ_A and the volumes of trade with $\tau_B = 0$ is similar to Figure 3 (b). If $x_{AB} > x_{BA}$ holds with free trade, however, an increase in τ_A simply decreases x_{BA} without affecting x_{AB} at all.

However, the decrease in the freight rate is less than the tariff rate, implying that the total trade costs from country A to country B increase and the shipping-load decreases. The total trade costs from country A to country B are given by $T^t_{AB}(= T^\tau_{AB} + \tau_B)$. Therefore, as shown in the upper panel, the price of good A in country B (importing country) rises from P^F_{AB} to P^τ_{AB} and the price of good A in country A (exporting country) falls from P^F_{AA} to P^τ_{AA}.

Next we examine the welfare effects of country B's tariffs with the aid of Figure 1.[18] Welfare is measured by the total surplus (i.e., the sum of consumer surplus, producer surplus and tariff revenue). We begin with the case in which the profits of firm T are not included in welfare.[19] Compared with autarky, free trade increases the total surplus in the market of good A by the area abP^F_{AB} in country B and by the area cdP^F_{AA} in country A. When the tariff, τ_B, is imposed under free trade, the sum of consumer surplus and producer surplus in the market of good A decreases by the area $b'bP^F_{AB}P^\tau_{AB}$ in country B and by the area $cc'P^\tau_{AA}P^F_{AA}$ in country A. The tariff also generates tariff revenue, TR_B for country B and improves the terms of trade of country B. In the market of good A in country B, the total surplus increases as long as the tariff rate is small. In the market of good A in country A, the total surplus decreases. These changes in surpluses are basically the conventional optimal-tariff argument and they are the only changes if type-1 equilibrium is realized with the tariff.

If type-2 or type 3 equilibrium arises with country B's tariff, we have to take the other market (i.e., the market of good B) into account when analyzing welfare. Because of a decrease in the shipping capacity, country B's tariff decreases not only exports of good A from country A to country B but also exports of good B from country B to country A. As a result, the price of good B in country B falls. This benefits consumers of good B in country B and producers of good B in country A but harms producers of good B in country B and consumers of good B in country A. In fact, the sum of consumer surplus and producer surplus in the market of good B decreases in both countries. Country B's tariff may not improve country B's terms of trade. For country A, the deterioration of its terms of trade is magnified because not only the export price falls but also the import price rises.

Figure 2 shows the case where type-2 equilibrium arises with and without the tariff.[20] As shown in the lower panel of Figure 2, the tariff decreases the total surplus in the market of good B by the area δ in country B and by the area ε in country A. In country B, therefore, the total surplus in the market of good A increases if the area β is greater than the area γ, but the total surplus in the market B necessarily decreases. The net change in the total

[18]The welfare effects of country A's tariffs are analogous to those of country B's tariffs.

[19]This is the case if the transport firms are located in a third country.

[20]If type-3 equilibrium arises as a result of country B's tariff, $x_{BA} > x_{AB}$ holds but the qualitative results would not change.

surplus, or, welfare, which is the area $(\beta - \gamma - \delta)$, may be negative. The analysis here indicates another backfiring effect: an increase in country B's import tariff harms its export sector and hence may reduce country B's welfare even if the tariff is small. In country A, the total surplus decreases by the area $(\alpha + \varepsilon)$.

We now consider the changes in the profits of firm T. It is obvious that firm T loses from any tariff, because tariffs reduce the demand for transport services. Thus, the location of firm T is crucial for welfare evaluation. In particular, even if a tariff set by country B under free trade is small, country B's welfare necessarily deteriorates when it includes firm T's profits (see Appendix B for the proof). It is obvious that country B's tariffs worsen country A's welfare farther when it includes firm T's profits.

Thus, we can establish the following proposition.

Proposition 3 *Suppose that country $B(A)$ sets a small tariff under free trade. In the case where $x_{AB} > x_{BA}$ holds under both free trade and the tariff, country $B(A)$'s welfare improves if and only if firm T is not located in country $B(A)$. However, in the other cases, country $B(A)$'s welfare may not improve even if firm T is not located in country $B(A)$. In both cases, country $A(B)$ always loses form country $B(A)$'s tariff.*

3.2 Taxes on Shipping Capacity

In this subsection, we compare a specific tax, t, on shipping capacity with tariffs.[21]

With the tax, the effective MC for firm T becomes $r+t$. In type-1 equilibrium, an increase in the effective MC affects only T_{AB} and x_{AB}. T_{AB} increases and x_{AB} decreases. We can verify that if country B sets a tax on shipping capacity, the tax is basically equivalent to country B's tariff on good A in type-1 equilibrium. With $t = \tau_B$, we have $T_{AB}^{t1} \neq T_{AB}^{\tau 1}$ (where t stands for the tax equilibrium) but the trade costs are the same, i.e., $T_{AB}^{t1} = T_{AB}^{\tau 1} + \tau_B$ and hence $x_{AB}^{t1} = x_{AB}^{\tau 1}$ holds. In Figure 1, the freight rate and the capacity are indicated by point t in the lower panel. Thus, country B's tax on shipping capacity is equivalent to country B's tariff on good A. If country A sets the tax instead, its effects on consumers, producers and firm T are the same with the effects of country B's tariff but tax revenue accrues to country A's government.

We should note that the effects of country A's tariff on good B are different from those of a shipping-capacity tax in type-1 equilibrium, because in type-1 equilibrium, τ_A affects only T_{BA} and x_{BA} while t affects only T_{AB} and x_{AB}. It is straightforward that in type-3 equilibrium, country A's shipping-capacity tax and country A's tariff are equivalent with

[21] When country i imposes a tax on shipping capacity of firm T, we implicitly assume that firm T is located in country i.

$t = \tau_A$ but the equivalence does not hold between country B's shipping-capacity tax and country B's tariff.[22]

In type-2 equilibrium, a specific tax on shipping capacity increases both T_{AB} and T_{BA} and decreases x_{AB} and x_{BA}. We can easily verify that $T_{AB}^{t2} = T_{AB}^{\tau 2} + \tau_B$ and $T_{BA}^{t2} = T_{BA}^{\tau 2} + \tau_A$. Also the effects on x_{ji} are the same between a shipping-capacity tax and country i's tariff, τ_i $(i, j = 1, 2; i \neq j)$. Thus, we obtain the following proposition.

Proposition 4 *Country B's shipping-capacity tax and country B's tariff set at the same levels are equivalent in type-1 and type-2 equilibria. Similarly, country A's shipping-capacity tax and country A's tariff set at the same levels are equivalent in type-2 and type-3 equilibria.*

The above proposition implies that in type-1(type-3) and type-2 equilibria, country $B(A)$ can substitute the tax for a tariff if country $B(A)$ can impose the tax on firm T.

4 Multiple Carriers

In this section, we extend the basic model to the case with multiple carriers and investigate how the results in the basic model (i.e., the case with a single carrier) are modified. We assume that there are two transport firms: firm T_1 and firm T_2 and that these firms are engaged in Cournot competition. Without loss of generality, we assume that $0 < r_1 \leq r_2$, where r_h $(h = 1, 2)$ is the MC of operating a means of transport for firm T_h. In (1), we have $x_{AB} = x_{1AB} + x_{2AB}$ and $x_{BA} = x_{1BA} + x_{2BA}$. We focus on the case in which both firms T_1 and T_2 supply positive transport services.

Appendix C shows that there are five possible equilibria with $r_1 < r_2$, which are stated in the following lemma (see the upper panel of Figure 4).

Lemma 1 *Type 1) $x_{1AB} > x_{1BA}$ and $x_{2AB} > x_{2BA}$ hold if $\Lambda\,(\equiv \Omega_A^\tau \mu_B - \Omega_B^\tau \mu_A) < \mu_A (r_1 - 2r_2)$; Type 2) $x_{1AB} = x_{1BA}$ and $x_{2AB} = x_{2BA}$ hold if $-\mu_A r_1 \leq \Lambda \leq \mu_B r_1$; Type 3) $x_{1AB} < x_{1BA}$ and $x_{2AB} < x_{2BA}$ hold if $\mu_B (2r_2 - r_1) < \Lambda$; Type 4) $x_{1AB} > x_{1BA}$ and $x_{2AB} = x_{2BA}$ hold if $\mu_A (r_1 - 2r_2) \leq \Lambda < -\mu_A r_1$; and Type 5) $x_{1AB} < x_{1BA}$ and $x_{2AB} = x_{2BA}$ hold if $\mu_B r_1 < \Lambda \leq \mu_B (2r_2 - r_1)$.*

Figure 4 here

[22]Since we have assumed $x_{AB} \geq x_{BA}$ with free trade, type-3 equilibrium does not arise with country A's tariff alone. We implicitly assume that country B also imposes a tariff in the analysis of country A's tariff in type-3 equilibrium.

If $r_1 = r_2$, only three types of equilibrium are possible, i.e., $x_{1AB} > x_{1BA}$ and $x_{2AB} > x_{2BA}$ (type 1), $x_{1AB} = x_{1BA}$ and $x_{2AB} = x_{2BA}$ (type 2), and $x_{1AB} < x_{1BA}$ and $x_{2AB} < x_{2BA}$ (type 3). If $r_1 < r_2$, we have two more types, i.e., $x_{1AB} > x_{1BA}$ and $x_{2AB} = x_{2BA}$ (type 4) and $x_{1AB} < x_{1BA}$ and $x_{2AB} = x_{2BA}$ (type 5). This implies that firm T_1 is more likely to operate without a full load in equilibrium. With given r_2, as r_1 becomes smaller, the range of type-2 equilibrium becomes smaller and the ranges of type-4 and type-5 equilibria become larger. Thus, as r_1 becomes small relative to r_2, the range in which firm T_1 has a full load becomes smaller while the range in which firm T_2 has a full load becomes larger. The economic intuition behind this result is as follows. The MC of operating a means of transport is lower for firm T_1 than for firm T_2, implying that the cost to operate shipping without a full load is lower for firm T_1 than for firm T_2. Thus, firm T_1 has less incentive to adjust freight rates to have a full load in both directions. The following proposition is immediate.

Proposition 5 *With $r_1 < r_2$, the range of parameterization for operating without a full load is larger for firm T_1 than for firm T_2.*

Figure 4 (the middle panel) also shows the relationship between five types of equilibrium and country B's tariff rates (with $\tau_A = 0$). Since $x_{1ij} > 0$ and $x_{2ij} > 0$ $(i, j = A, B)$, τ_B must satisfy $0 \le \tau_B < \Omega_B$. The free trade equilibrium is determined by $\tau_B = 0$. For example, if $-\frac{1}{\mu_A}(\Omega_A\mu_B - \Omega_B\mu_A - \mu_A r_1 + 2\mu_A r_2) < 0 < -\frac{1}{\mu_A}(\Omega_A\mu_B - \Omega_B\mu_A + \mu_A r_1)$ holds, then the free trade equilibrium (i.e., $\tau_B = \tau_A = 0$) is type 4. We can obtain a similar relationship for country A's tariff rates (see the bottom panel in Figure 4). We should note that neither type-3 equilibrium nor type-5 equilibrium arises with country A's tariff alone, because $x_{AB} \ge x_{BA}$ is assumed under free trade. As in the case of country B's tariff, τ_A must satisfy $0 \le \tau_A < \Omega_A$ and $\tau_A = 0$ determines the free trade equilibrium. If $\frac{1}{\mu_B}(\Omega_A\mu_B - \Omega_B\mu_A + \mu_A r_1) > 0$, for example, the free trade equilibrium is type 2. In this case, as τ_A increases, equilibrium shifts from type 2 to type 4 and then to type 1.

We now compare the above five types of equilibrium with the three types of equilibrium with a single carrier. With $x_{1AB} > x_{1BA}$ and $x_{2AB} > x_{2BA}$, the equilibrium is given by

$$T_{AB}^{C1} = \frac{1}{3}(\Omega_B^\tau + r_1 + r_2), T_{BA}^{C1} = \frac{1}{3}\Omega_A^\tau, \quad (5)$$

$$x_{1AB}^{C1} = \frac{1}{3\mu_B}(\Omega_B^\tau - 2r_1 + r_2), x_{2AB}^{C1} = \frac{1}{3\mu_B}(\Omega_B^\tau - 2r_2 + r_1), x_{1BA}^{C1} = x_{2BA}^{C1} = \frac{1}{3\mu_A}\Omega_A^\tau, \quad (6)$$

$$x_{AB}^{C1} = x_{1AB}^{C1} + x_{2AB}^{C1} = \frac{1}{3\mu_B}(2\Omega_B^\tau - r_1 - r_2), x_{BA}^{C1} = x_{1BA}^{C1} + x_{2BA}^{C1} = \frac{2}{3\mu_A}\Omega_A^\tau. \quad (7)$$

The characteristics of this equilibrium are essentially the same with those of type-1 equilibrium with a single carrier. A change in τ_i affects only shipping from country j to i, x_{1ji} and

x_{2ji}. It should be noted that we have $x_{1AB} > x_{2AB}$ but $x_{1BA} = x_{2BA}$, that is, $x_{1BA} = x_{2BA}$ holds even if $x_{1AB} \neq x_{2AB}$. This is because T_{BA} is independent of r_1 and r_2.

Similarly, with $x_{1AB} < x_{1BA}$ and $x_{2AB} < x_{2BA}$, we have (A7)-(A9). The equilibrium characteristics are essentially the same with those of type-3 equilibrium with a single carrier. A change in τ_i affects only shipping from country j to i, x_{1ji} and x_{2ji}. With $x_{1AB} = x_{1BA}$ and $x_{2AB} = x_{2BA}$, we have (A1)-(A6). The characteristics of this equilibrium are also the same with those of type-2 equilibrium with a single carrier. A change in τ_i ($i = 1, 2$) equally affects all shipping volumes (i.e., x_{1AB}, x_{2AB}, x_{1BA} and x_{2BA}).

With $x_{1AB} > x_{1BA}$ and $x_{2AB} = x_{2BA}$, we have

$$T_{AB}^{C4} = \frac{1}{6(\mu_A + \mu_B)} \left(3\Omega_B^\tau \mu_A - \Omega_A^\tau \mu_B + 2\Omega_B^\tau \mu_B + 3\mu_A r_1 + 2\mu_B r_1 + 2\mu_B r_2\right), \tag{8}$$

$$T_{BA}^{C4} = \frac{1}{6(\mu_A + \mu_B)} \left(2\Omega_A^\tau \mu_A + 3\Omega_A^\tau \mu_B - \Omega_B^\tau \mu_A - \mu_A r_1 + 2\mu_A r_2\right), \tag{9}$$

$$x_{1AB}^{C4} = -\frac{1}{6\mu_B(\mu_A + \mu_B)} \left(\Omega_A^\tau \mu_B - 3\Omega_B^\tau \mu_A - 2\Omega_B^\tau \mu_B + 3\mu_A r_1 - 2\mu_B r_2 + 4\mu_B r_1\right), \tag{10}$$

$$x_{1BA}^{C4} = \frac{1}{6\mu_A(\mu_A + \mu_B)} \left(2\Omega_A^\tau \mu_A + 3\Omega_A^\tau \mu_B - \Omega_B^\tau \mu_A + 2\mu_A r_2 - \mu_A r_1\right), \tag{11}$$

$$x_{2AB}^{C4} = x_{2BA}^{C4} = \frac{1}{3(\mu_A + \mu_B)} \left(\Omega_A^\tau + \Omega_B^\tau - 2r_2 + r_1\right), \tag{12}$$

$$x_{AB}^{C4} = \frac{1}{6\mu_B(\mu_A + \mu_B)} \left(\Omega_A^\tau \mu_B + 3\Omega_B^\tau \mu_A + 4\Omega_B^\tau \mu_B - 3\mu_A r_1 - 2\mu_B r_1 - 2\mu_B r_2\right), \tag{13}$$

$$x_{BA}^{C4} = \frac{1}{6\mu_A(\mu_A + \mu_B)} \left(4\Omega_A^\tau \mu_A + 3\Omega_A^\tau \mu_B + \Omega_B^\tau \mu_A + \mu_A r_1 - 2\mu_A r_2\right). \tag{14}$$

Although $x_{AB} > x_{BA}$ holds, the characteristics of this equilibrium are different from those of type-1 equilibrium with a single carrier. In this equilibrium, a change in τ_i ($i = 1, 2$) affects both x_{AB} and x_{BA}, which does not occur in type-1 equilibrium with a single carrier. In particular, we should note that a change in τ_i affects both x_{1AB} and x_{1BA} even though $x_{1AB} > x_{1BA}$ holds. This stems from $x_{2AB} = x_{2BA}$. The direct effect of an increase in τ_i is to decrease x_{1ji} and x_{2ji}. The indirect effect is to decrease x_{2ij} because $x_{2ji} = x_{2ij}$, which in turn increases x_{1ij} as x_{1ij} and x_{2ij} are strategic substitutes with $x_{1ji} \neq x_{1ij}$. The decrease in x_{2ij} dominates the increase in x_{1ij} and hence x_{ij} falls. An increase in τ_i also decreases T_{ji} and increases T_{ij}.

With $x_{1AB} < x_{1BA}$ and $x_{2AB} = x_{2BA}$, we have

$$T_{AB}^{C5} = \frac{1}{6(\mu_A+\mu_B)}\left(3\Omega_B^\tau\mu_A - \Omega_A^\tau\mu_B + 2\Omega_B^\tau\mu_B - \mu_B r_1 + 2\mu_B r_2\right), \quad (15)$$

$$T_{BA}^{C5} = \frac{1}{6(\mu_A+\mu_B)}\left(2\Omega_A^\tau\mu_A + 3\Omega_A^\tau\mu_B - \Omega_B^\tau\mu_A + 2\mu_A r_1 + 2\mu_A r_2 + 3\mu_B r_1\right), \quad (16)$$

$$x_{1AB}^{C5} = \frac{1}{6\mu_B(\mu_A+\mu_B)}\left(3\Omega_B^\tau\mu_A - \Omega_A^\tau\mu_B + 2\Omega_B^\tau\mu_B - \mu_B r_1 + 2\mu_B r_2\right), \quad (17)$$

$$x_{1BA}^{C5} = -\frac{1}{6\mu_A(\mu_A+\mu_B)}\left(\Omega_B^\tau\mu_A - 3\Omega_A^\tau\mu_B - 2\Omega_A^\tau\mu_A + 4\mu_A r_1 - 2\mu_A r_2 + 3\mu_B r_1\right), \quad (18)$$

$$x_{2AB}^{C5} = x_{2BA}^{C5} = \frac{1}{3(\mu_A+\mu_B)}\left(\Omega_A^\tau + \Omega_B^\tau - 2r_2 + r_1\right), \quad (19)$$

$$x_{AB}^{C5} = \frac{1}{6\mu_B(\mu_A+\mu_B)}\left(\Omega_A^\tau\mu_B + 3\Omega_B^\tau\mu_A + 4\Omega_B^\tau\mu_B + \mu_B r_1 - 2\mu_B r_2\right), \quad (20)$$

$$x_{BA}^{C5} = \frac{1}{6\mu_A(\mu_A+\mu_B)}\left(4\Omega_A^\tau\mu_A + 3\Omega_A^\tau\mu_B + \Omega_B^\tau\mu_A - 2\mu_A r_1 - 2\mu_A r_2 - 3\mu_B r_1\right). \quad (21)$$

Although $x_{AB} < x_{BA}$ holds, the characteristics of this equilibrium are different from those of type-3 equilibrium with a single carrier. As in type-4 equilibrium above, a change in τ_i $(i = 1, 2)$ affects both x_{1AB} and x_{1BA} even though $x_{1AB} < x_{1BA}$ holds. Also T_{ij} increases and x_{ij} decreases.

Figure 5 here

Figure 6 here

Figure 5 illustrates the relationship between shipping volumes and country B's tariff rates when type-1 equilibrium arises with free trade (i.e., when $\Omega_A\mu_B - \Omega_B\mu_A - \mu_A r_1 + 2\mu_A r_2 < 0$ holds).[23] The upper panel and the lower panel show shipping volumes of firm T_1 and those of firm T_2, respectively. The lower panel is similar to Figure 3 (a): x_{2AB} monotonically decreases as τ_B rises. x_{2BA} is constant in type-1 and type-3 equilibria but decreases with τ_B in type-2, type-4 and type-5 equilibria. In the upper panel, x_{1AB} monotonically decreases, while x_{1BA} does not. In type-4 and type-5 equilibria, an increase in τ_B increases x_{1BA}. Thus, when country B introduces a tariff under free trade, firm T_1's shipping volume from country A to country B necessarily decreases but that from country B to country A may increase.

In particular, it is easy to verify that x_{1BA} in type-1 equilibrium is less than x_{1BA} in type-5 and type-3 equilibria if $2\mu_A r_1 - \mu_A r_2 + \mu_B r_1 < 0$ and that x_{1BA} in type-1 and tpye-4 equilibria is less than x_{1BA} in type-3 equilibrium if $\mu_A r_1 + 2\mu_B r_1 - \mu_B r_2 < 0$. These cases are

[23] As was mentioned above, the free trade equilibrium is determined by the location of $\tau_B = 0$ in Figure 5. Setting the vertical axis at $\tau_B = 0$, we can easily analyze the cases in which the other types of equilibrium arise under free trade.

more likely to occur when r_1 is much smaller than r_2, that is, the range of type-2 equilibrium is much smaller than the ranges of type-4 and type-5 equilibria. A small r_1 relative to r_2 implies that firm T_1 can increase a means of transport less costly than firm T_2.

Figure 6 illustrates the relationship between shipping volumes and country A's tariff rates when type-2 equilibrium arises with free trade (i.e., when $\frac{1}{\mu_B}\left(\Omega_A\mu_B - \Omega_B\mu_A + \mu_A r_1\right) > 0$ holds).[24] As in Figure 5, the upper panel and the lower panel show shipping volumes of firm T_1 and those of firm T_2, respectively. Since x_{1AB} increases with τ_A in type-4 equilibrium, a tariff under free trade decreases the "total" shipping volumes in both directions but may increase firm T_1's shipping volume from country A to country B. In particular, x_{1AB} in type-1 equilibrium is greater than x_{1AB} in type-2 and type-4 equilibria if $\Omega_B\mu_A - \Omega_A\mu_B - 2\mu_A r_1 + \mu_A r_2 > 0$ holds.

In type-4 and type-5 equilibria, τ_B decreases firm T_1's profits from shipping the good from country A to country B but increases firm T_1's profits from shipping the good from country B to country A. The negative effect on firm T_1's profits is relatively stronger (weaker) than the positive effect in type-4 equilibrium (type-5 equilibrium), because $x_{1AB} > x_{1BA}$ ($x_{1AB} < x_{1BA}$) holds. Appendix D proves that an increase in τ_B decreases firm T_1's total profits in type-4 equilibrium, but could increase firm T_1's total profits in type-5 equilibrium. Firm T_1 gains from an increase in τ_B only if the gap between x_{1AB} and x_{1BA} is large. When x_{1BA} is much larger than x_{1AB}, the positive effect of the increase in x_{1BA} on firm T_1's profits could dominate the negative effect of the decrease in x_{1AB} on firm T_1's profits.

Similarly, in type-4 equilibrium, τ_A decreases firm T_1's profits from shipping the good from country B to country A but increases firm T_1's profits from shipping the good from country A to country B. Appendix D also shows that in type-4 equilibrium, an increase in τ_A could raise firm T_1's total profits. Again, firm T_1 gains from an increase in τ_A only if the gap between x_{1AB} and x_{1BA} is large.

With respect to the effects of tariffs on each transport firm, the following proposition can be established.

Proposition 6 *Suppose* $0 < r_1 < r_2$ *and* τ_i *increases. In type-2, type-4 and type-5 equilibria,* T_{ij} *increases and* x_{ij} *decreases (the backfiring effect). However, in type-4 and type-5 equilibria,* x_{1ij} *increases. Firm* T_2 *necessarily loses but firm* T_1 *may gain from an increase in* τ_B *in type-5 equilibrium and from an increase in* τ_A *in type-4 equilibrium.*

The changes in firm T_1's shipping volume caused by tariffs are not simple, but the effects of tariffs on the "total" shipping quantities from one country to the other are similar to Proposition 2. That is, any tariff of country B, which satisfies $\max\left\{0, -\frac{1}{\mu_A}\left(\Omega_A\mu_B - \Omega_B\mu_A - \mu_A r_1 + 2\mu_A r_2\right)\right\}$

[24]If type-1 equilibrium arises with free trade, an increase in τ_A simply decreases x_{1BA} and x_{2BA} without affecting x_{1AB} and x_{2AB}.

$< \tau_B < \Omega_B$, increases the freight rate from country B to country A and decreases country B's exports as well as country B's imports; and any tariff of country A increases the freight rate from country A to country B and decreases country A's exports as well as country A's imports if $0 < \frac{1}{\mu_B}(\Omega_A\mu_B - \Omega_B\mu_A - \mu_A r_1 + 2\mu_A r_2)$ holds.

The effects of tariffs on the sum of consumer surplus and producer surplus depend not on the shipping volumes of each transport firm but on the total volumes of shipping coming in and out from the country. This implies that as long as the profits of transport firms are not included in welfare, the analysis of the welfare effects of tariffs with a single carrier remains valid with multiple carriers. Thus, Proposition 3 holds for the case of multiple carriers as well.

Next we examine the effects of taxes on shipping capacity and compare them with those of tariffs. For this, we specifically consider the case in which the same specific tax rate, t, applies to both firms T_1 and T_2. It is straightforward to confirm that in type-1 (type-3) equilibrium, x_{1AB} (x_{1BA}) and x_{2AB} (x_{2BA}) decrease but x_{1BA} (x_{1AB}) and x_{2BA} (x_{2AB}) are constant; in type-2 equilibrium, all shipping volumes, x_{1AB}, x_{2AB}, x_{1BA}, and x_{2BA}, decrease; and in type-4 (type-5) equilibrium, x_{1AB} (x_{1BA}), x_{2AB}, x_{2BA}, x_{AB} and x_{BA} decrease but x_{1BA} (x_{1AB}) increases.

In fact, country B's shipping-capacity tax and country B's tariff set at the same levels are equivalent in type-4 equilibrium as well as in type-1 and type-2 equilibria. Similarly, country A's shipping-capacity tax and country A's tariff set at the same levels are equivalent in type-5 equilibrium as well as in type-2 and type-3 equilibria. Whereas $x_{AB} \geq x_{BA}$ holds in type-1, type-2, and type-4 equilibria, $x_{AB} \leq x_{BA}$ holds in type-2, type-3, and type-5 equilibria. Thus, the effects of taxes on shipping capacity with multiple carriers are basically the same with those with a single carrier.

5 Multiple Exportable Goods

In this section, we extend the basic model to the case with multiple exportable goods and examine the effects of tariffs. For this, we consider a model with three goods: A_1, A_2, and B. Country A exports goods A_1 and A_2 to country B while country B exports good B to country A. Firm T faces the following inverse demand for shipping good A_k from country A to country B:

$$T_{AB} = \Omega_B^{A_k\tau} - \mu_B^{A_k} x_{AB}^{A_k}, \quad k = 1, 2, \tag{22}$$

where $x_{AB}^{A_k}$ is the quantity demanded for shipping good A_k from country A to country B. As in the previous section, the intercepts are inclusive of tariffs: $\Omega_B^{A_k\tau} \equiv \Omega_B^{A_k} - \tau_{kB}$ $(k = 1, 2)$

where τ_{kB} is country B's specific tariff on good A_k. Regarding the shipping from country B to country A, firm T remains to face (1). Arranging (22), we obtain

$$x_{AB}^{A_k} = \frac{1}{\mu_B^{A_k}} \left(\Omega_B^{A_k \tau} - T_{AB} \right), k = 1, 2.$$

The total demand for transport services from country A to country B and its inverse demand are given by

$$\begin{aligned} x_{AB} &= x_{AB}^{A_1} + x_{AB}^{A_2} = \frac{1}{\mu_B^{A_1} \mu_B^{A_2}} \left(\Omega_B^{A_1 \tau} \mu_B^{A_2} + \Omega_B^{A_2 \tau} \mu_B^{A_1} - \mu_B^{A_1} T_{AB} - \mu_B^{A_2} T_{AB} \right), \\ T_{AB} &= \frac{1}{\mu_B^{A_1} + \mu_B^{A_2}} \left(\Omega_B^{A_1 \tau} \mu_B^{A_2} + \Omega_B^{A_2 \tau} \mu_B^{A_1} - \mu_B^{A_1} \mu_B^{A_2} x_{AB} \right). \end{aligned}$$

Again we have three cases with profit maximization. If $x_{AB} (= x_{AB}^{A_1} + x_{AB}^{A_2}) > x_{BA}$ holds, we have

$$\begin{aligned} T_{AB}^{M1} &= \frac{\Omega_B^{A_1 \tau} \mu_B^{A_2} + \Omega_B^{A_2 \tau} \mu_B^{A_1} + r(\mu_B^{A_1} + \mu_B^{A_2})}{2 \left(\mu_B^{A_1} + \mu_B^{A_2} \right)}, \ T_{BA}^{M1} = \frac{\Omega_A^{\tau}}{2}, \\ x_{AB}^{A_1 M1} &= -\frac{1}{2 \mu_B^{A_1} \left(\mu_B^{A_1} + \mu_B^{A_2} \right)} \left(\Omega_B^{A_2 \tau} \mu_B^{A_1} - \Omega_B^{A_1 \tau} \mu_B^{A_2} - 2 \Omega_B^{A_1 \tau} \mu_B^{A_1} + r \mu_B^{A_1} + r \mu_B^{A_2} \right), \\ x_{AB}^{A_2 M1} &= -\frac{1}{2 \mu_B^{A_2} \left(\mu_B^{A_1} + \mu_B^{A_2} \right)} \left(\Omega_B^{A_1 \tau} \mu_B^{A_2} - \Omega_B^{A_2 \tau} \mu_B^{A_1} - 2 \Omega_B^{A_2 \tau} \mu_B^{A_2} + r \mu_B^{A_1} + r \mu_B^{A_2} \right), \\ x_{AB}^{M1} &= \frac{1}{2 \mu_B^{A_1} \mu_B^{A_2}} \left(\Omega_B^{A_1 \tau} \mu_B^{A_2} + \Omega_B^{A_2 \tau} \mu_B^{A_1} - r \mu_B^{A_1} - r \mu_B^{A_2} \right), \ x_{BA}^{M1} = \frac{\Omega_A^{\tau}}{2 \mu_A}. \end{aligned}$$

If $x_{AB} < x_{BA}$ holds instead, we have

$$\begin{aligned} T_{AB}^{M3} &= \frac{\Omega_B^{A_1 \tau} \mu_B^{A_2} + \Omega_B^{A_2 \tau} \mu_B^{A_1}}{2 \left(\mu_B^{A_1} + \mu_B^{A_2} \right)}, \ T_{BA}^{M3} = \frac{\Omega_A^{\tau} + r}{2}, \\ x_{AB}^{A_1 M3} &= -\frac{1}{2 \mu_B^{A_1} \left(\mu_B^{A_1} + \mu_B^{A_2} \right)} \left(\Omega_B^{A_2 \tau} \mu_B^{A_1} - \Omega_B^{A_1 \tau} \mu_B^{A_2} - 2 \Omega_B^{A_1 \tau} \mu_B^{A_1} \right), \\ x_{AB}^{A_2 M3} &= -\frac{1}{2 \mu_B^{A_2} \left(\mu_B^{A_1} + \mu_B^{A_2} \right)} \left(\Omega_B^{A_1 \tau} \mu_B^{A_2} - \Omega_B^{A_2 \tau} \mu_B^{A_1} - 2 \Omega_B^{A_2 \tau} \mu_B^{A_2} \right), \\ x_{AB}^{M3} &= \frac{1}{2 \mu_B^{A_1} \mu_B^{A_2}} \left(\Omega_B^{A_1 \tau} \mu_B^{A_2} + \Omega_B^{A_2 \tau} \mu_B^{A_1} \right), \ x_{BA}^{M3} = \frac{\Omega_A^{\tau} - r}{2 \mu_A}. \end{aligned}$$

In both cases, an increase in τ_{1B} or τ_{2B} decreases T_{AB}, while an increase in τ_A decreases T_{BA}. Thus, a tariff on good A_k affects not only the market of good A_k but also the market of good A_l $(k, l = 1, 2; k \neq l)$ through a change in the freight rate. That is, a tariff on good A_k has a spillover effect on the the market of good A_l. An increase in τ_{kB} directly decreases $x_{AB}^{A_k}$

but indirectly increases $x_{AB}^{A_l}$. The total load from country A to country B, $x_{AB} = x_{AB}^{A1} + x_{AB}^{A2}$, decreases, because the direct effect dominates the indirect effect.

If $x_{AB} = x_{BA}$ holds, then we have another spillover effect. In type-2 equilibrium, we obtain

$$
\begin{aligned}
T_{AB}^{M2} &= \frac{\Gamma}{\mu_B^{A_1} + \mu_B^{A_2}} \{ \mu_B^{A_1}\mu_B^{A_2} r(\mu_B^{A_2} + \mu_B^{A_1}) - \mu_B^{A_1}\mu_B^{A_2}\left(\mu_B^{A_1} + \mu_B^{A_2}\right)\Omega_A^{\tau} \\
&\quad + \mu_B^{A_2}\left(\mu_B^{A_1}\mu_B^{A_2} + 2\mu_B^{A_2}\mu_A + 2\mu_B^{A_1}\mu_A\right)\Omega_B^{A_1\tau} + \mu_B^{A_1}\left(\mu_B^{A_1}\mu_B^{A_2} + 2\mu_B^{A_1}\mu_A + 2\mu_B^{A_2}\mu_A\right)\Omega_B^{A_2\tau}\}, \\
T_{BA}^{M2} &= \Gamma\{ r\mu_A(\mu_B^{A_1} + \mu_B^{A_2}) + \left(2\mu_B^{A_1}\mu_B^{A_2} + \mu_B^{A_1}\mu_A + \mu_B^{A_2}\mu_A\right)\Omega_A^{\tau} - \mu_B^{A_1}\mu_A\Omega_B^{A_2\tau} - \mu_B^{A_2}\mu_A\Omega_B^{A_1\tau}\}, \\
x_{AB}^{M2} &= x_{BA}^{M2} = \Gamma\{\Omega_B^{A_1\tau}\mu_B^{A_2} + \Omega_B^{A_2\tau}\mu_B^{A_1} + (\mu_B^{A_1} + \mu_B^{A_2})\Omega_A^{\tau} - r(\mu_B^{A_1} + \mu_B^{A_2})\},
\end{aligned}
$$

where $\Gamma \equiv 1/\left\{2\left(\mu_B^{A_1}\mu_B^{A_2} + \mu_B^{A_1}\mu_A + \mu_B^{A_2}\mu_A\right)\right\}$. An increase in τ_{kB} $(k = 1, 2)$ decreases T_{AB} but increases T_{BA}. As a result, $x_{AB}^{A_k}$ and x_{BA} decrease but $x_{AB}^{A_l}$ increases $(k, l = 1, 2; k \neq l)$. Since the decrease in $x_{AB}^{A_k}$ dominates the increase in $x_{AB}^{A_l}$, $x_{AB}^{A_1} + x_{AB}^{A_2} = x_{BA}$ decreases. The economic intuition behind the spillover effects is as follows. When τ_{kB} rises, to keep a full load in both directions, firm T decreases the reduction of the load from country A to country B by lowering T_{AB} and decreases the load from country B to country A by raising T_{BA}. Similarly, when the load from country B to country A falls because of an increase in τ_A, firm T increases T_{AB} to reduce the load from country A to country B.

In any equilibrium, an increase in τ_{kB} $(k, l = 1, 2; k \neq l)$ decreases $x_{AB}^{A_k}$ but increase $x_{AB}^{A_l}$. Thus, an increase in τ_{kB} harms producers of good A_k but benefits producers of good A_l in country A and vice versa in country B. In both countries, the sum of producer surplus and consumer surplus decreases in the market of good A_k but increases in the market of good A_l. The latter increase may exceed the former decrease. This implies that a small tariff on good A_k set by country B under free trade may benefit country A.

The above results are summarized in the following proposition.[25]

Proposition 7 *Suppose $x_{AB} \geq x_{BA}$ holds under the free-trade equilibrium. Any tariff on good A_k set by country B lowers the freight rate from country A to country B, decreases*

[25] With $\tau_A = 0$, we have type-1 equilibrium if $0 < \tau_{kB} < -\frac{\Omega_A\mu_B^{A_1}\mu_B^{A_2} - \Omega_B^{A_1\tau}\mu_A\mu_B^{A_2} - \Omega_B^{A_2\tau}\mu_A\mu_B^{A_1} + r\mu_A(\mu_B^{A_1} + \mu_B^{A_2})}{\mu_A\mu_B^{A_l}}$, type 2 equilibrium if $-\frac{\Omega_A\mu_B^{A_1}\mu_B^{A_2} - \Omega_B^{A_1\tau}\mu_A\mu_B^{A_2} - \Omega_B^{A_2\tau}\mu_A\mu_B^{A_1} + r\mu_A(\mu_B^{A_1} + \mu_B^{A_2})}{\mu_A\mu_B^{A_l}} < \tau_{kB} < \frac{-\Omega_A\mu_B^{A_1}\mu_B^{A_2} + \Omega_B^{A_1\tau}\mu_A\mu_B^{A_2} + \Omega_B^{A_2\tau}\mu_A\mu_B^{A_1} + r\mu_B^{A_1}\mu_B^{A_2}}{\mu_A\mu_B^{A_l}}$ and type-3 equilibrium if $\tau_{kB} > \frac{-\Omega_A\mu_B^{A_1}\mu_B^{A_2} + \Omega_B^{A_1\tau}\mu_A\mu_B^{A_2} + \Omega_B^{A_2\tau}\mu_A\mu_B^{A_1} + r\mu_B^{A_1}\mu_B^{A_2}}{\mu_A\mu_B^{A_l}}$ $(k, l = 1, 2; k \neq l)$. With $\tau_B = 0$, we have type-2 equilibrium if $0 < \tau_A < \frac{\Omega_A\mu_B^{A_1}\mu_B^{A_2} - \Omega_B^{A_1\tau}\mu_A\mu_B^{A_2} - \Omega_B^{A_2\tau}\mu_A\mu_B^{A_1} + r\mu_A\mu_B^{A_1} + r\mu_A\mu_B^{A_2}}{\mu_B^{A_1}\mu_B^{A_2}}$ and type-1 equilibrium if $\tau_A > \max\{0, \frac{\Omega_A\mu_B^{A_1}\mu_B^{A_2} - \Omega_B^{A_1\tau}\mu_A\mu_B^{A_2} - \Omega_B^{A_2\tau}\mu_A\mu_B^{A_1} + r\mu_A\mu_B^{A_1} + r\mu_A\mu_B^{A_2}}{\mu_B^{A_1}\mu_B^{A_2}}\}$.

country B's imports of good A_k, and increases country B's imports of good A_l ($k, l = 1, 2; k \neq l$). Any tariff of country B, which results in $x_{AB} \leq x_{BA}$, increases the freight rate from country B to country A and decreases country B's exports.

When country B sets a tariff on good A_k ($k = 1, 2$), firm T lowers the freight rate T_{AB} and its profits decrease. Thus, firm T may stop shipping good A_k when τ_{kB} is large enough. Appendix E shows that this case actually occurs under some parameter values.

Thus, we obtain the following proposition.

Proposition 8 *An increase in τ_{1B} (τ_{2B}) may lead firm T to stop shipping good A_1 (good A_2). This may increase T_{BA}.*

It may seem that the above analyses crucially depend on the assumption that firm T sets a single freight rate for shipping from country A to country B even though there are multiple exportable goods. In the following, therefore, we briefly consider the case in which firm T can price-discriminate between goods A_1 and A_2. With price discrimination, the profits of firm T become

$$\Pi_T = T_{AB}^{A_1} x_{AB}^{A_1} + T_{AB}^{A_2} x_{AB}^{A_2} + T_{BA} x_{BA} - r\kappa,$$

where $T_{AB}^{A_k}$ is the freight rate of good A_k ($k = 1, 2$). Firm T sets three freight rates, $T_{AB}^{A_1}$, $T_{AB}^{A_2}$ and T_{BA}. With profit maximization, type-1 equilibrium is given by

$$T_{AB}^{A_1 m1} = \frac{1}{2}r + \frac{1}{2}\Omega_B^{A_1\tau}, \quad T_{AB}^{A_2 m1} = \frac{1}{2}r + \frac{1}{2}\Omega_B^{A_2\tau}, \quad T_{BA}^{m1} = \frac{1}{2}\Omega_A^{\tau}.$$

Type-3 equilibrium is

$$T_{AB}^{A_1 m3} = \frac{1}{2}\Omega_B^{A_1\tau}, \quad T_{AB}^{A_2 m3} = \frac{1}{2}\Omega_B^{A_2\tau}, \quad T_{BA}^{m3} = \frac{1}{2}r + \frac{1}{2}\Omega_A^{\tau}.$$

In type-1 and type-3 equilibria, a change in τ_{kB} lowers $T_{AB}^{A_k}$ but affects neither $T_{AB}^{A_l}$ nor T_{BA} ($k, l = 1, 2; k \neq l$). Intuitively, the spillover effects through a single freight rate disappear, because firm T can set the different freight rates between goods A_1 and A_2.

If $x_{AB} = x_{BA}$, firm T's profit maximization is given by:

$$\begin{aligned} \max \Pi_T &= \max\{T_{AB}^{A_1} x_{AB}^{A_1} + T_{AB}^{A_2} x_{AB}^{A_2} + T_{BA} x_{BA} - r x_{BA}\} \\ s.t. \quad x_{BA} &= x_{AB}^{A_1} + x_{AB}^{A_2}. \end{aligned}$$

Type-2 equilibrium is

$$\begin{aligned}
T_{AB}^{A_1m2} &= \Gamma^m \left(2\Omega_B^{A_1\tau}\mu_B^{A_1} + \Omega_B^{A_1\tau}\mu_B^{A_2} + \Omega_B^{A_2\tau}\mu_B^{A_1} + \Omega_B^{A_1\tau}\mu_A - \Omega_A\mu_1 + r\mu_B^{A_1}\mu_A\right), \\
T_{AB}^{A_2m2} &= \Gamma^m \left(\Omega_B^{A_1\tau}\mu_B^{A_2} + \Omega_B^{A_2\tau}\mu_B^{A_1} + 2\Omega_B^{A_2\tau}\mu_B^{A_2} + \Omega_B^{A_2\tau}\mu_A - \Omega_A\mu_B^{A_2} + r\mu_B^{A_2}\mu_A\right), \\
T_{BA}^{m2} &= \Gamma^m \left(\Omega_A\mu_B^{A_1} - \Omega_B^{A_1\tau}\mu_A - \Omega_B^{A_2\tau}\mu_A + \Omega_A\mu_B^{A_2} + 2\Omega_A\mu_A + r\mu_B^{A_1}\mu_A + r\mu_B^{A_2}\mu_A\right),
\end{aligned}$$

where $\Gamma^m \equiv 1/\left\{2\left(\mu_B^{A_1} + \mu_B^{A_2} + \mu_A\right)\right\}$. An increase in τ_{1B} or τ_{2B} decreases both $T_{AB}^{A_1}$ and $T_{AB}^{A_2}$ and increases T_{BA} while an increase in τ_A increases both $T_{AB}^{A_1}$ and $T_{AB}^{A_2}$ and decreases T_{BA}. In contrast to the case with $x_{AB} \neq x_{BA}$, therefore, firm T adjusts all freight rates to keep a full load in both directions. That is, when τ_{1B} or τ_{2B} rises, firm T avoids the reduction in the load from country A to country B by lowering $T_{AB}^{A_1}$ and $T_{AB}^{A_2}$ and decrease the load from country B to country A by raising T_{BA}. Analogously, when the load from country B to country A falls because of an increase in τ_A, firm T increases both $T_{AB}^{A_1}$ and $T_{AB}^{A_2}$ to reduce the load from country A to country B. In type-2 equilibrium, therefore, even if firm T can set different freight rates among different exportable goods, the effects of tariffs are qualitatively similar to those of tariffs in the case where firm T sets a single freight rate from one country to the other country.

6 Discussion

Here we discuss the robustness of our findings regarding competition in the output markets and empirical relevance of our main results.

6.1 Product market competition

In our basic model, we have assumed that the product market is perfectly competitive. Most of our main results would survive under various kinds of international product market competition. In particular, domestic import tariffs could decrease not only domestic imports but also domestic exports given other types of product market competition.

In Ishikawa and Tarui (2015), the case of an international duopoly in the product market is explored. In the model, there is a single manufacturing firm in each country and the two firms engage in Cournot competition in the segmented domestic and foreign markets. When domestic import tariffs decrease both domestic imports and exports, consumers in both countries lose because of higher consumer prices. There are two conflicting effects of tariffs on the firms, the direct effect and the indirect effect, the sizes of which depend on parameter values in the model. The direct effect is conventional, that is, domestic import tariffs benefit the domestic firm at the cost of the foreign firm. The indirect effect stemming from a decrease in domestic exports benefits the foreign firm at the cost of the domestic firm. As a result, domestic import tariffs could harm the domestic firm and benefit the foreign firm. It is also possible that both firms gain. In this case, the decrease in the domestic imports and the decrease in the domestic exports caused by a domestic tariff strengthen the market power in the firm's home market, that is, for both firms, the gain from the decrease in imports dominates the loss from the decrease in exports.

In the case of a standard model of monopolistic competition in the product market, tariffs are also detrimental to consumers because they face both higher consumer prices and less varieties. Import tariffs do not affect the profits of producers, which always equal zero because of free entry and exit.

6.2 Suggestive evidence

Our main result implies that domestic tariff reductions may increase domestic exports. Whether removing import restrictions (such as reducing tariffs) may enhance exports has been a subject of trade policy research in the literature. Previous studies have identified a few channels through which an import tariff reduction may influence export. Though early studies indicate a negative effect of liberalizing imports on exports (e.g., restricting import could enhance export when the protected industry exhibits increasing returns to scale, Krugman, 1984), more recent studies identify positive effects. For example, a tariff reduction on intermediate goods may expand the sectors that use those goods as inputs, enabling them to increase their exports (Cruz and Bussolo, 2015). This effect via supply chain may be through direct effects on production costs (that drop due to lower input costs) or indirect effects through more intense import competition and resulting productivity increases for the affected firms (Trefler, 2004; Amiti and Konings, 2007). Our study identifies another channel—endogenous transport costs—through which import liberalization has a positive effect on the country's exports—an empirical question of high policy relevance.

Which channels are present or have larger effects in magnitude than others? Answering this question would require careful empirical investigations. India's trade liberalization in the 1990s presents a suitable case study for our purpose because India reduced its trade barriers unilaterally in this period (see, e.g., Topalova and Khandelwal, 2011).[26] One may wonder if India's container imports and exports have been balanced.[27] However, multiple carriers

[26]We thank the referees for encouraging us to investigate this case study to support our theoretical results discussed in this subsection.

[27]India's container exports were 1.90 million TEUs in 2010, 2.95 million TEUs in 2013, and 3.07 million TEUs in 2014 while India's container imports were 2.00 million TEUs in 2010, 2.21 million TEUs in 2013, and 2.39 million TEUs in 2014 (`http://www.worldshipping.org/about-the-industry/global-trade/`

have been operating between India and the ROW. As the analysis on our multiple-carrier model indicates, the backfiring effects may occur even with imbalance between imported and exported containers.

The United States has been a major destination of India's exports (with its share about 20% as of 2000). Figure 7 describes the trend of India's average import tariff rates and the real unit (per kg) transportation costs of exports from India to the United States. It compares those with the tariff rates and the transport costs to the United States from Japan and the European Union.[28] The figure demonstrates that India's average tariff rates decreased substantially while those of EU and Japan changed little over the period. The trends in the transport costs of exports from the three economies show a contrast in a way consistent with our theoretical prediction and are not explained by a factor that may influence transports on all routes uniformly (such as across-the-board technological change). Unlike EU's and Japan's transport costs, which did not decrease between 1991 and 2003, India's transport costs decreased by about 40% over the same period. A closer look at the figure reveals that the transport costs decreased for EU's and Japan's exports as well from 1995 to 1998. Indeed, these declines are likely due to a drop in the fuel costs as lower fuel costs can translate into lower transport costs. The real crude oil prices, which are highly correlated with bunker fuel prices, decreased over the same years as shown in Figure 7. It is notable that, when the oil prices increased substantially between 1998 and 2000 (by 118%), the transport costs of Japan's (EU's) exports increased by 165% (25%) while India's transport costs did not increase as much (by 15%). This may be another indication of a link between India's declining import tariffs and its lower transport costs despite a substantial increase in the fuel costs.[29]

While the United States was India's top trading partner during the period, our theory predicts that the decline in transport costs should apply to all other trading partners as well

`trade-statistics#1`). Thus, India was a net importer of containers from the the rest of the world (ROW) in 2010, but a net exporter of containers to the ROW in 2013 and 2014.

[28]The figure displays the weighted average unit transport costs of all 2-digit HS code products that are subject to containerized trade, where the weights are based on the export quantity in weights by HS code. The transport costs are taken from OECD Maritime Transport Costs (MTC) database (Korinek, 2008). All values are normalized so that the 1991 values equal one. European Union refers to the member countries as of 1995-2004, i.e., Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and United Kingdom. The tariff rates refer to weighted average MFN rates.

[29]Our theory also predicts that the transport costs of India's imports from the United States increase as India's import tariffs decrease. This result is due to the transport firms' market power and does not depend on their capacity constraints or the associated backhaul problem. Because the transport costs of India's imports in the 1990s are not available at OECD's Maritime Transport Costs data (except for cereals, which are shipped via clean bulk carriers and not containers), we do not have a figure similar to Figure 7 on India's imports.

given India's unilateral tariff rate reductions. Figure 8 displays India's average unit transport costs on the exports to the United States, Australia, and New Zealand.[30] It illustrates a similar, substantial reduction in the transport costs across destinations. A more careful econometric study would be necessary to quantify the impacts of trade liberalization on the transport costs, taking into account other time-varying factors such as technological change specific to trade routes. However, the figures indicate that countries with different trends in import tariffs experience different changes in the transport costs and the changes apply to multiple importers of the exporter with reduced tariff rates.

Figures 7 and 8 here

7 Conclusion

This paper explicitly incorporated the transport sector into a standard international trade model and studied the effects of trade policies when transport costs are endogenously determined. Our model captures key stylized facts about international shipping: market power by transport firms and asymmetric transport costs across countries. Furthermore, we explicitly took into account "backhaul problems" that have not been paid much attention in the international trade literature. Transport firms need to commit to a shipping capacity sufficient for a round trip. This may lead to imbalance in shipping volume in two directions, that is, an opportunity cost associated with returning without a full load. Given such backhaul problems, we demonstrated how the freight rate from one country to another, as well as the freight rate of the return trip, is determined and explored the effects of import tariffs on transported goods and taxes on shipping capacity.

Our analysis reveals that domestic tariffs reduce domestic exports as well as domestic imports when transport firms try to avoid the backhaul problem. Domestic tariffs, which benefit the domestic import sector and harm the foreign export sector in a standard model of international trade, can also harm the domestic export sector and benefit the foreign import sector. Thus, a domestic tariff may not improve domestic welfare even if the tariff rate is small. These unconventional results, i.e., the "backfiring effects," occur because transport firms choose their shipping capacity levels, subject to backhaul problems, while the export sector cannot export beyond the transport firm's shipping capacity. Clearly, tariffs reduce the transport firms' profits.

A tax on shipping capacity could be equivalent to an import tariff on shipped goods. This implies that the subsidies on shipping capacity may work as a substitute for an export

[30] Australia and New Zealand are the only countries other than the United States for which we can obtain the Indian exports data for 1991-2003 from the same data base.

subsidy on shipped goods. If a foreign country hesitates to lower its tariffs, the domestic country can increase its exports by providing export subsidies. However, export subsidies are prohibited by the WTO and countervailing duties may be applied. Alternatively, the domestic country could increase its exports by providing subsidies to carriers. The subsidies may also increase domestic imports (i.e., foreign exports).

The extensions of our basic model revealed that the non-conventional impacts of trade policies discussed above also arise in richer contexts under less restrictive assumptions. In particular, in the presence of multiple carriers, even if the shipping volumes are not balanced between the two directions, a tariff could decrease the shipping volumes in both directions. We also obtained additional results in the extensions. When multiple exportable goods are considered, a tariff affects not only the targeted sector but also other independent import sectors (i.e., goods that are neither substitutes nor complements of the targeted good).

For simplicity, we focused on a two-country model. In reality, a carrier may call at several places en route. In our analysis, we can regard one of the two countries as the ROW. However, a promising direction for future research is to explicitly investigate the case with more than two countries.[31]

We investigated how India's unilateral trade liberalization in the 1990s affected its freight rates. According to our main results, India's freight rates for imports should increase and its freight rates for exports should decrease. Although data on India's freight rates for imports are not available, India's freight rates for exports show declining trends. We should mention that this is just a suggestive evidence consistent with our results. More rigorous empirical analysis is left for the future research.

Appendix A

This appendix shows that Propositions 1 and 2 hold with more general demand functions

$$x_{AB} = \phi_{AB}(T_{AB} + \tau_B), x_{BA} = \phi_{BA}(T_{BA} + \tau_A),$$

which are twice continuously differentiable. In this appendix, we focus on the case where τ_B changes with $\tau_A = 0$.

First, we consider the case with $x_{AB} > x_{BA}$. In this case, firm T maximizes its profits

$$\Pi_T = T_{AB}x_{AB} + T_{BA}x_{BA} - rx_{AB}.$$

[31]See Higashida (2015) for a three-country shipping model with capacity choice by transport firms with market power.

The first order conditions (FOCs) are

$$\phi_{AB} + (T_{AB} - r)\phi'_{AB} = 0, \phi_{BA} + T_{BA}\phi'_{BA} = 0.$$

We assume that the second order conditions (SOCs) are satisfied:

$$\phi'_{AB}(2 - \varepsilon_{AB}) < 0, \phi'_{BA}(2 - \varepsilon_{BA}) < 0,$$

where $\varepsilon_{ij} \equiv \frac{\phi_{ij}\phi''_{ij}}{(\phi'_{ij})^2}$ $(i, j = A, B; i \neq j)$ is the elasticity of the slope of demand curve of shipping services from country i to country j. The demand curve is convex if $0 \leq \varepsilon_{ij}(< 2)$ and is concave if $\varepsilon_{ij} \leq 0$. Totally differentiating the FOCs, we have

$$\begin{pmatrix} \phi'_{AB}(2 - \varepsilon_{AB}) & 0 \\ 0 & \phi'_{BA}(2 - \varepsilon_{BA}) \end{pmatrix} \begin{pmatrix} dT_{AB} \\ dT_{BA} \end{pmatrix} = \begin{pmatrix} -\phi'_{AB}(1 - \varepsilon_{AB}) \\ 0 \end{pmatrix} d\tau_B,$$

Then we obtain

$$\begin{pmatrix} dT_{AB} \\ dT_{BA} \end{pmatrix} = \begin{pmatrix} \frac{1}{\phi'_{AB}(2-\varepsilon_{AB})} & 0 \\ 0 & \frac{1}{\phi'_{BA}(2-\varepsilon_{BA})} \end{pmatrix} \begin{pmatrix} -\phi'_{AB}(1 - \varepsilon_{AB}) \\ 0 \end{pmatrix} d\tau_B.$$

Thus, $\frac{dT_{AB}}{d\tau_B} = -\frac{1-\varepsilon_{AB}}{2-\varepsilon_{AB}}$ and $\frac{dT_{BA}}{d\tau_B} = 0$. Noting the SOCs, $\frac{dT_{AB}}{d\tau_B} < 0$ if and only if $\varepsilon_{AB} < 1$. We also have $\frac{d(T_{AB}+\tau_B)}{d\tau_B} = 1 + \frac{dT_{AB}}{d\tau_B} > 0$. These results are basically the same with Brander and Spencer (1984).

Next, we consider the case with $x_{AB} = x_{BA}$. In this case, firm T maximizes it profits subject to $x_{AB} = x_{BA}$. Using the Lagrange multiplier method, the FOCs are

$$\phi_{AB} + (T_{AB} - r + \lambda)\phi'_{AB} = 0, \phi_{BA} + (T_{BA} - \lambda)\phi'_{BA} = 0, \phi_{AB} - \phi_{BA} = 0,$$

where λ is the Lagrange multiplier. Totally differentiating the FOCs, we have

$$\begin{pmatrix} \phi'_{AB}(2 - \varepsilon_{AB}) & 0 & \phi'_{AB} \\ 0 & \phi'_{BA}(2 - \varepsilon_{BA}) & -\phi'_{BA} \\ \phi'_{AB} & -\phi'_{BA} & 0 \end{pmatrix} \begin{pmatrix} dT_{AB} \\ dT_{BA} \\ d\lambda \end{pmatrix} = \begin{pmatrix} -\phi'_{AB}(1 - \varepsilon_{AB}) \\ 0 \\ -\phi'_{AB} \end{pmatrix} d\tau_B$$

and then

$$\begin{pmatrix} dT_{AB} \\ dT_{BA} \\ d\lambda \end{pmatrix} = \begin{pmatrix} \frac{\phi'_{BA}}{\phi'_{AB}\Psi} & \frac{1}{\Psi} & \frac{2-\varepsilon_{BA}}{\Psi} \\ \frac{1}{\Psi} & \frac{\phi'_{AB}}{\phi'_{BA}\Psi} & -\frac{2-\varepsilon_{AB}}{\Psi} \\ \frac{2-\varepsilon_{BA}}{\Psi} & \frac{2-\varepsilon_{AB}}{\Psi} & \frac{(2-\varepsilon_{AB})(2-\varepsilon_{BA})}{\Psi} \end{pmatrix} \begin{pmatrix} -\phi'_{AB}(1 - \varepsilon_{AB}) \\ 0 \\ -\phi'_{AB} \end{pmatrix} d\tau_B,$$

where $\Psi \equiv \phi'_{BA}(2-\varepsilon_{AB})+\phi'_{AB}(2-\varepsilon_{BA}) < 0$. Thus, we obtain $\frac{dT_{AB}}{d\tau_B} = -\frac{\phi'_{BA}(1-\varepsilon_{AB})+\phi'_{AB}(2-\varepsilon_{BA}))}{\Psi}$, which is negative if $\varepsilon_{AB} < 1$, and $\frac{dT_{BA}}{d\tau_B} = \frac{\phi'_{AB}}{\Psi} > 0$. $1 + \frac{dT_{AB}}{d\tau_B} > 0$ also holds.

In both cases, therefore, if the demand for shipping is not very convex, country B's tariff decreases the freight rate from country A to country B. Country B's tariff necessarily increases the trade costs from country A to country B and decreases country B's imports. Moreover, with $x_{AB} = x_{BA}$, country B's tariff necessarily increases the freight rate from country B to country A and decreases country B's exports.

Appendix B

In this appendix, we prove that even if the equilibrium remains to be type 1 after a small tariff set by country B, country B's welfare deteriorates when it includes firm T's profits.

In the upper panel of Figure 1, free trade increases the total surplus in the market of good A by the area abP^F_{AB} relative to autarky in country B. Free trade also generates firm T's profits. The profits from shipping good A from country A to country B are given by its revenue $bcP^F_{AA}P^F_{AB}$ minus its costs to ship x^F_{AB} units, rx^F_{AB}. In the lower panel of Figure 1, point F gives the largest profits on the derived demand curve DD_{AB}.

When a tariff is imposed, an increase in the total surplus in the market of good A relative to autarky is given by the area $ab'P^\tau_{AB}$ plus the tariff revenue TR_B in the upper panel. Firm T's profits from shipping good A from country A to country B are given by its revenue $\tau x^\tau_{AB}OT^\tau_{AB}$ minus its costs to ship x^τ_{AB} units in the lower panel. In the lower panel, the sum of the tariff revenue and firm T's profits is given by $tx^\tau_{AB}OT^t_{AB}$ minus firm T's costs, which actually equals firm T's profits minus its costs to ship x^τ_{AB} units at point t without any tariff. Since point F gives the largest profits of firm T along DD_{AB}, the sum of the tariff revenue and firm T's profits is smaller than firm T's profits under free trade.

Thus, in terms of the net change in surplus relative to autarky, the sum of the surplus in the market of good A and firm T's profits from shipping good A from country A to country B with the tariff, which equals the area $ab'c'P^\tau_{AA}$ minus firm T's costs to ship x^τ_{AB} units, is less than that without the tariff, which equals the area $abcP^F_{AA}$ minus firm T's costs to ship x^F_{AB} units.

Appendix C

In this appendix, we show Lemma 1.

There are nine possible combinations: i) $x_{1AB} > x_{1BA}$ and $x_{2AB} > x_{2BA}$; ii) $x_{1AB} > x_{1BA}$ and $x_{2AB} = x_{2BA}$; iii) $x_{1AB} > x_{1BA}$ and $x_{2AB} < x_{2BA}$; iv) $x_{1AB} = x_{1BA}$ and $x_{2AB} > x_{2BA}$; v) $x_{1AB} = x_{1BA}$ and $x_{2AB} = x_{2BA}$; vi) $x_{1AB} = x_{1BA}$ and $x_{2AB} < x_{2BA}$; vii) $x_{1AB} < x_{1BA}$ and $x_{2AB} > x_{2BA}$; viii) $x_{1AB} < x_{1BA}$ and $x_{2AB} = x_{2BA}$; and ix) $x_{1AB} < x_{1BA}$ and $x_{2AB} < x_{2BA}$. As shown below, however, only five combinations arise in equilibrium.

We start by characterizing each equilibrium. First, suppose that $x_{1AB} > x_{1BA}$ and $x_{2AB} > x_{2BA}$ hold in equilibrium. Then the profits of firms T_1 and T_2 are given by

$$\Pi_1 = T_{AB}x_{1AB} + T_{BA}x_{1BA} - r_1 x_{1AB}, \Pi_2 = T_{AB}x_{2AB} + T_{BA}x_{2BA} - r_2 x_{2AB}.$$

In equilibrium, we have (6) - (7).

Second, suppose that $x_{1AB} = x_{1BA}$ and $x_{2AB} = x_{2BA}$ hold in equilibrium. Then

$$\Pi_1 = (T_{AB} + T_{BA})x_{1AB} - r_1 x_{1AB}, \Pi_2 = (T_{AB} + T_{BA})x_{2AB} - r_2 x_{2AB}.$$

In equilibrium, we have

$$\begin{aligned}
T_{AB}^{C2} &= \frac{1}{3\left(\mu_A + \mu_B\right)}\left(3\Omega_B^\tau \mu_A - 2\Omega_A^\tau \mu_B + \Omega_B^\tau \mu_B + \mu_B r_1 + \mu_B r_2\right), && \text{(A1)}\\
T_{BA}^{C2} &= \frac{1}{3\left(\mu_A + \mu_B\right)}\left(\Omega_A^\tau \mu_A + 3\Omega_A^\tau \mu_B - 2\Omega_B^\tau \mu_A + \mu_A r_1 + \mu_A r_2\right), && \text{(A2)}\\
x_{1AB}^{C2} &= x_{1BA}^{C2} = \frac{1}{3\left(\mu_A + \mu_B\right)}\left(\Omega_A^\tau + \Omega_B^\tau - 2r_1 + r_2\right), && \text{(A3)}\\
x_{2AB}^{C2} &= x_{2BA}^{C2} = \frac{1}{3\left(\mu_A + \mu_B\right)}\left(\Omega_A^\tau + \Omega_B^\tau + r_1 - 2r_2\right) && \text{(A4)}\\
x_{AB}^{C2} &= \frac{1}{3\left(\mu_A + \mu_B\right)}\left(2\Omega_A^\tau + 2\Omega_B^\tau - r_1 - r_2\right), && \text{(A5)}\\
x_{BA}^{C2} &= \frac{1}{3\left(\mu_A + \mu_B\right)}\left(2\Omega_A^\tau + 2\Omega_B^\tau - r_1 - r_2\right). && \text{(A6)}
\end{aligned}$$

Third, suppose that $x_{1AB} < x_{1BA}$ and $x_{2AB} < x_{2BA}$ hold in equilibrium. Then the profits of firms T_1 and T_2 are given by

$$\Pi_1 = T_{AB}x_{1AB} + T_{BA}x_{1BA} - r_1 x_{1BA}, \Pi_2 = T_{AB}x_{2AB} + T_{BA}x_{2BA} - r_2 x_{2BA}.$$

In equilibrium, we have

$$\begin{aligned}
T_{AB}^{C3} &= \frac{1}{3}\Omega_B^\tau, \quad T_{BA}^{C3} = \frac{1}{3}\left(\Omega_A^\tau + r_1 + r_2\right), && \text{(A7)}\\
x_{1AB}^{C3} &= x_{2AB}^{C3} = \frac{1}{3\mu_B}\Omega_B^\tau, x_{1BA}^{C3} = \frac{1}{3\mu_A}\left(\Omega_A^\tau - 2r_1 + r_2\right), x_{2BA}^{C3} = \frac{1}{3\mu_A}\left(\Omega_A^\tau + r_1 - 2r_2\right), && \text{(A8)}\\
x_{AB}^{C3} &= x_{1AB}^{C3} + x_{2AB}^{C3} = \frac{2}{3\mu_B}\Omega_B^\tau, x_{BA}^{C3} = x_{1BA}^{C3} + x_{2BA}^{C3} = \frac{1}{3\mu_A}\left(2\Omega_A^\tau - r_1 - r_2\right). && \text{(A9)}
\end{aligned}$$

Fourth, suppose that $x_{1AB} > x_{1BA}$ and $x_{2AB} = x_{2BA}$ hold in equilibrium. Then

$$\Pi_1 = T_{AB}x_{1AB} + T_{BA}x_{1BA} - r_1 x_{1AB}, \Pi_2 = (T_{AB} + T_{BA})x_{2AB} - r_2 x_{2AB}.$$

In equilibrium, we have (8) - (14).

Fifth, suppose that $x_{1AB} < x_{1BA}$ and $x_{2AB} = x_{2BA}$ hold in equilibrium. Then

$$\Pi_1 = T_{AB}x_{1AB} + T_{BA}x_{1BA} - r_1 x_{1AB}, , \Pi_2 = (T_{AB} + T_{BA})x_{2AB} - r_2 x_{2AB}.$$

In equilibrium, we have (15) - (21).

Sixth, suppose that $x_{1AB} = x_{1BA}$ and $x_{2AB} > x_{2BA}$ hold in equilibrium. Then

$$\Pi_1 = (T_{AB} + T_{BA})x_{1AB} - r_1 x_{1AB}, \Pi_2 = T_{AB}x_{2AB} + T_{BA}x_{2BA} - r_2 x_{2AB}.$$

In equilibrium, we have

$$\begin{aligned}
x_{1AB}^{C6} &= x_{1BA}^{C6} = \frac{1}{3(\mu_A + \mu_B)}\left(\Omega_A^\tau + \Omega_B^\tau - 2r_1 + r_2\right), \\
x_{2AB}^{C6} &= -\frac{1}{6\mu_B(\mu_A + \mu_B)}\left(\Omega_A^\tau \mu_B - 3\Omega_B^\tau \mu_A - 2\Omega_B^\tau \mu_B + 3\mu_A r_2 - 2\mu_B r_1 + 4\mu_B r_2\right), \\
x_{2BA}^{C6} &= \frac{1}{6\mu_A(\mu_A + \mu_B)}\left(2\Omega_A^\tau \mu_A + 3\Omega_A^\tau \mu_B - \Omega_B^\tau \mu_A + 2\mu_A r_1 - \mu_A r_2\right).
\end{aligned}$$

Seventh, suppose that $x_{1AB} = x_{1BA}$ and $x_{2AB} < x_{2BA}$ hold in equilibrium. Then

$$\Pi_1 = (T_{AB} + T_{BA})x_{1AB} - r_1 x_{1AB}, \Pi_2 = T_{AB}x_{2AB} + T_{BA}x_{2BA} - r_2 x_{2AB}.$$

In equilibrium, we have

$$\begin{aligned}
x_{1AB}^{C7} &= x_{1BA}^{C7} = \frac{1}{3(\mu_A + \mu_B)}\left(\Omega_A^\tau + \Omega_B^\tau - 2r_1 + r_2\right), \\
x_{2AB}^{C7} &= \frac{1}{6\mu_B(\mu_A + \mu_B)}\left(3\Omega_B^\tau \mu_A - \Omega_A^\tau \mu_B + 2\Omega_B^\tau \mu_B + 2\mu_B r_1 - \mu_B r_2\right), \\
x_{2BA}^{C7} &= -\frac{1}{6\mu_A(\mu_A + \mu_B)}\left(\Omega_B^\tau \mu_A - 3\Omega_A^\tau \mu_B - 2\Omega_A^\tau \mu_A - 2\mu_A r_1 + 4\mu_A r_2 + 3\mu_B r_2\right).
\end{aligned}$$

It should be pointed out that the combination of $x_{1AB} > x_{1BA}$ and $x_{2AB} < x_{2BA}$ never arises in equilibrium. To show this, suppose in contradiction that the combination arises in equilibrium. Then we should have

$$\begin{aligned}
x_{1AB} &= \frac{1}{3\mu_B}\left(\Omega_B^\tau - 2r_1\right), x_{2AB} = \frac{1}{3\mu_B}\left(\Omega_B^\tau + r_1\right), \\
x_{1BA} &= \frac{1}{3\mu_A}\left(\Omega_A^\tau + r_2\right), x_{2BA} = \frac{1}{3\mu_A}\left(\Omega_A^\tau - 2r_2\right).
\end{aligned}$$

We need $x_{1AB} - x_{1BA} = -\frac{1}{3\mu_A\mu_B}\left(\Omega_A^\tau \mu_B - \Omega_B^\tau \mu_A + 2\mu_A r_1 + \mu_B r_2\right) > 0$, which implies $\Omega_A^\tau \mu_B <$

$\Omega^\tau_B\mu_A$. However, we also need $x_{2BA} - x_{2AB} = -\frac{1}{3\mu_A\mu_B}\left(\Omega^\tau_B\mu_A - \Omega^\tau_A\mu_B + \mu_A r_1 + 2\mu_B r_2\right) > 0$, which implies $\Omega^\tau_A\mu_B > \Omega^\tau_B\mu_A$. Thus, the combination of $x_{1AB} > x_{1BA}$ and $x_{2AB} < x_{2BA}$ never arises. Similarly, the combination of $x_{1AB} < x_{1BA}$ and $x_{2AB} > x_{2BA}$ never arises.

We next examine the conditions under which the above equilibria are actually realized as Nash equilibria.

The condition under which $x_{2AB} > x_{2BA}$ arises given $x_{1AB} > x_{1BA}$ is that $x_{2AB}(= \frac{1}{3\mu_B}\left(\Omega^\tau_B - 2r_2 + r_1\right)) > x_{2BA}(= \frac{1}{3\mu_A}\Omega^\tau_A)$, which becomes $\Omega^\tau_A\mu_B - \Omega^\tau_B\mu_A - \mu_A r_1 + 2\mu_A r_2 < 0$, i.e., $\Lambda\,(\equiv \Omega^\tau_A\mu_B - \Omega^\tau_B\mu_A) < \mu_A(r_1 - 2r_2)$. Now the condition under which $x_{1AB} > x_{1BA}$ arises given $x_{2AB} > x_{2BA}$ is that $x_{1AB}(= \frac{1}{3\mu_B}\left(\Omega^\tau_B - 2r_1 + r_2\right)) > x_{1BA}(= \frac{1}{3\mu_A}\Omega^\tau_A)$, which becomes $\Omega^\tau_A\mu_B - \Omega^\tau_B\mu_A + 2\mu_A r_1 - \mu_A r_2 < 0$, i.e., $\Lambda < \mu_A(r_2 - 2r_1)$. Since $\mu_A(r_1 - 2r_2) < \mu_A(r_2 - 2r_1)$ with $r_1 < r_2$, the combination of $x_{2AB} > x_{2BA}$ and $x_{1AB} > x_{1BA}$ arises as a Nash equilibrium if $\Lambda < \mu_A(r_1 - 2r_2)$.

The condition under which $x_{2AB} = x_{2BA}$ arises given $x_{1AB} = x_{1BA}$ is that neither $x_{2AB} > x_{2BA}$ nor $x_{2AB} < x_{2BA}$ holds given $x_{1AB} = x_{1BA}$. Suppose $x_{2AB} > x_{2BA}$ given $x_{1AB} = x_{1BA}$. Then

$$x_{2AB}\left(= -\frac{1}{6\mu_B\left(\mu_A + \mu_B\right)}\left(\Omega^\tau_A\mu_B - 3\Omega^\tau_B\mu_A - 2\Omega^\tau_B\mu_B + 3\mu_A r_2 - 2\mu_B r_1 + 4\mu_B r_2\right)\right)$$

$$> x_{2BA}\left(= \frac{1}{6\mu_A\left(\mu_A + \mu_B\right)}\left(2\Omega^\tau_A\mu_A + 3\Omega^\tau_A\mu_B - \Omega^\tau_B\mu_A + 2\mu_A r_1 - \mu_A r_2\right)\right).$$

Thus, the condition under which $x_{2AB} > x_{2BA}$ does not hold given $x_{1AB} = x_{1BA}$ is $x_{2AB} - x_{2BA} \leq 0$, i.e., $\Lambda \geq -\mu_A r_2$. Suppose $_{2AB} < x_{2BA}$ given $x_{1AB} = x_{1BA}$. Then

$$x_{2AB}\left(= \frac{1}{6\mu_B\left(\mu_A + \mu_B\right)}\left(3\Omega^\tau_B\mu_A - \Omega^\tau_A\mu_B + 2\Omega^\tau_B\mu_B + 2\mu_B r_1 - \mu_B r_2\right)\right)$$

$$< x_{2BA}\left(= -\frac{1}{6\mu_A\left(\mu_A + \mu_B\right)}\left(\Omega^\tau_B\mu_A - 3\Omega^\tau_A\mu_B - 2\Omega^\tau_A\mu_A - 2\mu_A r_1 + 4\mu_A r_2 + 3\mu_B r_2\right)\right).$$

Thus, the condition under which $x_{2AB} < x_{2BA}$ does not hold given $x_{1AB} = x_{1BA}$ is $x_{2AB} - x_{2BA} \geq 0$, i.e., $\Lambda \leq \mu_B r_2$. The condition under which $x_{1AB} = x_{1BA}$ arises given $x_{2AB} = x_{2BA}$ is that neither $x_{1AB} > x_{1BA}$ nor $x_{1AB} < x_{1BA}$ holds given $x_{2AB} = x_{2BA}$. Suppose $x_{1AB} > x_{1BA}$ given $x_{2AB} = x_{2BA}$. Then

$$x_{1AB}\left(= -\frac{1}{6\mu_B\left(\mu_A + \mu_B\right)}\left(\Omega^\tau_A\mu_B - 3\Omega^\tau_B\mu_A - 2\Omega^\tau_B\mu_B + 3\mu_A r_1 - 2\mu_B r_2 + 4\mu_B r_1\right)\right)$$

$$> x^{C4}_{1BA}\left(= \frac{1}{6\mu_A\left(\mu_A + \mu_B\right)}\left(2\Omega^\tau_A\mu_A + 3\Omega^\tau_A\mu_B - \Omega^\tau_B\mu_A + 2\mu_A r_2 - \mu_A r_1\right)\right).$$

Thus, the condition under which $x_{1AB} > x_{1BA}$ does not hold given $x_{2AB} = x_{2BA}$ is $x_{1AB} \leq x_{1BA}$, i.e., $\Lambda \geq -\mu_A r_1$. Suppose $x_{1AB} < x_{1BA}$ given $x_{2AB} = x_{2BA}$. Then

$$x_{1AB} \left(= \frac{1}{6\mu_B (\mu_A + \mu_B)} (3\Omega_B^\tau \mu_A - \Omega_A^\tau \mu_B + 2\Omega_B^\tau \mu_B - \mu_B r_1 + 2\mu_B r_2) \right)$$

$$\leq x_{1BA} \left(= -\frac{1}{6\mu_A (\mu_A + \mu_B)} (\Omega_B^\tau \mu_A - 3\Omega_A^\tau \mu_B - 2\Omega_A^\tau \mu_A + 4\mu_A r_1 - 2\mu_A r_2 + 3\mu_B r_1) \right).$$

Thus, the condition under which $x_{1AB} < x_{1BA}$ does not hold given $x_{2AB} = x_{2BA}$ is $x_{1AB} \geq x_{1BA}$, i.e., $\Lambda \leq \mu_B r_1$. Therefore, the combination of $x_{1AB} = x_{1BA}$ and $x_{2AB} = x_{2BA}$ arises as a Nash equilibrium if $-\mu_A r_1 < \Lambda < \mu_B r_1$.

The condition under which $x_{2AB} < x_{2BA}$ arises given $x_{1AB} < x_{1BA}$ is that $x_{2AB}(= \frac{1}{3\mu_B} (\Omega_B^\tau)) < x_{2BA}(= \frac{1}{3\mu_A} (\Omega_A^\tau + r_1 - 2r_2))$, which becomes $\Omega_A^\tau \mu_B - \Omega_B^\tau \mu_A + \mu_B r_1 - 2\mu_B r_2 > 0$. This condition is equivalent to $\Lambda > \mu_B(2r_2 - r_1)$. Now the condition under which $x_{1AB} < x_{1BA}$ arises given $x_{2AB} < x_{2BA}$ is that $x_{1AB}(= \frac{1}{3\mu_B} \Omega_B^\tau) > x_{1BA}(= \frac{1}{3\mu_A} (\Omega_A^\tau - 2r_1 + r_2))$, which becomes $(\Omega_A^\tau \mu_B - \Omega_B^\tau \mu_A - 2\mu_B r_1 + \mu_B r_2) > 0$. This condition is equivalent to $\Lambda > \mu_B(2r_1 - r_2)$. Since $r_1 < r_2$, the combination of $x_{2AB} > x_{2BA}$ and $x_{1AB} > x_{1BA}$ arises as a Nash equilibrium if $\Lambda > \mu_B(2r_2 - r_1)$.

The condition under which $x_{2AB} = x_{2BA}$ arises given $x_{1AB} > x_{1BA}$ is that neither $x_{2AB} > x_{2BA}$ nor $x_{2AB} < x_{2BA}$ holds given $x_{1AB} > x_{1BA}$. Suppose $x_{2AB} > x_{2BA}$ holds given $x_{1AB} > x_{1BA}$. Then we have $x_{2AB}(= \frac{1}{3\mu_B} (\Omega_B^\tau - 2r_2 + r_1)) > x_{2BA}(= \frac{1}{3\mu_A} (\Omega_A^\tau))$. As pointed out above, the combination of $x_{2AB} < x_{2BA}$ and $x_{1AB} > x_{1BA}$ never occurs. Thus, the condition under which $x_{2AB} = x_{2BA}$ arises given $x_{1AB} > x_{1BA}$ is that $\frac{1}{3\mu_B} (\Omega_B^\tau - 2r_2 + r_1) < \frac{1}{3\mu_A} \Omega_A^\tau$ holds, that is, $(\Omega_A^\tau \mu_B - \Omega_B^\tau \mu_A - \mu_A r_1 + 2\mu_A r_2) > 0$ holds. Thus, the condition becomes $\mu_A (r_1 - 2r_2) < \Lambda$. Now the condition under which $x_{1AB} > x_{1BA}$ arises given $x_{2AB} = x_{2BA}$ is that

$$x_{1AB} \left(= -\frac{1}{6\mu_B (\mu_A + \mu_B)} (\Omega_A^\tau \mu_B - 3\Omega_B^\tau \mu_A - 2\Omega_B^\tau \mu_B + 3\mu_A r_1 - 2\mu_B r_2 + 4\mu_B r_1) \right)$$

$$> x_{1BA} \left(= \frac{1}{6\mu_A (\mu_A + \mu_B)} (2\Omega_A^\tau \mu_A + 3\Omega_A^\tau \mu_B - \Omega_B^\tau \mu_A + 2\mu_A r_2 - \mu_A r_1) \right),$$

which becomes $(\Omega_A^\tau \mu_B - \Omega_B^\tau \mu_A + \mu_A r_1) < 0$. This condition is equivalent to $\Lambda < -\mu_A r_1$.Thus, the combination of $x_{2AB} = x_{2BA}$ and $x_{1AB} > x_{1BA}$ arises as a Nash equilibrium if $\mu_A (r_1 - 2r_2) < \Lambda < -\mu_A r_1$.

The condition under which $x_{2AB} = x_{2BA}$ arises given $x_{1AB} < x_{1BA}$ is that neither $x_{2AB} > x_{2BA}$ nor $x_{2AB} < x_{2BA}$ holds given $x_{1AB} < x_{1BA}$. The combination of $x_{2AB} > x_{2BA}$ and $x_{1AB} < x_{1BA}$ never occurs. Suppose that $x_{2AB} < x_{2BA}$ holds given $x_{1AB} < x_{1BA}$. Then we have $x_{2AB}\left(=\frac{1}{3\mu_B}\Omega_B^\tau\right) < x_{2BA}\left(=\frac{1}{3\mu_A}\left(\Omega_A^\tau - 2r_2 + r_1\right)\right)$. Thus, the condition under which $x_{2AB} = x_{2BA}$ arises given $x_{1AB} < x_{1BA}$ is that $\frac{1}{3\mu_B}\Omega_B^\tau > \frac{1}{3\mu_A}\left(\Omega_A^\tau - 2r_2 + r_1\right)$ holds, that is, $(\Omega_A^\tau\mu_B - \Omega_B^\tau\mu_A + \mu_B r_1 - 2\mu_B r_2) < 0$ holds. Thus, the condition becomes $\Lambda < \mu_B(2r_2 - r_1)$. Now the condition under which $x_{1AB} < x_{1BA}$ arises given $x_{2AB} = x_{2BA}$ is that

$$x_{1AB}\left(=\frac{1}{6\mu_B\left(\mu_A+\mu_B\right)}\left(3\Omega_B^\tau\mu_A - \Omega_A^\tau\mu_B + 2\Omega_B^\tau\mu_B - \mu_B r_1 + 2\mu_B r_2\right)\right)$$

$$< x_{1BA}\left(=-\frac{1}{6\mu_A\left(\mu_A+\mu_B\right)}\left(\Omega_B^\tau\mu_A - 3\Omega_A^\tau\mu_B - 2\Omega_A^\tau\mu_A + 4\mu_A r_1 - 2\mu_A r_2 + 3\mu_B r_1\right)\right),$$

which becomes $(\Omega_B^\tau\mu_A - \Omega_A^\tau\mu_B + \mu_B r_1) < 0$. This condition is equivalent to $\Lambda > \mu_B r_1$. Thus, the combination of $x_{2AB} = x_{2BA}$ and $x_{1AB} < x_{1BA}$ arises as a Nash equilibrium if $\mu_B r_1 < \Lambda < \mu_B(2r_2 - r_1)$.

The condition under which $x_{1AB} = x_{1BA}$ arises given $x_{2AB} > x_{2BA}$ is that neither $x_{1AB} > x_{1BA}$ nor $x_{1AB} < x_{1BA}$ holds given $x_{2AB} > x_{2BA}$. Suppose $x_{2AB} > x_{2BA}$ holds given $x_{1AB} > x_{1BA}$. Then we have $x_{1AB}\left(=\frac{1}{3\mu_B}\left(\Omega_B^\tau - 2r_1 + r_2\right)\right) > x_{1BA}\left(=\frac{1}{3\mu_A}\Omega_A^\tau\right)$. The combination of $x_{1AB} < x_{1BA}$ and $x_{2AB} > x_{2BA}$ never occurs. Thus, the condition under which $x_{1AB} = x_{1BA}$ arises given $x_{2AB} > x_{2BA}$ is that $\frac{1}{3\mu_B}\left(\Omega_B^\tau - 2r_1 + r_2\right) < \frac{1}{3\mu_A}\Omega_A^\tau$ holds, that is, $(\Omega_A^\tau\mu_B - \Omega_B^\tau\mu_A - \mu_A r_2 + 2\mu_A r_1) > 0$ holds. Thus, the condition becomes $2\mu_A\left(r_2 - 2r_1\right) < \Lambda$. Now the condition under which $x_{2AB} > x_{2BA}$ arises given $x_{1AB} = x_{1BA}$ is that

$$x_{2AB}\left(=-\frac{1}{6\mu_B\left(\mu_A+\mu_B\right)}\left(\Omega_A^\tau\mu_B - 3\Omega_B^\tau\mu_A - 2\Omega_B^\tau\mu_B + 3\mu_A r_2 - 2\mu_B r_1 + 4\mu_B r_2\right)\right)$$

$$> x_{2BA}\left(=\frac{1}{6\mu_A\left(\mu_A+\mu_B\right)}\left(2\Omega_A^\tau\mu_A + 3\Omega_A^\tau\mu_B - \Omega_B^\tau\mu_A + 2\mu_A r_1 - \mu_A r_2\right)\right),$$

which becomes $(\Omega_A^\tau\mu_B - \Omega_B^\tau\mu_A + \mu_A r_2) < 0$. This condition is equivalent to $\Lambda < -\mu_A r_2$. Since $-\mu_A r_2 < 2\mu_A\left(r_2 - 2r_1\right)$ with $r_1 < r_2$, the combination of $x_{2AB} = x_{2BA}$ and $x_{1AB} > x_{1BA}$ never arises as a Nash equilibrium.

The condition under which $x_{1AB} = x_{1BA}$ arises given $x_{2AB} < x_{2BA}$ is that neither $x_{1AB} > x_{1BA}$ nor $x_{1AB} < x_{1BA}$ holds given $x_{2AB} < x_{2BA}$. The combination of $x_{1AB} > x_{1BA}$ and $x_{2AB} < x_{2BA}$ never occurs. Suppose $x_{1AB} < x_{1BA}$ holds given $x_{2AB} < x_{2BA}$. Then we have $x_{1AB}\left(=\frac{1}{3\mu_B}\Omega_B^\tau\right) < x_{1BA}\left(=\frac{1}{3\mu_A}\left(\Omega_A^\tau - 2r_1 + r_2\right)\right)$. Thus, the condition under which $x_{1AB} = x_{1BA}$ arises given $x_{2AB} < x_{2BA}$ is that $\frac{1}{3\mu_B}\Omega_B^\tau > \frac{1}{3\mu_A}\left(\Omega_A^\tau - 2r_1 + r_2\right)$ holds, that is, $(\Omega_A^\tau\mu_B - \Omega_B^\tau\mu_A - 2\mu_B r_1 + \mu_B r_2) < 0$ holds. Thus, the condition becomes $\Lambda < \mu_B\left(2r_1 - r_2\right)$.

Now the condition under which $x_{2AB} < x_{2BA}$ arises given $x_{1AB} = x_{1BA}$ is that

$$x_{2AB}\left(= \frac{1}{6\mu_B\left(\mu_A+\mu_B\right)}\left(3\Omega_B^{\tau}\mu_A - \Omega_A^{\tau}\mu_B + 2\Omega_B^{\tau}\mu_B + 2\mu_B r_1 - \mu_B r_2\right)\right)$$

$$< x_{2BA}\left(= -\frac{1}{6\mu_A\left(\mu_A+\mu_B\right)}\left(\Omega_B^{\tau}\mu_A - 3\Omega_A^{\tau}\mu_B - 2\Omega_A^{\tau}\mu_A - 2\mu_A r_1 + 4\mu_A r_2 + 3\mu_B r_2\right)\right),$$

which becomes $(\Omega_B^{\tau}\mu_A - \Omega_A^{\tau}\mu_B + \mu_B r_2) < 0$. This condition is equivalent to $\Lambda > \mu_B r_2$. Since $\mu_B\left(2r_1 - r_2\right) < \mu_B r_2$ with $r_1 < r_2$, the combination of $x_{1AB} = x_{1BA}$ and $x_{2AB} > x_{2BA}$ never arises as a Nash equilibrium.

Appendix D

In this appendix, we first prove that an increase in τ_B decreases firm T_1's total profits in type-4 equilibrium and then show that an increase in τ_A may increase firm T_1's total profits in type-4 equilibrium and an increase in τ_B may increase firm T_1's total profits in type-5 equilibrium.

Firm T_1's total profits in type-4 equilibrium is given by $\Pi_1^{C4} = \mu_B(x_{1AB}^{C4})^2 + \mu_A(x_{1BA}^{C4})^2$. Differentiating this with respect to τ_i $(i = A, B)$, we have

$$\frac{d\Pi_1^{C4}}{d\tau_i} = 2\mu_B x_{1AB}^{C4}\frac{dx_{1AB}^{C4}}{d\tau_i} + 2\mu_A x_{1BA}^{C4}\frac{dx_{1BA}^{C4}}{d\tau_i}.$$

In type-4 equilibrium, $x_{1AB}^{C4} > x_{1BA}^{C4}$ with $\tau_A = 0$. Since $\mu_B\frac{dx_{1AB}^{C4}}{d\tau_B} = -\frac{3\mu_A+2\mu_B}{6(\mu_A+\mu_B)}$ and $\mu_A\frac{dx_{1BA}^{C4}}{d\tau_B} = \frac{\mu_A}{6(\mu_A+\mu_B)}$, we obtain $\frac{d\Pi_1^{C4}}{d\tau_B} < 0$ in type-4 equilibrium.

Next we consider the effect of an increase in τ_A on firm T_1's total profits in type-4 equilibrium. With $\tau_B = 0$, $x_{1AB}^{C4} > x_{1BA}^{C4}$. We have $\mu_B\frac{dx_{1AB}^{C4}}{d\tau_A} = \frac{\mu_B}{6(\mu_A+\mu_B)}$ and $\mu_A\frac{dx_{1BA}^{C4}}{d\tau_A} = -\frac{2\mu_A+3\mu_B}{6(\mu_A+\mu_B)}$. Thus, as long as the gap between x_{1AB}^{C4} and x_{1BA}^{C4} is small, we obtain $\frac{d\Pi_1^{C4}}{d\tau_A} < 0$. The gap becomes the largest with $\tau_A = \frac{\Omega_A\mu_B - \Omega_B\mu_A - \mu_A r_1 + 2\mu_A r_2}{\mu_B}$. Thus, if the following holds, for example,

$$\begin{aligned} x_{1AB}^{C4}\Big|_{\tau_A=\frac{\Omega_A\mu_B-\Omega_B\mu_A-\mu_A r_1+2\mu_A r_2}{\mu_B}}\ (\quad &= \quad x_{1AB}^{C1}) < 3\, x_{1BA}^{C4}\Big|_{\tau_A=\frac{\Omega_A\mu_B-\Omega_B\mu_A-\mu_A r_1+2\mu_A r_2}{\mu_B}} \\ &\Leftrightarrow \quad 2\Omega_B + 5r_1 - 7r_2 > 0, \end{aligned} \tag{A10}$$

then we have $\frac{d\Pi_1^{C4}}{d\tau_A} < 0$ in type-4 equilibrium. We can easily find a set of parameter values, Ω_A, Ω_B, μ_A, μ_B, r_1 and r_2, which satisfies (A10), $T_{AB}^{C4} > 0$, $T_{BA}^{C4} > 0$, $x_{1AB}^{C4} > x_{1BA}^{C4} > 0$, and $x_{2AB}^{C4} = x_{2BA}^{C4} > 0$. The condition (A10) is likely to hold if the gap between x_{1AB}^{C4} and x_{1BA}^{C4} is small, or, the gap between r_1 and r_2 is small. However, if the gap is large, $\frac{d\Pi_1^{C4}}{d\tau_A} > 0$ could hold. To see this, suppose $\mu_A = \mu_B$. Then we have $\frac{d\Pi_1^{C4}}{d\tau_A} > 0$ for τ_A the range of which is close enough to $\frac{\Omega_A\mu_B-\Omega_B\mu_A-\mu_A r_1+2\mu_A r_2}{\mu_B}$ if the following holds:

$$\begin{aligned} x^{C4}_{1AB}\Big|_{\tau_A=\frac{\Omega_A\mu_B-\Omega_B\mu_A-\mu_A r_1+2\mu_A r_2}{\mu_B}} (&= x^{C1}_{1AB}) > 5\, x^{C4}_{1BA}\Big|_{\tau_A=\frac{\Omega_A\mu_B-\Omega_B\mu_A-\mu_A r_1+2\mu_A r_2}{\mu_B}} \\ &\Leftrightarrow 4\Omega_B+7r_1-11r_2<0. \end{aligned} \tag{A11}$$

We consider the conditions under which (A11) holds. Setting $\Omega_B = ar_1$ and $r_2 = br_2$, (A11) is equivalent to $4a+7-11b < 0$. For $x^{C4}_{1AB} > 0$ and $x^{C4}_{2AB} > 0$, we need $r_2 < \frac{\Omega_B+r_1}{2} \Leftrightarrow 2b < a+1$. Once we find a pair (a, b) which satisfies both $4a - 11b < -7$ and $a - 2b > -1$, it is easy to find a set of parameter values, Ω_A, Ω_B, μ_A, μ_B, r_1 and r_2, which satisfies (A11), $T^{C4}_{AB} > 0$, $T^{C4}_{BA} > 0$, $x^{C4}_{1AB} > x^{C4}_{1BA} > 0$, and $x^{C4}_{2AB} = x^{C4}_{2BA} > 0$. For example, $\Omega_A = 30$, $\Omega_B = 20$, $\mu_A = 1$, $\mu_B = 1$, $r_1 = 11$ and $r_2 = 15$ are such a set of parameters.

Lastly, we consider the effect of an increase in τ_B on firm T_1's total profits in type-5 equilibrium, which is given by given by $\Pi^{C5}_1 = \mu_B(x^{C5}_{1AB})^2 + \mu_A(x^{C5}_{1BA})^2$. Differentiating this with respect to τ_B, we have

$$\frac{d\Pi^{C5}_1}{d\tau_B} = 2\mu_B x^{C5}_{1AB}\frac{dx^{C4}_{1AB}}{d\tau_B} + 2\mu_A x^{C5}_{1BA}\frac{dx^{C5}_{1BA}}{d\tau_B}.$$

With $\tau_A = 0$, $x^{C5}_{1AB} < x^{C5}_{1BA}$. We have $\mu_B\frac{dx^{C5}_{1AB}}{d\tau_B} = -\frac{3\mu_A+2\mu_B}{6(\mu_A+\mu_B)}$ and $\mu_A\frac{dx^{C5}_{1BA}}{d\tau_B} = \frac{\mu_A}{6(\mu_A+\mu_B)}$. Thus, as long as the gap between x^{C5}_{1AB} and x^{C5}_{1BA} is small, we obtain $\frac{d\Pi^{C5}_1}{d\tau_B} < 0$. The gap becomes the largest with $\tau_B = \frac{-\Omega_A\mu_B+\Omega_B\mu_A-\mu_B r_1+2\mu_B r_2}{\mu_A}$. For example, if the following holds:

$$\begin{aligned} x^{C5}_{1AB}\Big|_{\tau_B=\frac{-\Omega_A\mu_B+\Omega_B\mu_A-\mu_B r_1+2\mu_B r_2}{\mu_A}} (&= x^{C3}_{1AB}) < 3\, x^{C5}_{1BA}\Big|_{\tau_A=\frac{-\Omega_A\mu_B+\Omega_B\mu_A-\mu_B r_1+2\mu_B r_2}{\mu_A}} \\ &\Leftrightarrow 2\Omega_A+5r_1-7r_2>0, \end{aligned} \tag{A12}$$

then we have $\frac{d\Pi^{C5}_1}{d\tau_B} < 0$ in type-5 equilibrium. The difference between (A10) and (A12) is that Ω_B in (A10) is replaced by Ω_A in (A12). It is easy to find a set of parameter values, Ω_A, Ω_B, μ_A, μ_B, r_1 and r_2, which satisfies (A12), $T^{C5}_{AB} > 0$, $T^{C5}_{BA} > 0$, $x^{C5}_{1BA} > x^{C5}_{1AB} > 0$, and $x^{C5}_{2AB} = x^{C5}_{2BA} > 0$. Similarly, we have $\frac{d\Pi^{C5}_1}{d\tau_B} > 0$ for τ_B which is close enough to $\frac{-\Omega_A\mu_B+\Omega_B\mu_A-\mu_B r_1+2\mu_B r_2}{\mu_A}$ if

$$\begin{aligned} x^{C5}_{1AB}\Big|_{\tau_B=\frac{-\Omega_A\mu_B+\Omega_B\mu_A-\mu_B r_1+2\mu_B r_2}{\mu_A}} &> 5\, x^{C3}_{1AB}\Big|_{\tau_B=\frac{-\Omega_A\mu_B+\Omega_B\mu_A-\mu_B r_1+2\mu_B r_2}{\mu_A}} \\ &\Leftrightarrow 4\Omega_A+7r_1-11r_2<0 \end{aligned} \tag{A13}$$

holds. The difference between (A11) and (A13) is that Ω_B in (A11) is replaced by Ω_A in (A13). Thus, we can find a set of parameter values, Ω_A, Ω_B, μ_A, μ_B, r_1 and r_2, which satisfies (A13), $T^{C5}_{AB} > 0$, $T^{C5}_{BA} > 0$, $x^{C5}_{1BA} > x^{C5}_{1AB} > 0$, and $x^{C5}_{2AB} = x^{C5}_{2BA} > 0$.

Appendix E

In this appendix, we show Proposition 8→. For this, we find a case in which an increase in τ_{1B} (τ_{2B}) actually leads firm T to stop shipping good A_1 (good A_2). For simplicity, we assume $\tau_{1B} > 0$, $\tau_{2B} = 0$ and $x_{AB}^{A_1} + x_{AB}^{A_2} < x_{BA}$. Then we have

$$T_{AB}^{M3} = \frac{\Omega_B^{A_1\tau}\mu_B^{A_2} + \Omega_B^{A_2\tau}\mu_B^{A_1}}{2\left(\mu_B^{A_1} + \mu_B^{A_2}\right)}, \quad x_{AB}^{A_k} = \frac{1}{\mu_B^{A_k}}\left(\Omega_B^{A_k\tau} - T_{AB}\right).$$

The profits of firm T from shipping both goods A_1 and A_2 are $\frac{\left(\Omega_B^{A_1\tau}\mu_B^{A_2} + \Omega_B^{A_2\tau}\mu_B^{A_1}\right)^2}{4\mu_B^{A_2}\mu_B^{A_1}\left(\mu_B^{A_1} + \mu_B^{A_2}\right)}$. When firm T ships only good A_2, we have $T_{AB} = \frac{1}{2}\Omega_B^{A_2\tau}$ and the profits from shipping only good A_2 are $\frac{(\Omega_B^{A_2\tau})^2}{4\mu_B^{A_2}}$. Thus, if $\Omega_B^{A_2\tau} > \frac{\Omega_B^{A_1\tau}}{\mu_B^{A_1}}\left(\mu_B^{A_1} + \sqrt{\mu_B^{A_1}\left(\mu_B^{A_1} + \mu_B^{A_2}\right)}\right)$, then the profits from shipping only firm A_2 are greater than those from shipping both goods A_1 and A_2. It should be noted that even if $x_{AB} > x_{BA}$ initially holds, stopping shipping good A_1 may lead to $x_{AB} \leq x_{BA}$ (where $x_{AB}^{A_1} = 0$). If this is the case, T_{BA} increases.

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Figures

Figure 1: Import demand and export supply curves and freight rate

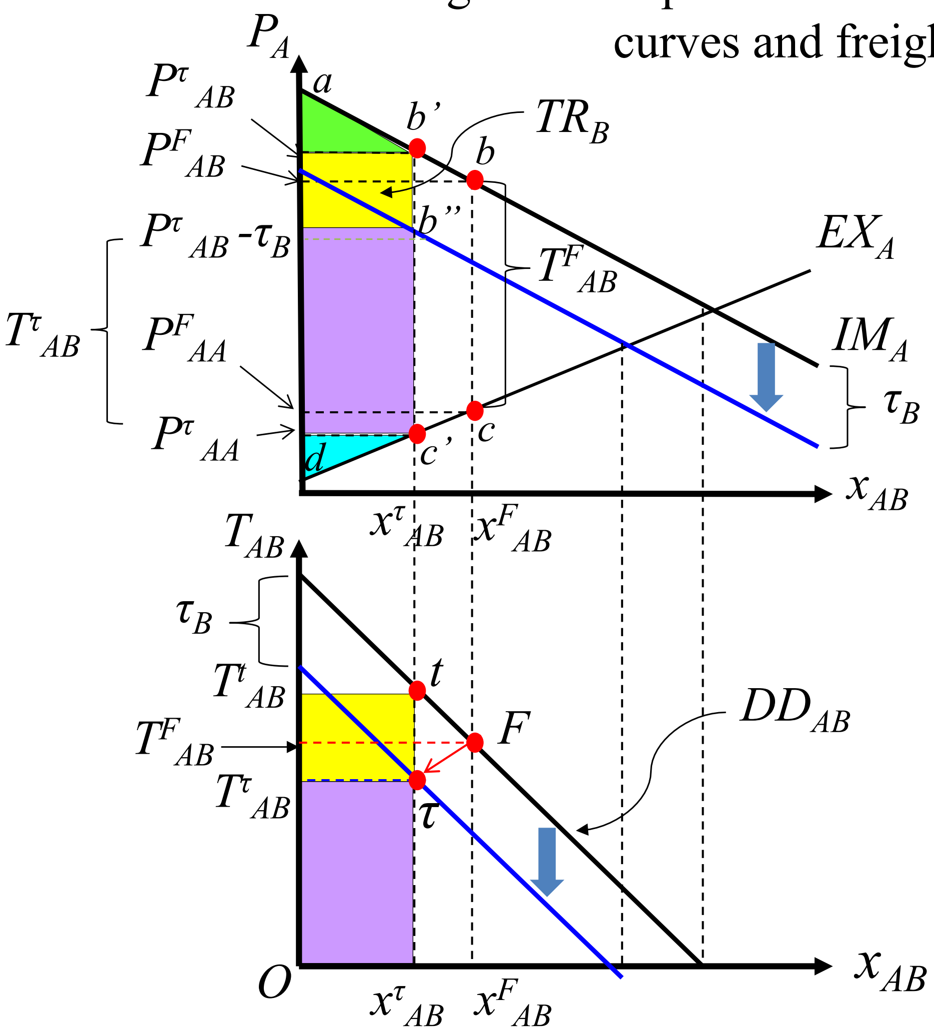


Figure 2: Type-2 equilibrium

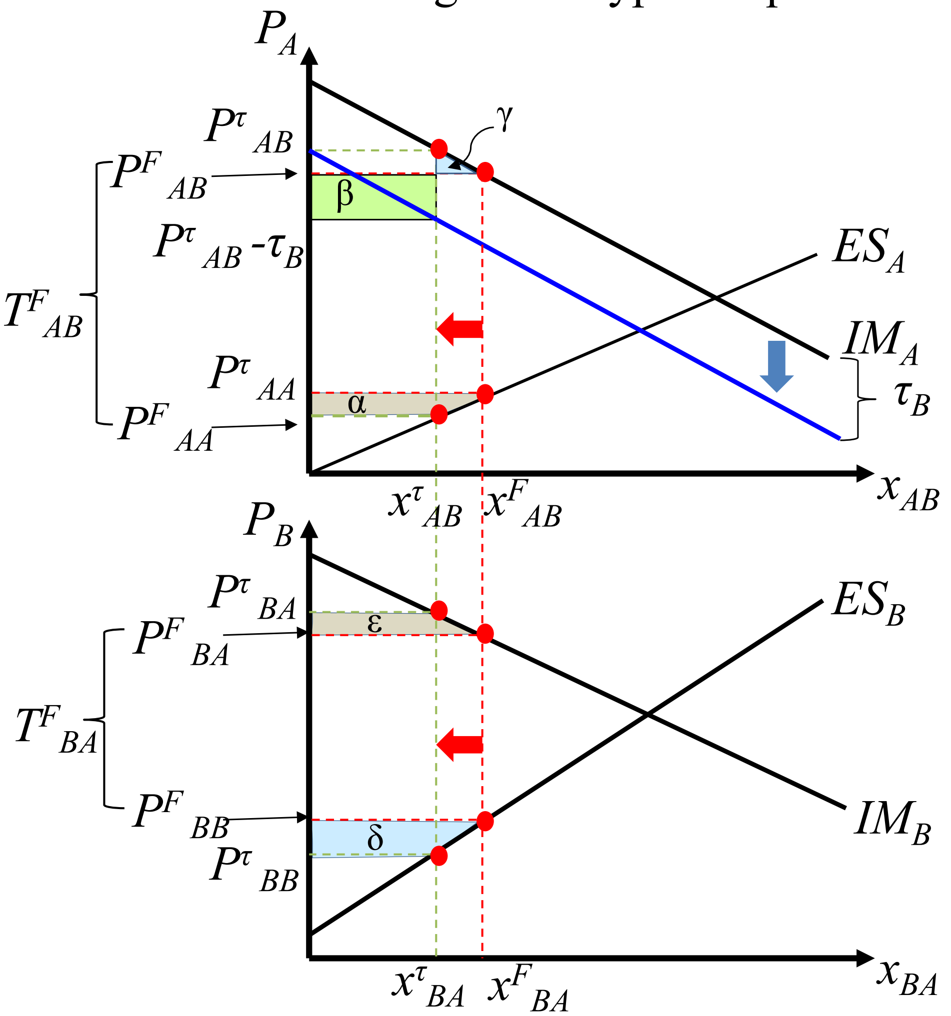


Figure 3 (a): Tariffs set by country B

($x_{AB} > x_{BA}$ with free trade)

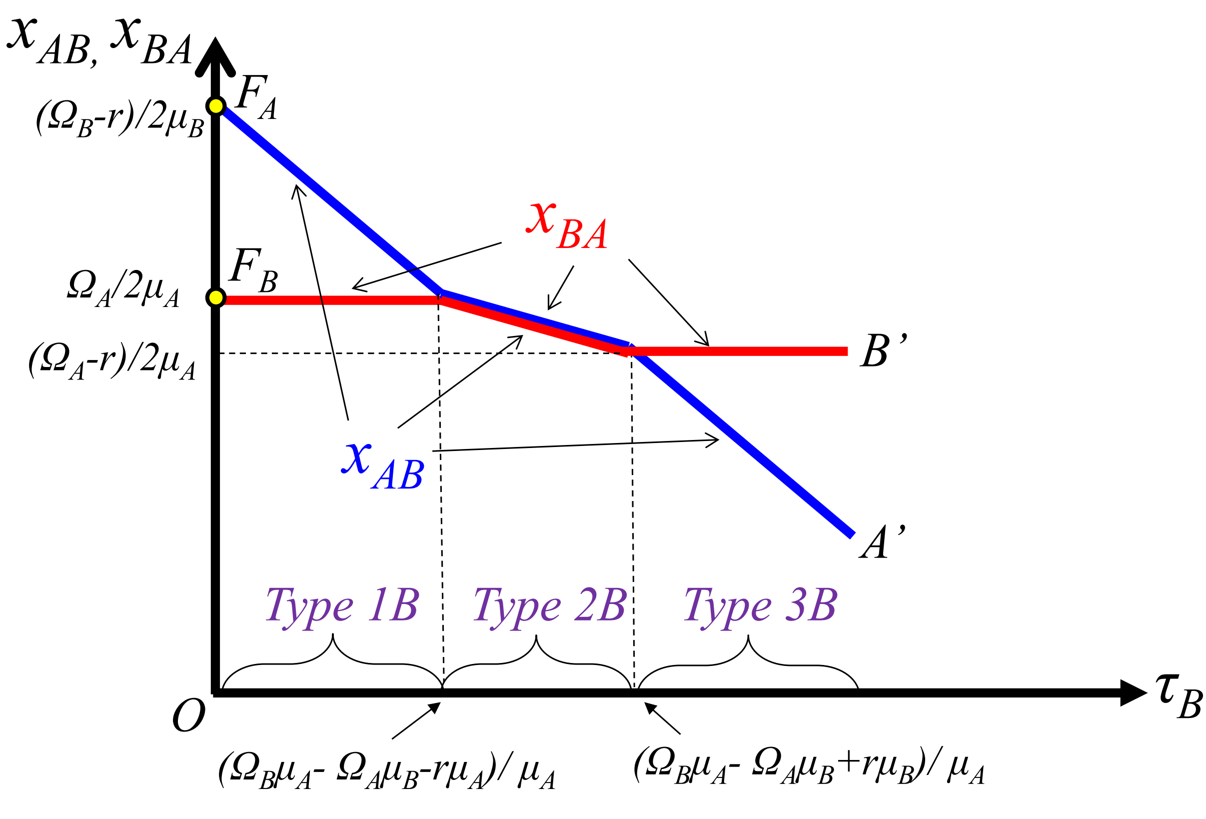


Figure 3 (b): Tariffs set by country *B*

($x_{AB} = x_{BA}$ with free trade)

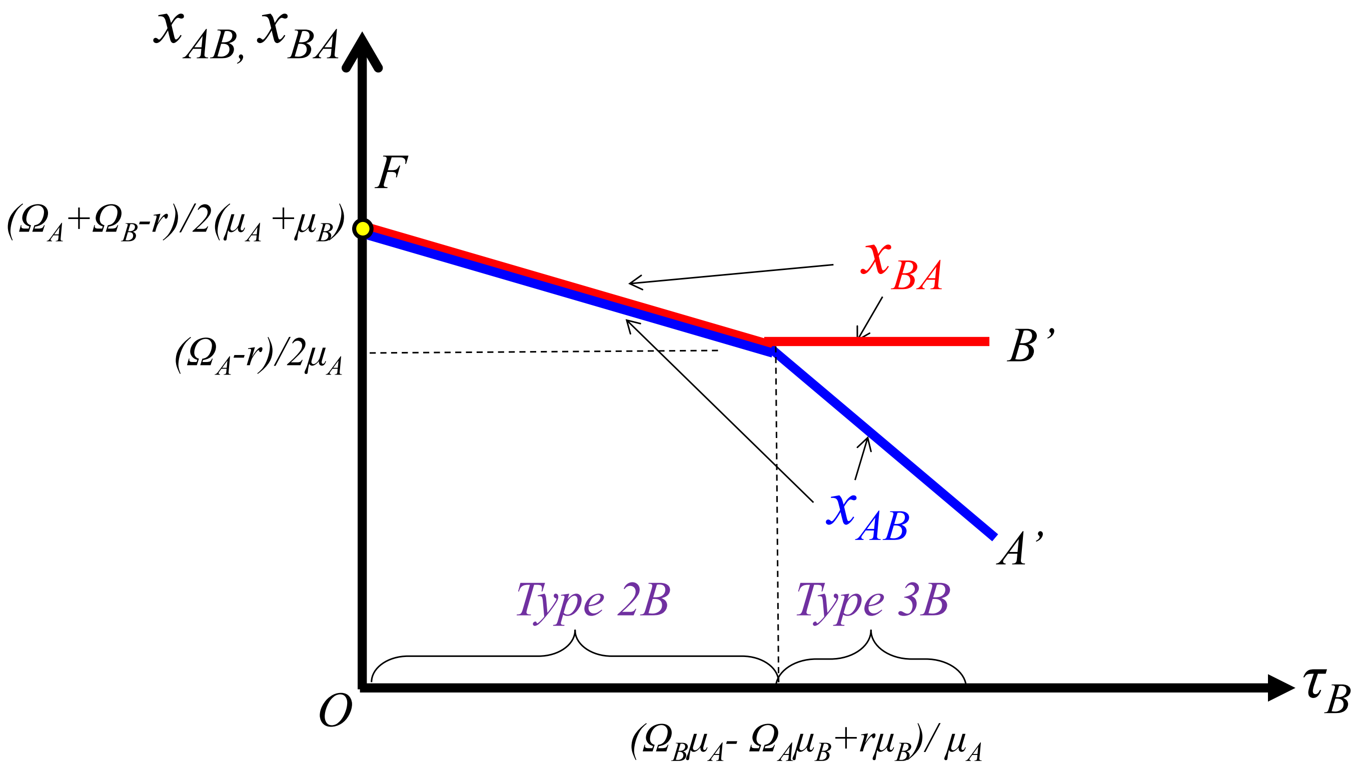


Figure 4: Multiple transport firms

(with $r_1 < r_2$)

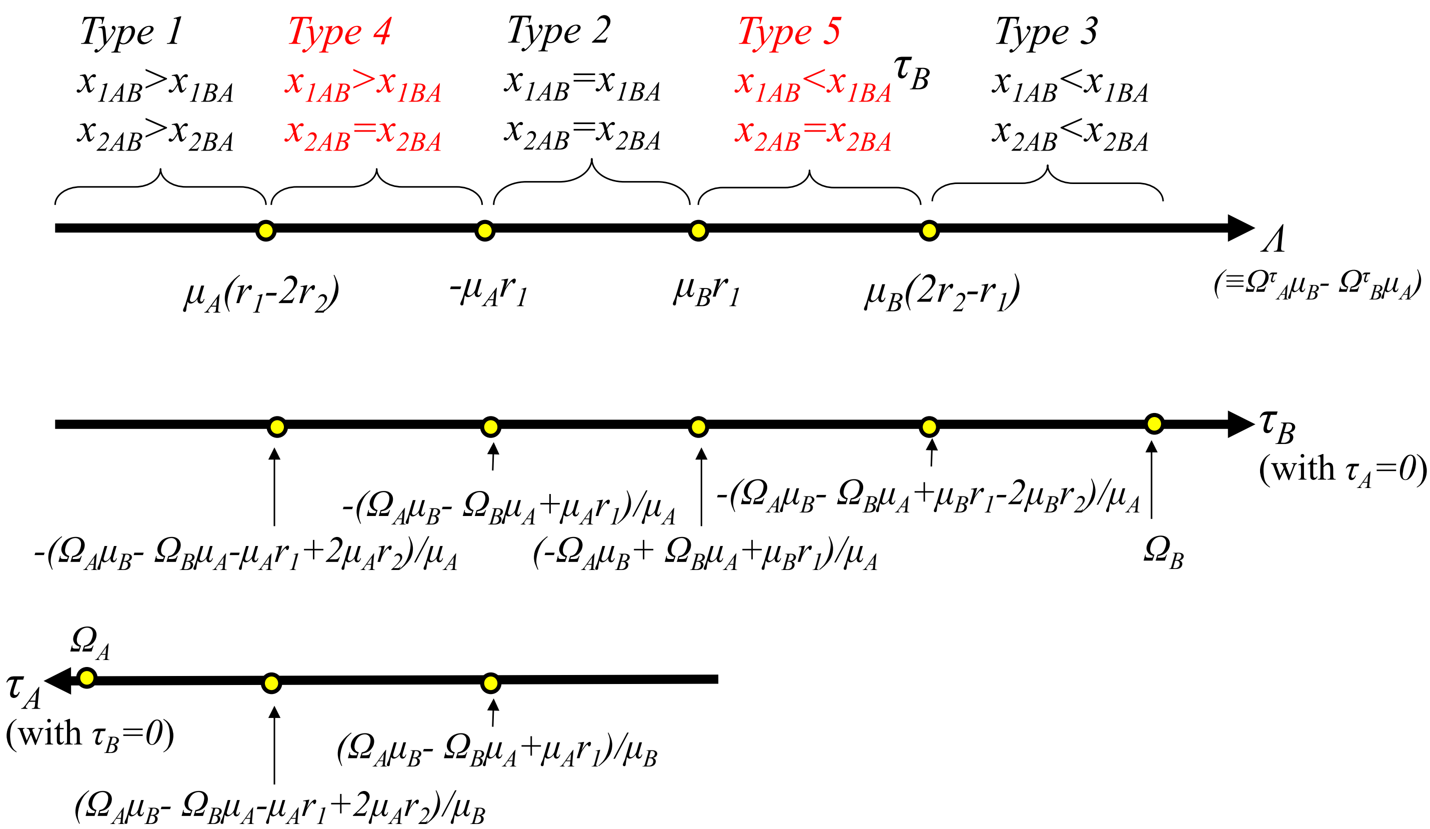


Figure 5: Country B's tariffs and shipping volumes

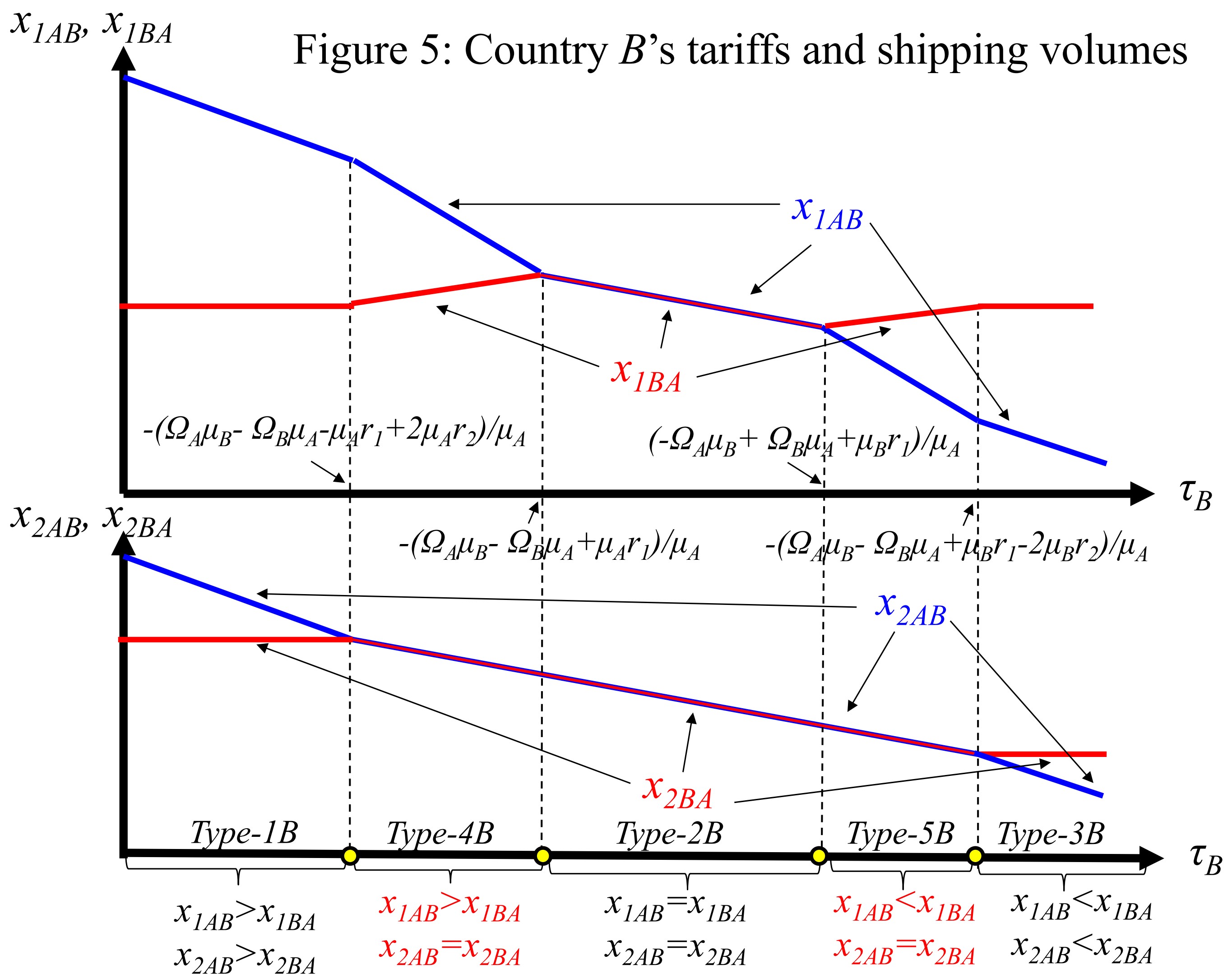


Figure 6: Country A's tariffs and shipping volumes

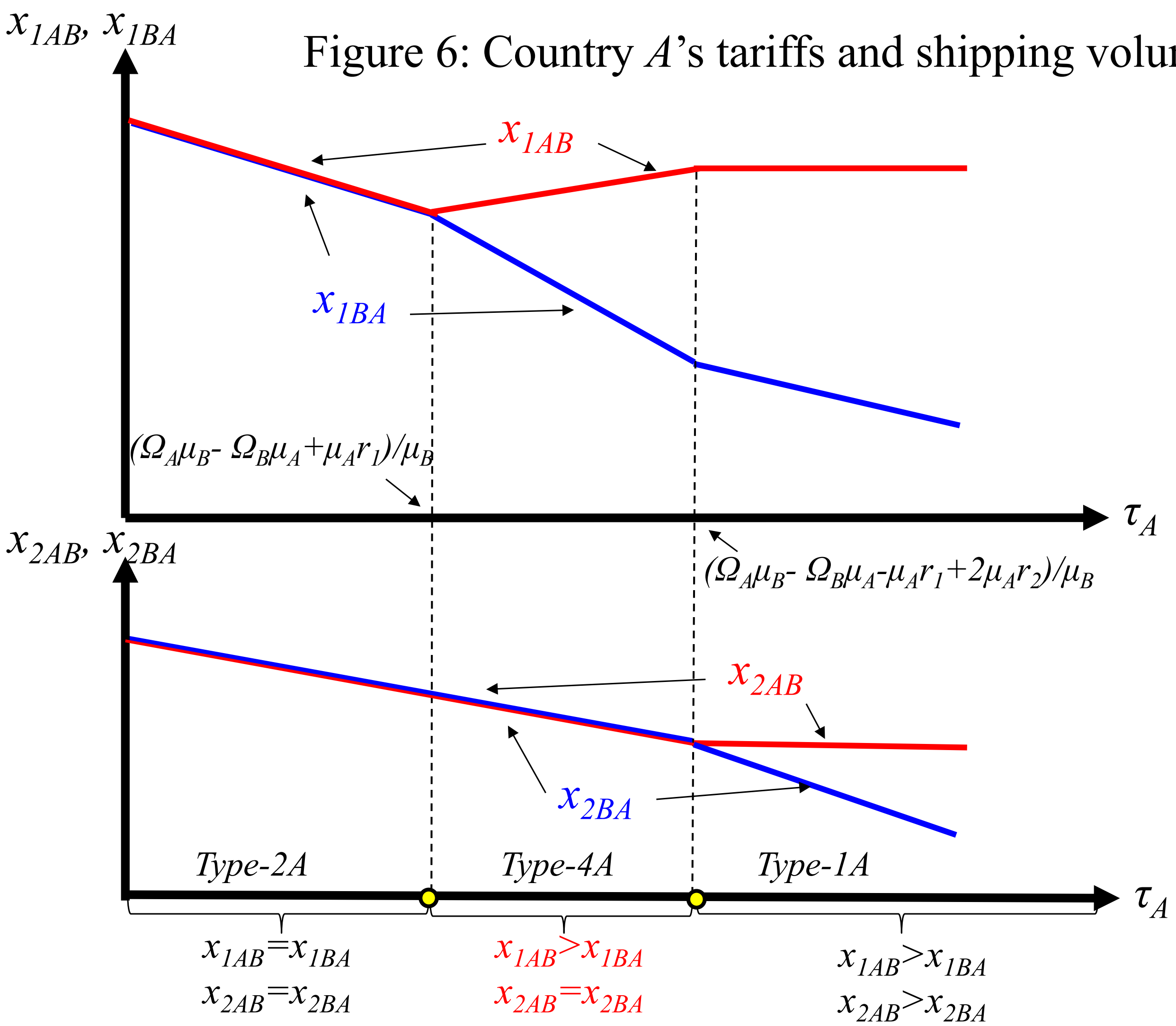
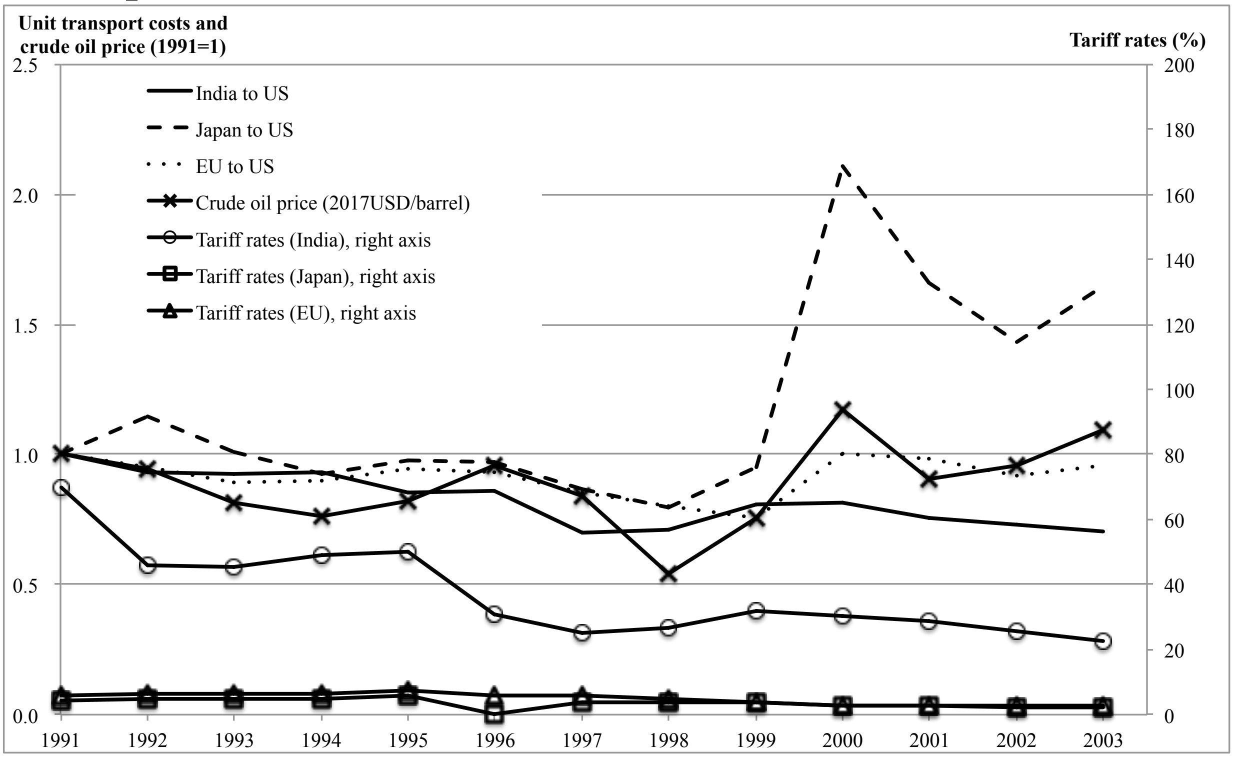
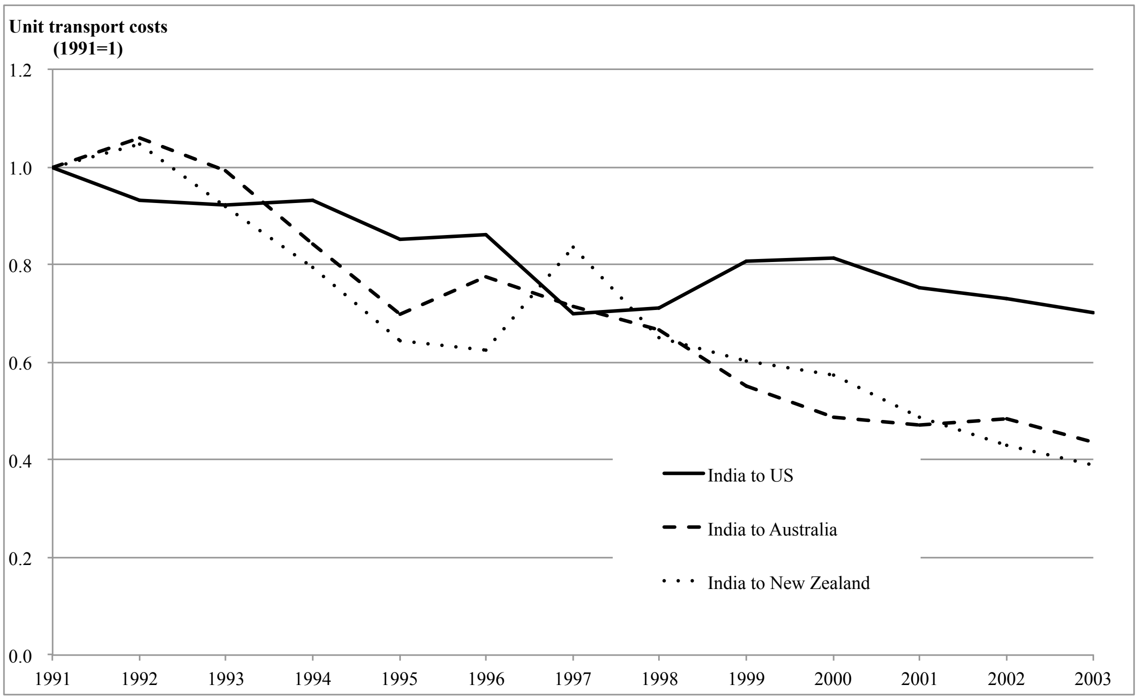


Figure 7: Import tariffs and transport costs on exports to the United States, 1991-2003



Note: Average unit transport costs (in 1990 US dollars) for all 2-digit HS code products subject to container transport from OECD Maritime Transport Costs database (adjusted with US GDP deflator). Tariff rates refer to the weighted average of each country's MFN rates from the World Development Indicators.

Figure 8 : India's transport costs on exports to the United States, Australia, and New Zealand



Note: Average unit transport costs (in 1990 US dollars) for all 2-digit HS code products subject to container transport from OECD Maritime Transport Costs database (adjusted with importing countries' GDP deflator). Tariff rates refer to the weighted average of each country's MFN rates from the World Development Indicators.