Chukyo University Institute of Economics

Discussion Paper Series

July 2016

No. 1605

Trade and Transportation in a Ricardian World

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Abstract

We propose a new linkage between comparative advantage and transportation costs by incorporating shipping-service trade into a continuum-of-good Ricardian model. In contrast to a simple Ricardian model, comparative advantage in supplying goods is prescribed not only by a given distribution of production technology but also by the trade pattern of shipping services. This complex structure leads to an unintuitive result that a technical improvement in shipping may reduce the number of export goods. Moreover, it is shown that a country importing shipping services may not be able to gain from trade in shipping services.

JEL Classification: F11, F61

Keywords: Transportation costs, Shipping-service trade, Comparative advantage, Gains from trade

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†We would like to thank Kenzo Abe, Jota Ishikawa, Takeshi Ogawa, Yasuhiro Takarada, Makoto Tawada, Taiyo Yoshimi, and the participants in the seminar at Nagoya Gakuin University, National University of Kaohsiung, Niigata University, and Okinawa University. Tomaru gratefully acknowledges financial support from the Japan Society for the Promotion of Science (Grant # 26780160).

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1 Introduction

Comparative advantage is a driving force of international trade. Recently, the role of comparative advantage in trade has been reappraised in the literature. (e.g., Costinot, 2009a, 2009b; Costinot et al, 2015). In particular, by endogenizing productivity differences, Costinot (2009a) argues that comparative advantage may not originate from given distributions of technologies and factor endowments. Moreover, Deardorff (2005, 2014) points out that trade costs can be a source of comparative advantage. While trade costs include a wide range of costs, such as tariffs, transportation costs, insurance, and so on, recent empirical studies suggest the importance of transportation costs (Anderson and Van Wincoop, 2004: Hummels, 2007). The main purpose of this study is to explore the relationship between transportation costs and comparative advantage.

Iceberg costs, which are a tractable way to express transportation costs, are applied in the broad field of economics.[1] In addition to simplicity of specification, interchangeability with shipping-service costs arguably facilitates this broad use of iceberg costs. The iceberg costs take a form of shrinkage in transit such that a portion of goods shipped actually arrives at export markets. Inevitably, a firm wishing to sell one unit of its good in other countries must ship more than one unit. This implies that whether or not the iceberg cost or the shipping-service cost is adopted does not matter for the realized resource allocation if the labor needed to produce the additional units is interpreted as the labor working in shipping-service sectors. As such, the iceberg costs are interchangeable with shipping-service costs. However, this interchangeability crucially depends on the assumption that there is no trade in shipping services. Grossman and Rossi-Hansberg (2008) describe offshoring as enabling a country to use foreign labor indirectly, which affects domestic resource allocation. By a similar mechanism, the trade in shipping services should reallocate the domestic labor, preventing the interchangeability between iceberg and shipping-service costs. This may cast doubt on the plausibility of the iceberg-cost assumption.

In this study, we endogenize transportation costs by introducing shipping-service sectors. En-

[1] Indeed, there are many studies that impose the iceberg-cost assumption. For example, see Melitz (2003) in international trade, Baldwin and Krugman (2004) in public economics, McCann (2005) in new economic geography, and Zeng and Zhao (2009) in environmental economics.

dogenous transportation costs themselves have been examined in the existing literature, in particular, on spatial economics (e.g., Behrens et al., 2009; Behrens and Picard, 2011). Nevertheless, to the best of our knowledge, there are no studies that analyze how the trade in shipping services affects comparative advantage in supplying goods. When related to comparative advantage, the shipping-service trade exhibits a new point of view in the patterns of production and trade. Consider a Ricardian model with two goods and one shipping service to export the goods. The comparative advantage, which is modified by exogenous unit-labor requirements for shipping, determines the trade pattern of goods if there is no trade in shipping services. However, this no longer holds true when the shipping-service trade begins. The trade pattern of goods is determined stepwise. First, comparative advantage in shipping services determines which country exports them, that is, the *pattern of trade in shipping service*. This pattern next influences the comparative advantage in supplying goods, which finally determines the trade pattern of goods. In this sense, the comparative advantage and the trade pattern of goods are endogenous. This point is in sharp contrast to a simple trade model, which claims that exogenous distributions of technology and/or factor endowments are a main source of trade.

This study aims to crystalize the complex structure that determines the comparative advantage in supplying goods and the trade patterns as simply as possible. To this end, we incorporate the shipping-service sectors into a continuum-of-goods, two-country, Ricardian trade model à la Dornbusch et al. (1977) (henceforth, DFS). The most closely related study is Matsuyama (2007). He extends the DFS model by introducing more than one production factor and two sectors: a domestic sector that supplies to the domestic market and an export sector that supplies to the export market. Using only domestic factors, the export sector performs all the activities associated with supplying goods, such as production, shipping goods, documentation for exports, communication with foreign dealers, and so on. Matsuyama (2007) shows that his model is isomorphic to the DFS model with iceberg costs, only if the unit costs in the export sector are proportionate to those in the domestic sector. However, while his model succeeds in compactly generalizing the DFS model with iceberg costs, it fails to nest the complex relationship between comparative advantage and shipping-service trade. We then rearrange the division of sectors as production and shipping-service sectors: all the goods for both domestic and export markets are produced in the production sector and the shipping services needed for the export market are supplied by the shipping-service sector. This division of sectors allows us to investigate how the pattern of trade in shipping services affects comparative advantage in supplying goods.

We obtain several unintuitive results that do not emerge in the DFS model with iceberg costs. The first result pertains to the impacts of technical improvements on the pattern of trade. A technical improvement in shipping seems to increase the number of export goods, because it reduces unit costs to supply goods to the export market. However, we show that if a country importing shipping services experiences a technical improvement, then the number of its export goods decreases. This unintuitive result is explained by the reallocation of labor from the production sector to the shipping-service sector. The technical improvement in shipping encourages the country to use more domestic services. Generating excess labor demand, this raises the relative wage. This increased relative wage makes the country lose its comparative advantage in supplying goods, which reduces the number of its export goods.

The second result is that a country importing shipping services may not be able to enjoy the gains from trade in shipping services. This can be explained by two offsetting effects: a positive welfare effect (*extensive margin effect*) and a negative welfare effect (*implicit tariff effect*). The extensive margin effect captures the welfare enhancement that the trade in shipping services generates through increasing the number of goods that can be produced. This effect is a key to Itoh and Kiyono's (1987) result, in which export subsidies enhance welfare in the DFS model. On the other hand, in contrast to Itoh and Kiyono (1987), the implicit tariff effect encompasses not only a terms-of-trade deteriorating effect due to a reduction in unit costs, but also a real-income decreasing effect that arises from the payments for shipping services to the foreign country. Owing to this strong, negative welfare effect, the trade in shipping services gives rise to a different welfare implication to Itoh and Kiyono (1987).

The remainder of this paper proceeds as follows. Section 2 presents the basic assumptions and describes our model in which there is no trade in shipping services. Section 3 then introduces trade in shipping services and demonstrates how this trade affects patterns of specialization. In Section 4, we compare the patterns of trade and welfare before and after trade in shipping services begins. Section 5 concludes.

2 Model

In this section, we propose a simple extension of the DFS model. While earlier works on the DFS model adopt iceberg costs as transportation costs, we introduce shipping-service sectors to explore the relationship between comparative advantage and transportation costs. We call the former the *iceberg model* and the latter the *shipping-service model*.

2.1 Consumers

Consider a world economy with two countries (home and foreign), one factor (labor), and a continuum of goods indexed by a real number $z \in [0, 1]$. Labor is perfectly mobile within countries and is immobile across them. Without loss of generality, we normalize labor endowments in the home and foreign countries to unity. Let home and foreign wages denote w and w^*, respectively. Throughout the study, we use asterisks to refer to foreign variables.

Preferences in the home and foreign countries are represented by the Cobb–Douglas utility,

$$U = \int_0^1 b(z) \ln c(z) dz \quad \text{and} \quad U^* = \int_0^1 b^*(z) \ln c^*(z) dz,$$

where $c(z)$ and $c^*(z)$ are the amounts of consumption good z, and $b(z)$ and $b^*(z)$ are the expenditure shares of good z with $\int_0^1 b(z)dz = \int_0^1 b^*(z)dz = 1$. The demand functions of good z are given by $c(z) = b(z)w/p(z)$ and $c^*(z) = b^*(z)w^*/p^*(z)$, where $p(z)$ and $p^*(z)$ are the prices of good z in the home and foreign countries, respectively.

2.2 Technology

Matsuyama (2007) assumes that (i) home and foreign unit costs of supplying each good depend on the destination, in particular, supplying goods to the export market is more costly than to the domestic market and (ii) all activities associated with supplying goods are served by domestic factors only.[2] We follow Matsuyama (2007) by assuming that the home cost for supplying one unit of good z to the home market is $\Phi(w)a(z) = wa(z)$, whereas the home unit cost for supplying to the foreign market is $\Psi(w, \theta)a(z) = w\psi(\theta)a(z)$ with $\psi = \psi(\theta) > 1$. The parameter $\theta \in (0, \infty)$ measures the extent of home export technology, such that $\psi'(\theta) > 0$.[3] Likewise, foreign unit costs are $\Phi^*(w^*)a^*(z) = w^*a^*(z)$ and $\Psi^*(w^*, \theta^*)a^*(z) = w^*\psi^*(\theta^*)a^*(z)$ with $\psi^* = \psi^*(\theta^*) > 1$ and $\psi^{*\prime}(\theta^*) > 0$ for any $\theta^* \in (0, \infty)$. We make the following assumption.

Assumption 1. *$A(z) := a^*(z)/a(z)$ satisfies the following properties:*

(1) $A'(z) < 0$.

(2) $\lim_{z\to 0} A(z) = \infty$ *and* $A(1) = 0$.

Under Assumption 1 (1), goods are ordered such that home has a comparative advantage in supplying goods with smaller z. Assumption 1 (2) implies that home cannot supply good $z = 1$ and foreign cannot supply good $z = 0$.[4] As indicated in the subsequent subsections 2.3 and 3.2, this assumption ensures that the free-trade equilibrium of the shipping-service model exists for any (θ, θ^*).

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[2]In Matsuyama's (2007) model with non-tradeable J factors of production, home and foreign factor prices are denoted by $\mathbf{w} = (w_1, w_2, \cdots, w_J)$ and $\mathbf{w}^* = (w_1^*, w_2^*, \cdots, w_J^*)$, respectively. Matsuyama (2007) assumes that home (res. foreign) can supply one unit of good z to its own market at a cost of $\Phi(\mathbf{w})a(z)$ (res. $\Phi^*(\mathbf{w}^*)a^*(z)$), while it can supply one unit of good z to the export market at a cost of $\Psi(\mathbf{w}, \theta)a(z)$ (res. $\Psi^*(\mathbf{w}^*, \theta^*)a^*(z)$). All functions Φ, Ψ, Φ^*, and Ψ^* are linear homogeneous, increasing, and concave in factor prices. In addition, $\Psi(\mathbf{w}, \theta) > \Phi(\mathbf{w})$ and $\Psi^*(\mathbf{w}^*, \theta^*) > \Phi(\mathbf{w}^*)$ are assumed.

[3]In Matsuyama (2007), an impact of θ is referred to as *unbiased globalization* if $\Psi(\mathbf{w}, \theta) = \theta\Phi(\mathbf{w})$, and *biased globalization* otherwise. In our model with only one factor, there is no difference between unbiased and biased globalization.

[4]The relaxation of Assumption 1 provides no additional insight. Rather, the assumption enables us to elude messy, meaningless proofs. Furthermore, it accommodates a wide class of functions, such as $A(z) = e^{\frac{1}{z}-1} - 1$, $A(z) = \cot \frac{\pi z}{2}$, $A(z) = \tan \frac{\pi}{2}(1 - z)$, $A(z) = -\ln z$, and so on.

In Matsuyama (2007), the word *supply* covers all the activities needed to convey goods to the consumers in a particular market. Inevitably, it is associated with various types of costs, such as production costs, shipping-service costs, distribution costs for local markets, and marketing costs. On the other hand, focusing only on production and shipping-service costs, we posit that each country has two sectors: a production sector and a shipping-service sector. In the production sector, each good is competitively produced with a linear technology in labor. Shipping one unit of good $z \in [0, 1]$ requires one unit of shipping service $z \in [0, 1]$. For the time being, we assume that all the shipping services are supplied domestically by the shipping-service sectors with a linear technology in labor. That is, there is no trade in shipping services between the home and foreign countries.

We make two further assumptions about the shipping services: (i) the unit costs are additively separable and (ii) the shipping services are required for international transportation only.[5] Under these assumptions, $a(z)$ (res. $a^*(z)$) is the home (res. foreign) unit labor requirement for production of good z and $A(z)$ is the relative unit labor requirement. Moreover, home and foreign unit labor requirements, $a_T(z)$ and $a_T^*(z)$, for shipping one unit of good z are in proportion to their unit labor requirements for production, that is, $a_T(z, \theta) := (\psi(\theta) - 1)\, a(z)$ and $a_T^*(z, \theta^*) := (\psi^*(\theta^*) - 1)\, a^*(z)$.

2.3 Equilibrium

To investigate the equilibrium of the shipping-service model, we define the following sets:

- Ω (res. Ω^*) is the set of goods that home (res. foreign) produces.
- E (res. E^*) is the set of home (res. foreign) export goods.
- N is the set of non-traded goods.

Since all consumers purchase each good from the supplier offering the lowest price, the sets of produced goods are given by $\Omega = \{z' \mid \omega \leq \psi^*(\theta^*)A(z')\}$ and $\Omega^* = \{z' \mid \omega \geq A(z')/\psi(\theta)\}$, where

[5] Recent empirical studies, such as Hummels and Skiba (2004) and Irarrazabal et al. (2015), support the first assumption by showing that ad valorem trade costs are rejected. The second assumption is made for simplicity, as in Falvey (1976), Cassing (1978), and Mai and Chiang (1983).

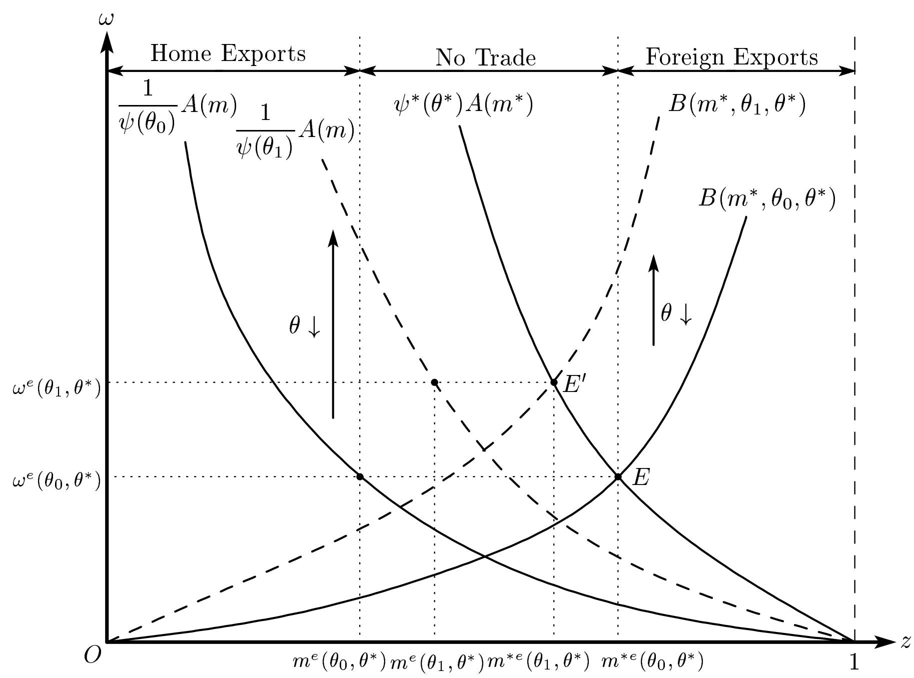

Figure 1: Equilibrium in the shipping-service model

$\omega := w/w^*$ is the home relative wage. By Assumption 1, there are unique borderline goods m and m^* satisfying

$$\omega = \frac{A(m)}{\psi(\theta)}, \tag{1}$$

$$\omega = \psi^*(\theta^*)A(m^*), \tag{2}$$

where $m < m^*$. Equations (1) and (2) simplify the patterns of production as $\Omega = [0, m^*]$ and $\Omega^* = [m, 1]$, respectively. In turn, good $z \in [0, m]$ is produced only by the home country and good $z \in [m^*, 1]$ is produced only by the foreign country. Hence, the patterns of trade are characterized by $E = [0, m]$, $E^* = [m^*, 1]$, and $N = (m, m^*)$. As observed from Figure 1, for a given ω, an improvement in home shipping technology (i.e., a decrease in θ) contracts Ω^* through an upward shift of $A(m)/\psi(\theta)$. Likewise, an improvement in foreign shipping technology contracts Ω through a downward shift of $\psi^*(\theta^*)A(m^*)$.

The relative wage rate ω is determined by the trade-balance condition, which is given by

$$\omega = B(m^*, \theta, \theta^*) := \frac{\int_0^{f_1(m^*,\theta,\theta^*)} b^*(z)dz}{\int_{m^*}^1 b(z)dz}, \tag{3}$$

where $m = f_1(m^*, \theta, \theta^*) := A^{-1}(\psi(\theta)\psi^*(\theta^*)A(m^*))$ and A^{-1} is the inverse function of A. The denominator on the right-hand side of equation (3) is the home average propensity to import, while the numerator is the foreign average propensity to import. Note that B increases with m^*; that is, the smaller is the number of foreign export goods (and thus, the larger is the number of home export goods), the larger is the relative wage. Moreover, B decreases with θ and θ^*, because the technical improvements in shipping increase the foreign propensity to import for a given m^*.

Let us denote the equilibrium by $(\omega^e(\theta, \theta^*), m^e(\theta, \theta^*), m^{*e}(\theta, \theta^*))$, which is characterized by equations (1), (2), and (3). Figure 1 illustrates the procedure to determine the equilibrium; the intersection of the schedules $\omega = \psi^*(\theta^*)A(m^*)$ and $\omega = B(m^*, \theta, \theta^*)$ determines ω^e and m^{*e}; and the schedule $\omega = A(m)/\psi(\theta)$ determines m^e in accordance with the equilibrium relative wage ω^e.

2.4 Comparative statics

We consider the home technical improvement in shipping, with the foreign technical improvement in shipping unchanged (i.e., $d\theta < 0$ and $d\theta^* = 0$). Let a caret indicate the relative change in a variable or parameter. For example, $\hat{\omega}^e$ denotes $d\omega^e/\omega^e$ and $\hat{\theta}$ denotes $d\theta/\theta$. It is straightforward to verify that $\hat{\omega}^e > 0$, $\hat{m}^{*e} < 0$, and $\hat{m}^e > 0$. The technical improvement in home shipping reduces home unit costs over a whole range of goods, so that the borderline good m^e increases. On the other hand, it increases the foreign propensity to import, which boosts the labor demand at home for a given ω. This excess labor demand raises the relative wage ω^e and in turn, the home country loses its comparative advantage in supplying some goods (i.e., there is a decrease in m^{*e}).

The results for the comparative statics with respect to θ are confirmed in Figure 1. In addition, the same procedure explains the results for the comparative statics with respect to θ^*. All the results are summarized as follows.

Proposition 1. *A technical improvement in home (res. foreign) shipping increases (res. decreases) the relative wage. Moreover, regardless of which country experiences the technical improvement in shipping, the numbers of export goods increase at home and in the foreign country.*

It should be noted that the technical improvements in production and shipping differ in terms of the impacts on the equilibrium variables. Oladi and Beladi (2010) and Beladi and Oladi (2011) show that home technical improvement in production reduces the number of foreign export goods. Suppose that home technical improvement in production, which is measured by β, enhances the home country's relative productivity (i.e., $\partial A/\partial\beta > 0$). In addition, suppose that the home technical improvement is unbiased in Beladi and Oladi's (2011) terminology (i.e., $\partial^2 A/\partial\beta\partial z = 0$). In this setting, the technical improvement in home production shifts the schedule $\omega = B(m^*, \theta, \theta^*)$ downward, because it causes excess supply in the home labor market for a given m^*.[6] In addition, it shifts the schedule $\omega = \psi^*(\theta^*)A(m^*)$ upward, decreasing home unit costs for supplying goods. These two effects work to cause loss in foreign comparative advantage in supplying goods.

2.5 Relationship between iceberg and shipping-service models

Iceberg costs take a form of shrinkage in transit such that a portion g (res. g^*) of goods shipped from the home (res. foreign) country actually arrives at its export market. In other words, for the home country to export one unit of its good, $(1-g)/g$ units of goods must be produced in addition to one unit. Similarly, the foreign country must produce additional $(1-g^*)/g^*$ units to export one unit of good. In the iceberg model, the following conditions, which are directly borrowed from

[6]Straightforward computation shows

$$\frac{\partial B}{\partial\beta} = \left(\frac{b^*(m)}{\int_{m^*}^{1} b(z)dz}\right)\left(\frac{\psi(\theta)\psi^*(\theta^*) - 1}{\partial A/\partial z}\right)\frac{\partial A}{\partial\beta} < 0,$$

so that the technical improvement in home production shifts $\omega = B(m^*, \theta, \theta^*)$ downward.

Dornbusch et al. (1977), must hold:

$$\omega = \frac{A(m^*)}{g^*}, \quad \omega = gA(m), \quad \omega = \frac{\int_0^m b^*(z)dz}{\int_{m^*}^1 b(z)dz}.$$

Apparently, these conditions are identical to equations (1)–(3) for $\psi(\theta) = 1/g$ and $\psi^*(\theta^*) = 1/g^*$. From the theoretical perspective, iceberg costs are the same as shipping-service costs, that is, $wa(z)(1-g)/g = w\,(\psi(\theta) - 1)\,a(z)$ for the home country and $w^*a^*(z)(1-g^*)/g^* = w^*\,(\psi^*(\theta^*) - 1)\,a^*(z)$ for the foreign country.

Proposition 2. *Suppose that there is no trade in shipping services. The iceberg model is identical to the shipping-service model if and only if* $\psi = 1/g$ *and* $\psi^* = 1/g^*$.

Iceberg costs are a very tractable way of modeling transportation costs, since it impacts no other markets (Deardorff, 2006), although the interpretation of them (e.g., melting and evaporation of goods) restricts their applicability only to limited situations (e.g., shipping liquid materials and natural gas).[7] Proposition 2 plays a role in improving the appropriateness of iceberg costs in addition to its theoretical usefulness, by showing that iceberg costs are interchangeable with shipping-service costs. Nevertheless, it should be noted that while the current globalization enables exporters to purchase more efficient shipping services at lower prices elsewhere in the world, Proposition 2 requires that there should be no trade in shipping services. We need to fill this gap that would otherwise cast doubt on the appropriateness of iceberg costs. In the next section, by introducing trade in shipping services, we reconsider the trade equilibrium.

3 International trade in shipping services

Given the preliminary results presented by Section 2, we explore international trade in shipping services. We refer to the shipping-service model in which shipping-service trade is impossible

[7] An interesting example of iceberg costs may be coal. Kindleberger (1973) described that after World War II, Silesian coal was sold by Poland in France, even though the round-trip train journey required burning up to one-third of the original trainload as fuel.

as the *non-shipping service trade economy* (*NS economy*), while the shipping-service model in which shipping-service trade is possible as the *free-trade economy* (*FT economy*). In this section, we examine how iceberg costs are related to shipping-service costs in the FT economy. Inter alia, we address issues about (i) how the patterns of production and trade are determined in the FT economy, (ii) how technical improvements in shipping affect the trade equilibrium, and (iii) whether the equivalence between the iceberg and shipping-service models can be preserved in the FT economy.

Proposition 2 suggests that the iceberg model is equivalent to the NS economy if and only if there are one-to-one correspondences $F : \psi \in S \mapsto 1/g \in (0, \infty)$ and $F^* : \psi^* \in S^* \mapsto 1/g^* \in (0, \infty)$ where S and S^* are subsets of $(1, \infty)$. This necessary and sufficient condition clearly shows that functional forms of $\psi(\theta)$ and $\psi^*(\theta^*)$ themselves never matter for the interchangeability between iceberg and shipping-service costs. Then, we make the following assumption:

Assumption 2. $\psi(\theta) = 1 + \theta$ *and* $\psi^*(\theta^*) = 1 + \theta^*$ *for* $\theta, \theta^* \in (0, \infty)$.

Under Assumption 2, our model features very simple unit labor requirements: home (res. foreign) unit labor requirement $a(z)$ (res. $a^*(z)$) for production and $a_T(z) = \theta a(z)$ (res. $a^*_T(z) = \theta^* a^*(z)$) for shipping. Moreover, Assumption 2 relates iceberg costs to shipping-service costs in a simple way. When the home country exports its goods to the foreign country by domestic shipping-services, the cost shares of production and shipping in the home unit cost are $1/(1+\theta) = g$ and $\theta/(1 + \theta) = 1 - g$, respectively. Analogously, for the foreign country, they are given by $1/(1 + \theta^*) = g^*$ and $\theta^*/(1 + \theta^*) = 1 - g^*$, respectively.

A salient point in the FT economy is that we have to take into account not only which country exports which goods, but also, which country exports *which shipping services* and which goods are exported *by whose shipping services*. Since the relative unit labor requirement for shipping $T(z, \theta, \theta^*) := a^*_T(z, \theta^*)/a_T(z, \theta) = (\theta^*/\theta)A(z)$ declines with z, the number z is ordered in terms of the home country decreasing comparative advantage not only in goods but also in shipping services. Furthermore, there is a unique borderline shipping service $t \in (0, 1)$, such that

$$\omega = T(t, \theta, \theta^*). \tag{4}$$

Accordingly, the home country supplies the shipping service $z \in \{z' \mid \omega \leq T(z', \theta, \theta^*)\} = [0, t]$ and the foreign country supplies the shipping service $z \in \{z' \mid \omega \geq T(z', \theta, \theta^*)\} = [t, 1]$. As pointed out by Deardorff (2005, 2014), the comparative advantage in final goods crucially depends on production technology of intermediate goods and transportation costs. As such, in the FT economy, the comparative advantage in shipping services, which are captured by equation (4), influences the home comparative advantage in supplying goods. In the following subsection, we consider how the patterns of production and trade in goods are determined.

3.1 Patterns of production and trade

The home country produces good z if the foreign unit cost for supplying the home market is not lower than the home unit cost $wa(z)$. Since the foreign unit cost is given by $w^*(1 + \theta^*)a^*(z)$ for $z \in [t, 1]$ and $w^*a^*(z) + w\theta a(z)$ for $z \in [0, t]$, The home country produces good $z \in [t, 1]$ for $\omega \leq (1 + \theta^*)A(z)$ and good $z \in [0, t]$ for $\omega(1 - \theta) \leq A(z)$. In other words, the home country produces good $z \in \Omega = \{z' \mid \omega \leq \Psi^*_T(z', \theta, \theta^*)\}$, where

$$\Psi^*_T(z, \theta, \theta^*) = \begin{cases} \psi^*_F(z, \theta^*) := (1 + \theta^*)A(z) & \text{if } z \in [t, 1], \\ \psi^*_H(z, \theta) := \begin{cases} \dfrac{A(z)}{1 - \theta} & \text{if } \theta \in (0, 1) \\ \omega_u & \text{if } \theta \in [1, \infty) \end{cases} & \text{if } z \in [0, t] \end{cases}$$

and ω_u is a sufficiently large constant.[8] The subscripts ψ^*_H and ψ^*_F identify the nationality of shipping sectors ($h = H, F$): $\psi^*_H(z)$ indicates that the foreign country exports good z using the home country's shipping service, while $\psi^*_F(z)$ indicates that the foreign country exports good z

[8]Suppose that $z \in [0, t]$ and $\theta \in [1, \infty)$. The condition for the home country to produce, $\omega(1 - \theta) \leq A(z)$, is always satisfied, not depending on ω. To express this, we use a sufficiently large constant ω_u.

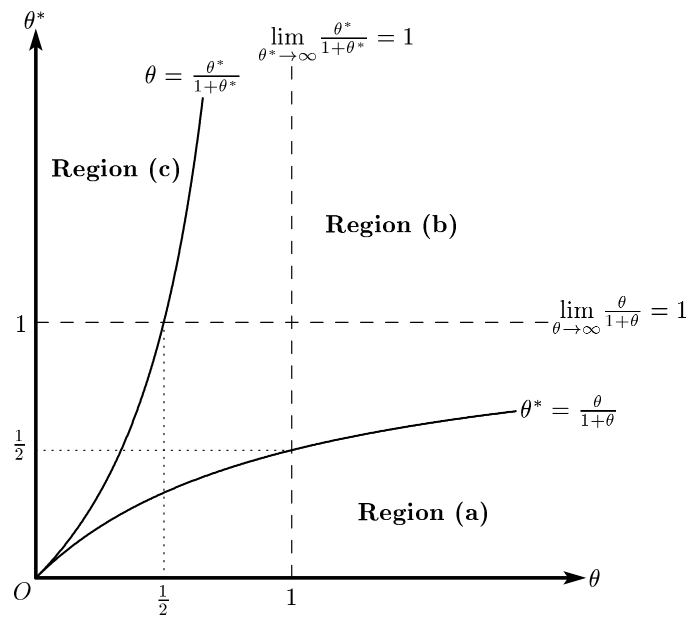

Figure 2: Relationship between (θ, θ^*) and trade patterns

using its own shipping service. Similarly, the foreign country produces good $z \in \Omega^* = \{z' \mid \omega \geq \Psi_T(z', \theta, \theta^*)\}$ where

$$\Psi_T(z, \theta, \theta^*) = \begin{cases} \psi_F(z, \theta^*) := \max\{(1 - \theta^*)A(z),\ 0\} & \text{if } z \in [t, 1], \\ \psi_H(z, \theta) := \dfrac{A(z)}{1 + \theta} & \text{if } z \in [0, t]. \end{cases}$$

The following lemma is useful for the subsequent analysis.

Lemma 1. *The relationships among Ψ_T, Ψ_T^*, and T are characterized by*

(a) $T(z, \theta, \theta^*) \leq \Psi_T(z, \theta, \theta^*) < \Psi_T^*(z, \theta, \theta^*)$, *for* $(\theta, \theta^*) \in R_a := \{(\theta', \theta^{*\prime}) \mid \theta^{*\prime} \leq \theta'/(1 + \theta')\}$,

(b) $\Psi_T(z, \theta, \theta^*) \leq T(z, \theta, \theta^*) \leq \Psi_T^*(z, \theta, \theta^*)$, *for* $(\theta, \theta^*) \in R_b := \{(\theta', \theta^{*\prime}) \mid \theta^{*\prime} \geq \theta'/(1 + \theta')$ *and* $\theta' \geq \theta^{*\prime}/(1 + \theta^{*\prime})\}$,

(c) $\Psi_T(z, \theta, \theta^*) < \Psi_T^*(z, \theta, \theta^*) \leq T(z, \theta, \theta^*)$ *for* $(\theta, \theta^*) \in R_c := \{(\theta', \theta^{*\prime}) \mid \theta' \leq \theta^{*\prime}/(1 + \theta^{*\prime})\}$.

The set R_i corresponds to Region (i) in Figure 2 ($i = a, b, c$). For any pair (θ, θ^*) on the boundary between Regions (a) and (b), three functions ψ_H, ψ_F, and T are identical, that is, $\Psi_T(z, \theta, \theta^*) = T(z, \theta, \theta^*)$. Analogously, $\Psi_T^*(z, \theta, \theta^*) = T(z, \theta, \theta^*)$ for all $z \in [0, 1]$ if and only if $(\theta, \theta^*) \in R_b \cap R_c$. Note that symmetric iceberg costs (i.e., $g = g^*$ or $\theta = \theta^*$), which are usually assumed in the existing literature, belong to Region (b).

Lemma 1 suggests two important properties about the patterns of specialization in goods and shipping services. The first property is that E, E^*, and N are connected sets, as in the NS economy. It follows from the definition of Ω and Ω^* that there are unique borderline goods $m < m^*$,

$$\omega = \Psi_T(m, \theta, \theta^*), \tag{5}$$

$$\omega = \Psi_T^*(m^*, \theta, \theta^*), \tag{6}$$

such that the home country exports goods $z \in E = [0, m]$, the foreign country exports goods $z \in E^* = [m^*, 1]$, and the non-traded goods are $z \in N = (m, m^*)$.

The second property is that there is no two-way trade in shipping services. This is confirmed by checking the ranking of t, m, and m^*. The possible rankings are exhausted by the following three cases: (i) $t < m < m^*$ for $(\theta, \theta^*) \in R_a \setminus R_b$, (ii) $m \leq t \leq m^*$ for $(\theta, \theta^*) \in R_b$, and (iii) $m < m^* < t$ for $(\theta, \theta^*) \in R_c \setminus R_b$. The home country imports shipping services for goods $z \in [t, m]$ as a sole importer if $(\theta, \theta^*) \in R_a \setminus R_b$, and the foreign country imports shipping services for goods $z \in [m^*, t]$ as a sole importer if $(\theta, \theta^*) \in R_c \setminus R_b$.[9] For $(\theta, \theta^*) \in R_b$, there is no trade in shipping services.[10] In short, as in a simple Ricardian model, shipping services are exported by a country

[9]Our model is quite relevant to the existing studies on fragmentation and trade in tasks, such as Jones and Kierzkowski (1990), Grossman and Rossi-Hansberg (2008), Rodríguez-Clare (2010), and Baldwin and Robert-Nicoud (2014). For example, Grossman and Rossi-Hansberg (2008) have regarded one production factor in the Heckscher-Ohlin model as infinite-multistep tasks and explored the degree to which a developed country offshores these tasks to a developing country. In our model, exporting one unit of goods is decomposed into two tasks. One is production of the goods and the other is transportation of the goods. For $(\theta, \theta^*) \in R_a \setminus R_b$, the home country offshores shipping services for goods $z \in [t, m]$ while it is engaged in both production and shipping tasks for $[0, t]$.

[10]The FT economy with $(\theta, \theta^*) \in R_b$ should not be confused with the NS economy. In the FT economy, the trade in shipping services is possible, but the home and foreign countries never choose this trade. On the other hand, this trade is impossible in the NS economy.

with comparative advantage in them. Nevertheless, it is not the case that the exporting country specializes in all the shipping services.

It is noteworthy that whether iceberg costs can be interpreted as shipping-service costs relies on (g, g^*) once trade in shipping service becomes possible. The interchangeability between these costs requires that there is no trade in shipping services, so that $(2g - 1)/g < g^* < 1/(2 - g)$ must hold.[11] Since $g = g^*$ meets the condition, the interchangeability between iceberg and shipping-service costs is warranted in the symmetric iceberg-cost case. However, it could be violated when the iceberg costs are extremely asymmetric.[12] This result provides a caveat against facile modeling. Many existing studies usually make the iceberg-cost assumption *for simplicity*. According to our result, the iceberg-cost assumption may be no longer good simplification if asymmetric iceberg costs are allowed. In some cases with extreme asymmetry, such a situation literally limits the transportation costs to evaporating and melting goods. This is because the iceberg costs lose the linkage with shipping-service costs.

3.2 Equilibrium

We are now prepared to present equations that characterize the equilibrium in the FT economy. As shown by Lemma 1, we need to consider the following three cases: (i) $(\theta, \theta^*) \in R_a \setminus R_b$, (ii) $(\theta, \theta^*) \in R_b$, and (iii) $(\theta, \theta^*) \in R_c \setminus R_b$. However, the most important situation in the FT economy is that shipping-service trade would actually occur. In addition, once the analysis in $(\theta, \theta^*) \in R_a \setminus R_b$ is completed, the results from $(\theta, \theta^*) \in R_c \setminus R_b$ can be inferred easily by symmetry. In what follows, we concentrate only on $(\theta, \theta^*) \in R_a \setminus R_b$ to prevent our analysis from being a worthless taxonomy.

In the FT economy with $(\theta, \theta^*) \in R_a \setminus R_b$, there are four endogenous variables ω, t, m, and m^*. Figure 3 illustrates the configuration of loci $T(t, \theta, \theta^*)$, $\Psi_T(m, \theta, \theta^*)$, and $\Psi^*_T(m^*, \theta, \theta^*)$. For a given ω, the three variables t, m, and m^* are determined by $T(t, \theta, \theta^*)$, $\psi_F(m, \theta^*)$, and $\psi^*_F(m^*, \theta^*)$,

[11] Recall that Assumption 2 leads to $g = 1/(1 + \theta)$ and $g^* = 1/(1 + \theta^*)$. Solving these two equations, we obtain $(\theta, \theta^*) = ((1 - g)/g, (1 - g^*)/g^*)$. As easily confirmed, the necessary and sufficient condition for this pair to belong to Region (b) in Figure 2 is $(2g - 1)/g < g^* < 1/(2 - g)$.

[12] A trivial way to regain the interchangeability is to impose prohibitive tariffs on foreign shipping services. For a detailed discussion, see Appendix A.

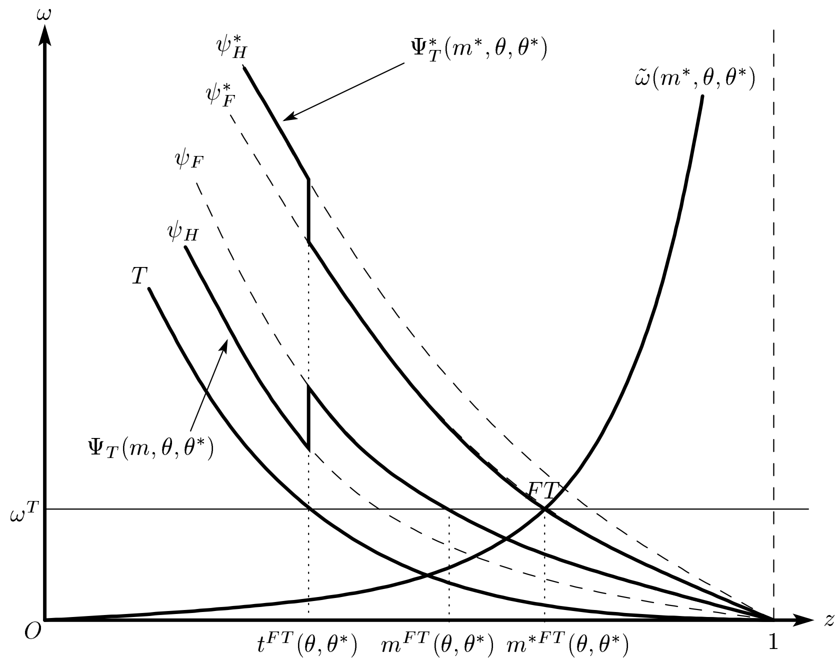

Figure 3: Equilibrium in the FT economy

respectively. Thus, the equilibrium conditions are characterized by equation (4) and

$$\omega = \psi_F(m, \theta^*), \tag{7}$$

$$\omega = \psi_F^*(m^*, \theta^*), \tag{8}$$

$$\omega = \widetilde{B}(\omega, m^*, \theta, \theta^*) := \frac{\int_0^{f_2(m^*,\theta,\theta^*)} b^*(z)dz + \int_{f_2(m^*,\theta,\theta^*)}^{f_3(m^*,\theta^*)} \frac{\omega b^*(z)}{\omega+\theta^* A(z)} dz}{\int_{m^*}^1 b(z)dz}, \tag{9}$$

where $t = f_2(m^*, \theta, \theta^*) := A^{-1}(\theta(1+\theta^*)A(m^*)/\theta^*)$ and $m = f_3(m^*, \theta^*) := A^{-1}((1+\theta^*)A(m^*)/(1-\theta^*))$ with $\partial f_2/\partial m^* > 0$ and $\partial f_3/\partial m^* > 0$. Equation (9) is the trade-balance condition, or the home-country labor-market clearing condition by virtue of Walras' law.

The denominator on the right-hand side of equation (9) is the home average propensity to import and the numerator is the foreign average propensity to import. The foreign average propensity to import is divided into two parts. The first term is associated with the import goods shipped by the home shipping-service sector. On the other hand, the second term is associated with the

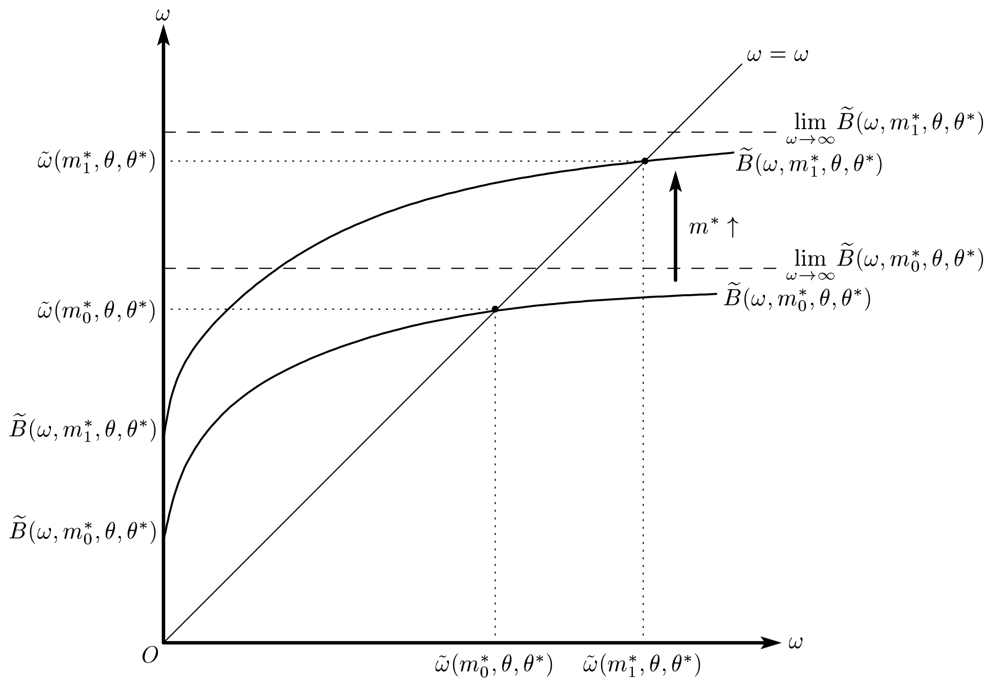

Figure 4: Home labor-market equilibrium

import goods shipped by the foreign shipping-service sector. Since the home country imports foreign shipping services for goods, the second term on the numerator represents the value of net imports, that is, the import value of goods less the export value of shipping services in terms of the foreign wage rate w^*.

A crucial difference between the trade-balance conditions (3) and (9) is that equation (9) is not a mapping from (m^*, θ, θ^*) into ω, but an equation of ω for a given triplet (m^*, θ, θ^*). Here, one question arises: do any solutions to equation (9) exist, that is, are there any fixed points? The answer to this question is provided by the following lemma.

Lemma 2. *For any $m^* \in (0, 1)$, there is a unique home labor-market equilibrium relative wage that satisfies equation (9).*

Proof: See Appendix B.

The existence of $\tilde{\omega}(m^*, \theta, \theta^*)$ is illustrated in Figure 4. The function $\widetilde{B}$ is bounded from above, increasing, and strictly concave in ω. As a result, its graph has a unique intersection with 45° line

$\omega = \omega$. Let us denote the solution to equation (9) by

$$\omega = \tilde{\omega}(m^*, \theta, \theta^*). \tag{10}$$

Equation (9) can be replaced with this equation as one of the equilibrium conditions.

We can elicit two important features from Figure 4. The first is that $\tilde{\omega}$ increases with m^*. Suppose that m^* increases for a given ω. Because $\partial f_2/\partial m^* > 0$ and $\partial f_3/\partial m^* > 0$, the home country's average propensity to import decreases and the foreign country's increases. This raises $\tilde{\omega}$ by shifting the locus $\widetilde{B}(\omega, m^*, \theta, \theta^*)$ upward. The second feature is that $(\partial/\partial\omega)\widetilde{B}(\tilde{\omega}(m^*, \theta, \theta^*), m^*, \theta, \theta^*) < 1$. From this property, we can apply the implicit function theorem to obtain

$$\frac{\partial \tilde{\omega}}{\partial \theta} = \frac{\partial \widetilde{B}/\partial \theta}{1 - (\partial \widetilde{B}/\partial \omega)} = \frac{b^*(t)(1 + \theta^*)A(m^*)A(t)}{(\omega + \theta^* A(t))\, A'(t) \left[1 - (\partial \widetilde{B}/\partial \omega)\right]} < 0.$$

When θ decreases for a given m^*, the home country substitutes some importing shipping-services with its own services. This generates excess demand in the home labor market, which raises the relative wage $\tilde{\omega}$.

Lemma 3. *(i)* $(\partial/\partial m^*)\tilde{\omega}(m^*, \theta, \theta^*) > 0$*, (ii)* $\lim_{m^* \to 0} \tilde{\omega}(m^*, \theta, \theta^*) = 0$*, (iii)* $\lim_{m^* \to 1} \tilde{\omega}(m^*, \theta, \theta^*) = \infty$*, and (iv)* $(\partial/\partial\theta)\tilde{\omega}(m^*, \theta, \theta^*) < 0$.

It should be noted that the sign of $(\partial/\partial\theta^*)\tilde{\omega}(m^*, \theta, \theta^*)$ is not clear. This can be explained by the two offsetting effects on the home labor market. One is that a decrease in θ^* makes the home country lose its comparative advantage in shipping services. This works to reduce home labor demand. The other effect is that the number of home export goods increases, since the home country can purchase foreign shipping services at lower prices. This expansion of home exports boosts home labor demand. The relative magnitude of these two effects determines whether the relative wage $\tilde{\omega}$ rises: if the former effect is stronger (res. weaker) than the latter, then a technical improvement in foreign shipping decreases (res. increases) the relative wage.

Figure 3 shows that the upward-sloping schedule $\omega = \tilde{\omega}(m^*, \theta, \theta^*)$ has a unique intersection

FT with the downward-sloping schedule $\omega = \psi_F^*(m^*, \theta^*)$. This point FT determines both the relative wage rate ω and the borderline good m^*. For the relative wage, the remaining borderline good m is determined by the schedule $\omega = \psi_F(m, \theta^*)$ and the borderline shipping service t is determined by the schedule $\omega = T(t, \theta, \theta^*)$. Let us denote the equilibrium in the FT economy with $(\theta, \theta) \in R_a \setminus R_b$ by $(\omega^{FT}(\theta, \theta^*), t^{FT}(\theta, \theta^*), m^{FT}(\theta, \theta^*), m^{*FT}(\theta, \theta^*))$. We finally obtain the following proposition.

Proposition 3. *Suppose that $(\theta, \theta^*) \in R_a \setminus R_b$. There is a unique equilibrium in the FT economy, $(\omega^{FT}(\theta, \theta^*), t^{FT}(\theta, \theta^*), m^{FT}(\theta, \theta^*), m^{*FT}(\theta, \theta^*))$, for which only the home country imports shipping services.*

3.3 Comparative statics

We conduct an analysis of comparative statics with respect to θ and θ^*. First, we consider an improvement in home shipping technology (i.e., $\hat{\theta} < 0$ and $\hat{\theta}^* = 0$). Totally differentiating (7), (8), and (10) yields $\hat{\omega}^{FT} > 0$, $\hat{m}^{*FT} < 0$, and $\hat{m}^{FT} < 0$. The former two relative changes are explained by the same reasoning in Subsection 2.4. The last one, a *decrease* in the number of home export goods, is in sharp contrast to the result in the NT economy. The key to this reversal is a change in borderline shipping service.

To understand the intuition behind $\hat{m}^{FT} < 0$, we present the relative change in t^{FT}. We differentiate equation (4) to obtain

$$\begin{aligned}
\hat{t}^{FT} &= \left(\frac{1}{\varepsilon_z^A(t^{FT})}\right)\hat{\theta} + \left(\frac{1}{\varepsilon_z^A(t^{FT})}\right)\hat{\omega}^{FT}, \\
&= \frac{\hat{\theta}}{\varepsilon_z^A(t^{FT})C(\theta,\theta^*)}\left\{\frac{(1-\theta^*)\varepsilon_z^A(m^{*FT})m^{FT}b^*(m^{FT}) + \omega^{FT}\varepsilon_z^A(m^{FT})m^{*FT}b(m^{*FT})}{\omega^{FT}\varepsilon_z^A(m^{FT})\int_{m^{*FT}}^1 b(z)dz\left[1-(\partial\widetilde{B}/\partial\omega)\right]} - \varepsilon_z^A(m^{*FT})\right\}, \\
&> 0,
\end{aligned}$$

where ε_k^f is the elasticity of function f with respect to variable k (i.e., $\varepsilon_k^f = k(\partial f/\partial k)/f$) and

$C(\theta, \theta^*) = \varepsilon^{\tilde{\omega}}_{m^*}(m^{*FT}, \theta, \theta^*) - \varepsilon^A_z(m^{*FT}) > 0$.[13] The first equality demonstrates that a technical improvement in home shipping has two offsetting effects on the borderline shipping service. The first term on the right-hand side indicates that the number of home shipping services increases because the home-country comparative advantage in shipping services is enhanced. On the other hand, the second term indicates that a rise in the relative wage decreases the number of home shipping services. The latter is an indirect effect through the wage adjustment to the home labor market, so that the former effect dominates the latter. Thus, home technical improvement leads to an increase in the number of home shipping services. This provides the reason for $\hat{m}^{FT} < 0$. The absorption of labor in the home shipping-service sector reduces the labor available to the home production sector. As a result, the number of home export goods must decrease.

We next consider foreign technical improvement (i.e., $\hat{\theta}^* < 0$ and $\hat{\theta} = 0$). The relative changes in all the endogenous variables are given by

$$\hat{\omega}^{FT} = \left[\frac{\left(\frac{\theta^*}{1+\theta^*}\right) \varepsilon^{\tilde{\omega}}_{m^*}(m^{*FT}, \theta, \theta^*) - \varepsilon^{\tilde{\omega}}_{\theta^*}(m^{*FT}, \theta, \theta^*) \varepsilon^A_z(m^{*FT})}{C(\theta, \theta^*)} \right] \hat{\theta}^*, \quad \hat{m}^{*FT} = \left(\frac{\frac{\theta^*}{1+\theta^*} - \varepsilon^{\tilde{\omega}}_{\theta^*}(m^{*FT}, \theta, \theta^*)}{C(\theta, \theta^*)} \right) \hat{\theta}^*,$$

$$\hat{m}^{FT} = \left\{ \frac{\left[\frac{2\theta^*}{(1+\theta^*)(1-\theta^*)}\right] \varepsilon^{\tilde{\omega}}_{m^*}(m^{*FT}, \theta, \theta^*) - \left(\varepsilon^{\tilde{\omega}}_{\theta^*}(m^{*FT}, \theta, \theta^*) + \frac{\theta^*}{1-\theta^*}\right) \varepsilon^A_z(m^{*FT})}{\varepsilon^A_z(m^{FT}) C(\theta, \theta^*)} \right\} \hat{\theta}^*,$$

$$\hat{t}^{FT} = -\left[\frac{\left(\frac{1}{1+\theta^*}\right) \varepsilon^{\tilde{\omega}}_{m^*}(m^{*FT}, \theta, \theta^*) - \left(1 - \varepsilon^{\tilde{\omega}}_{\theta^*}(m^{*FT}, \theta, \theta^*)\right) \varepsilon^A_z(m^{*FT})}{\varepsilon^A_z(m^{FT}) C(\theta, \theta^*)} \right] \hat{\theta}^*.$$

As inferred from the paragraph right below Lemma 3, their signs are ambiguous. Nevertheless, they become unambiguous for $\varepsilon^{\tilde{\omega}}_{\theta^*}(m^{*FT}, \theta, \theta^*) \in (0, \theta^*/(1+\theta^*))$. Suppose that $\tilde{\omega}$ inelastically decreases as foreign shipping technology improves. In this case, the impact of this decreased relative wage on home comparative advantage in goods (i.e., a downward shift of $\omega = \tilde{\omega}(m^*, \theta, \theta^*)$) is not large enough to dominate the direct impacts of foreign technical improvement (i.e., a downward shift of $\omega = \psi^*_F(m^*, \theta^*)$ and $\omega = T(t, \theta, \theta^*)$ and an upward shift of $\omega = \psi^*_H(m^*, \theta^*)$). Thus, the numbers of home and foreign export goods increase (i.e., $\hat{m}^{FT} > 0$ and $\hat{m}^{*FT} < 0$) and the number

[13] We do not define the elasticities in a way that they are positive. For example, $\varepsilon^{\tilde{\omega}}_{m^*}$ is positive, while ε^A_z is negative.

of home shipping services decreases (i.e., $\hat{t}^{FT} < 0$).

Proposition 4. *An improvement in home shipping technology increases the relative wage and the numbers of foreign export goods and home shipping services, while it decreases the number of home export goods. If* $\varepsilon_{\theta^*}^{\tilde{\omega}} \in (0, \theta^*/(1+\theta^*))$*, an improvement in foreign shipping technology decreases the relative wage and the number of home shipping services, while it increases the numbers of home and foreign export goods.*

4 Gains from trade in shipping services

In this section, we examine whether the home and foreign countries can enjoy gains from trade in shipping services, by comparing the NS and FT economies with $(\theta, \theta^*) \in R_a \backslash R_b$. For this analysis, we define the equilibrium in the NS economy by $(\omega^{NS}(\theta, \theta^*), m^{NS}(\theta, \theta^*), m^{*NS}(\theta, \theta^*))$, which is the same as the equilibrium presented in Section 2, $(\omega^e(\theta, \theta^*), m^e(\theta, \theta^*), m^{*e}(\theta, \theta^*))$. Hereafter, for convenience, a pair (θ, θ^*) is referred to as $(\theta, \theta^*) \in R_a \cap R_b$ and a pair $(\theta + \Delta\theta, \theta^*)$ with $\Delta\theta > 0$ is referred to as $(\theta + \Delta\theta, \theta^*) \in R_a \setminus R_b$ insofar as there is no particular remark otherwise stated.

For preparation, we first compare the equilibrium variables in the NS and FT economies. For $(\theta, \theta^*) \in R_a \cap R_b$, these two economies share an identical trade-balance condition, that is, $\omega = B(m^*, \theta, \theta^*) = \tilde{\omega}(m^*, \theta, \theta^*)$. As shown in Sections 2 and 3, the schedule $\omega = B(m^*, \theta + \Delta\theta, \theta^*)$ lies below the schedule $\omega = B(m^*, \theta, \theta^*)$ and the schedule $\omega = \tilde{\omega}(m^*, \theta + \Delta\theta, \theta^*)$ lies below the schedule $\omega = \tilde{\omega}(m^*, \theta, \theta^*)$. Hence, the difference between the equilibrium relative wages depends on the extent to which $\Delta\theta$ makes the schedules $\omega = B(m^*, \theta, \theta^*)$ and $\omega = \tilde{\omega}(m^*, \theta, \theta^*)$ shift downward. To gauge the difference between these extents, let us define

$$\begin{aligned} h(\theta) &:= B(m^*, \theta, \theta^*) - \tilde{\omega}(m^*, \theta, \theta^*), \\ &= B(m^*, \theta, \theta^*) - \widetilde{B}(\tilde{\omega}(m^*, \theta, \theta^*), m^*, \theta, \theta^*). \end{aligned}$$

By definition, $h(\theta) = 0$ for $(\theta, \theta^*) \in R_a \cap R_b$. The schedule $\omega = B(m^*, \theta + \Delta\theta, \theta^*)$ lies above the

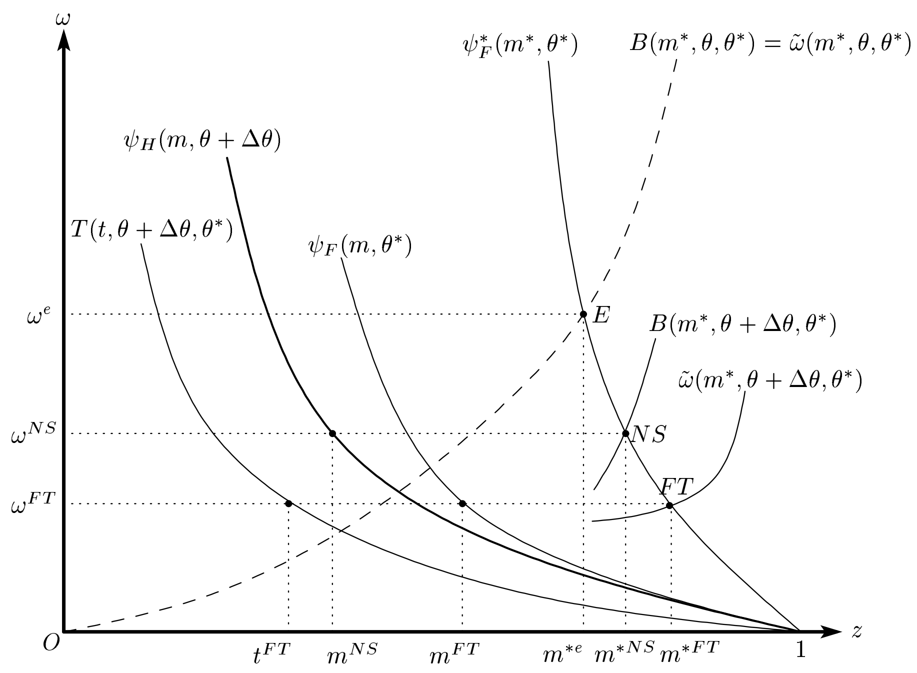

Figure 5: Equilibria in NS and FT economies

schedule $\omega = \tilde{\omega}(m^*, \theta + \Delta\theta, \theta^*)$ at $z = m^*$ if $h(\theta + \Delta\theta) > 0$ for a given m^*, and vice versa.

In general, it is not obvious whether $h(\theta+\Delta\theta)$ is positive. Then, to obtain clear-cut results, we focus only on a sufficiently small $\Delta\theta$. In other words, we consider a pair $(\theta+\Delta\theta, \theta^*)$ that is located within Region (a) in Figure 2 but is very close to the boundary of Regions (a) and (b). Such a pair $(\theta + \Delta\theta, \theta^*)$ allows us to take a linear approximation of h around θ:

$$\begin{aligned} h(\theta + \Delta\theta) &= h(\theta) + h'(\theta)\Delta\theta, \\ &= -\frac{(1+\theta^*)A(m^*)b^*(f_1(m^*,\theta,\theta^*))}{A'(f_1(m^*,\theta,\theta^*))\int_{m^*}^1 b(z)dz}\left[\frac{B(m^*,\theta,\theta^*) - \psi^*_F(m^*,\theta^*)}{B(m^*,\theta,\theta^*) + \theta^* A(f_1(m^*,\theta,\theta^*))}\right]\Delta\theta. \end{aligned} \tag{11}$$

It follows from $\partial B/\partial m^* > 0$ and $\partial\psi^*_F/\partial m^* < 0$ that $h(\theta + \Delta\theta) \gtreqless 0 \Leftrightarrow m^* \gtreqless m^{*e}(\theta, \theta^*)$, where m^{*e} is a borderline good which satisfies $B(m^{*e}, \theta, \theta^*) = \psi^*_F(m^{*e}, \theta^*)$. Figure 5 illustrates the relationship between the equilibria of the NS and FT economies. The schedule $\omega = B(m^*, \theta+\Delta\theta, \theta^*)$ lies above $\omega = \tilde{\omega}(m^*, \theta + \Delta\theta, \theta^*)$ for $m^* > m^{*e}(\theta, \theta^*)$. Consequently, the equilibrium of the NS economy is located in the north-west direction of the equilibrium of the FT economy. In addition, Figure 5 illustrates that the trade in shipping services increases both borderline goods m and m^*.

Proposition 5. *(i)* $\omega^{NS}(\theta+\Delta\theta,\theta^*) > \omega^{FT}(\theta+\Delta\theta,\theta^*)$, *(ii)* $m^{*FT}(\theta+\Delta\theta,\theta^*) > m^{*NS}(\theta+\Delta\theta,\theta^*)$, *and (iii)* $m^{FT}(\theta+\Delta\theta,\theta^*) > m^{NS}(\theta+\Delta\theta,\theta^*)$.

Trade in shipping services induces home exporters to replace domestic shipping services with more efficient foreign ones. The adjustment of labor allocation, which discards employees in the home shipping-service sector, reduces the home relative wage after the trade in shipping services begins. The reduced relative wage makes the home country gain comparative advantage in supplying goods and the foreign country lose, so that the trade in shipping services increases the number of home export goods and decreases the number of foreign ones.

We now consider whether there are gains from trade in shipping services. The home and foreign indirect utility functions, which are evaluated at equilibrium variables, are given by

$$\begin{aligned} V(\theta+\Delta\theta,\theta^*;i) &:= G(i) + \int_{m^{*i}(\theta+\Delta\theta,\theta^*)}^{1} b(z)\ln\frac{\omega^i(\theta+\Delta\theta,\theta^*)}{\psi_F^*(z,\theta^*)}dz, \\ V^*(\theta+\Delta\theta,\theta^*;i) &:= G^*(i) + \int_{0}^{t^i(\theta+\Delta\theta,\theta^*)} b^*(z)\ln\frac{\psi_H(z,\theta+\Delta\theta)}{\omega^i(\theta+\Delta\theta,\theta^*)}dz \\ &\quad + \int_{t^i(\theta+\Delta\theta,\theta^*)}^{m^i(\theta+\Delta\theta,\theta^*)} b^*(z)\ln\frac{A(z)}{\omega^i(\theta+\Delta\theta,\theta^*)+\theta^* A(z)}dz, \end{aligned} \tag{12}$$

where $G(i) = \int_0^1 b(z)\ln(b(z)/a(z))dz$ and $G^*(i) = \int_0^1 b^*(z)\ln(b^*(z)/a^*(z))dz$ for each equilibrium $i \in \{NS, FT\}$, and $t^i(\theta+\Delta\theta,\theta^*)$ is defined by

$$t^i(\theta+\Delta\theta,\theta^*) = \begin{cases} m^{NS}(\theta+\Delta\theta,\theta^*) & \text{if } i = NS \\ t^{FT}(\theta+\Delta\theta,\theta^*) & \text{if } i = FT \end{cases}$$

owing to the definition of R_a and R_b. For the analysis on gains from trade, we regard $V(\theta+\Delta\theta,\theta^*;i)$ and $V^*(\theta+\Delta\theta,\theta^*;i)$ as home and foreign welfare, respectively. Here, it may be considered that trade in shipping services enhances home-country welfare, because more efficient foreign shipping services are available to the home country. However, Proposition 6 is contrary to this conjecture.

Proposition 6. *Suppose that* $b(z) = b^*(z)$ *for any* $z \in [0, 1]$. *The foreign country enjoys the gains from trade in shipping services, while the home country suffers from the losses.*

Proof: See Appendix B.

As discussed in Appendix A, the FT economy with $(\theta, \theta^*) \in R_a \setminus R_b$ is equivalent to the NS economy if the home country imposes a uniform, prohibitive tariff on foreign shipping services. Coupled with this result, Proposition 6 provides an important policy implication: liberalization of shipping-service trade is harmful to the home country.[14] To understand this somewhat unintuitive result, we present the difference between $V(\theta + \Delta\theta, \theta^* FT)$ and $V(\theta + \Delta\theta, \theta^*; NS)$, which is written as

$$V(\theta + \Delta\theta, \theta^*; FT) - V(\theta + \Delta\theta, \theta^*; NS)$$
$$= \left(\ln \frac{\omega^{FT}(\theta + \Delta\theta, \theta^*)}{\omega^{NS}(\theta + \Delta\theta, \theta^*)}\right) \int_{m^{*NS}(\theta+\Delta\theta,\theta^*)}^{1} b(z)dz - \int_{m^{*NS}(\theta+\Delta\theta,\theta^*)}^{m^{*FT}(\theta+\Delta\theta,\theta^*)} b(z) \ln \frac{\omega^{FT}(\theta + \Delta\theta, \theta^*)}{\psi^*_F(z, \theta^*)} dz. \quad (13)$$

Trade in shipping services allows home exporters to replace some home shipping services with more efficient foreign shipping services. This replacement works to worsen home factor terms of trade, reducing the home unit costs and raising the relative prices of home import goods. This negative welfare effect is captured by the first term. We refer to this as the *implicit tariff effect* after Falvey (1976). Moreover, the reduced unit costs in the home country, which arise from the replacement of shipping services, enlarges the set of goods produced by the home country. This

[14]Using the DFS model with iceberg costs, Opp (2010) shows that the home-country optimal trade policy is uniform tariffs on foreign export goods. In this sense, we may be able to conclude that tariffs are desirable for the home country irrespective of whether they are imposed on foreign goods or shipping services. However, this does not mean that the optimal trade policy is always tariffs. In our model, the home country confronts a discrete choice between prohibitive tariffs and zero tariffs. We cannot deny the possibility that import subsidies on foreign shipping services are optimal from the perspective of home-country welfare. Unfortunately, it is difficult to verify whether this is true, because import subsidies gives rise to very complicated impacts on $\tilde{\omega}(m^*, \theta + \Delta, \theta^*)$.

positive welfare effect is represented by the second term in equation (13). We refer to it as the *extensive margin effect*.

We compare the implicit tariff and extensive margin effects by rewriting equation (13) as

$$V(\theta + \Delta\theta, \theta^*; FT) - V(\theta + \Delta\theta, \theta^*; NS) < \left(\ln \frac{\omega^{FT}(\theta + \Delta, \theta^*)}{\omega^{NS}(\theta + \Delta, \theta^*)}\right) \int_{m^{*FT}(\theta+\Delta\theta,\theta^*)}^{1} b(z)dz,$$

where the inequality comes from the fact that $\omega^{NS}(\theta+\Delta\theta, \theta^*) > \psi_F^*(z, \theta^*)$ for any $z \in [m^{*NS}, m^{*FT})$. It is apparent that the right-hand side of the inequality is negative, that is, the implicit tariff effect dominates the extensive margin effect. Hence, the home country loses from trade in shipping services.

Note that our result is in sharp contrast to Itoh and Kiyono (1987). They show that the export subsidies on goods in the vicinity of borderline good m enhances home-country welfare by enlarging the set of goods produced by the home country to a very small extent. Similarly, as shown in Proposition 5, the shipping-service trade liberalization in our model leads to a small increase in the number of home-country goods from m^{*NS} to m^{*FT}. However, Itoh and Kiyono (1987) and our model differ in terms of welfare implications in the following respects. In Itoh and Kiyono (1987), export subsidies are provided even to the goods that the home country exports in the absence of export subsidies, so that there is a terms-of-trade deteriorating effect. On the other hand, the implicit tariff effect in our model encompasses not only this sort of terms-of-trade deterioration, but also a reduction in home-country real income. While export subsidies are domestic income transfers from taxpayers to exporting firms, the payments for shipping services are outflows of home income to foreign income. Thus, trade in shipping services has a stronger negative welfare effect than Itoh and Kiyono's (1987) export subsidy policy.

5 Conclusion

While the iceberg-cost assumption is prevalent in many studies, it seems that the interpretation of iceberg costs (e.g., melting and evaporating goods in transit) restricts the appropriateness of trade models. This study presents a simple extension of a continuum-of-goods, two-country, Ricardian trade model à la Dornbusch et al. (1977) by introducing shipping-service sectors. We find that iceberg costs are interchangeable with shipping-service costs if and only if (i) unit labor requirements for producing goods are proportionate to those for shipping and (ii) there is no trade in shipping services. This is because the iceberg and shipping-service costs yield the same resource allocation when the labor producing additional units of goods to supply one unit is interpreted as the labor working in the shipping-service sector.

The necessary and sufficient condition for the equivalence of iceberg and shipping-service costs clearly shows that existing studies that adopt iceberg costs as transportation costs have focused on artificial situations, despite the fact that globalization currently allows exporters to purchase shipping services from the lowest price suppliers in the world. We then examine how trade in shipping services alters the resource allocation in equilibrium. In contrast to earlier works that impose the iceberg-cost assumption, we have to consider not only (i) which country produces which good, but also (ii) which country exports which shipping service and (iii) which good is exported by whose shipping service. This point of view adds a new insight to existing trade patterns—the pattern of trade in shipping services. As in a simple Ricardian model, the pattern of trade in shipping services itself is determined by their comparative advantage. However, this affects comparative advantage in supplying goods, which entails complex patterns of production and trade. In particular, we show that one country can export some goods using its domestic shipping-service sector and other goods using a foreign shipping-service sector, while the other country can export its goods using its domestic shipping services. The former country indirectly uses foreign labor through imports of shipping services, so that the resource allocation is different from that under the iceberg-cost assumption. This might cast doubt on the plausibility of the iceberg-cost assumption.

Furthermore, we investigate the impacts of trade in shipping services from two perspectives. One is to consider how a technical improvement in shipping influences resource allocation. If the country importing shipping services experiences an improvement in shipping technology, then the number of its export goods decreases. Technical improvement encourages the country to use its domestic shipping services. This raises the relative wage and thus, the country loses comparative advantage in supplying some goods. The other perspective is the issue of gains from trade. In particular, we analyze whether both countries can enjoy the gains from trade in shipping services. We show that a country importing shipping services can lose from trade in shipping services. This can be explained by two major offsetting effects of trade in shipping services: a positive welfare effect (extensive margin effect) and a negative welfare effect (implicit tariff effect). In contrast to Itoh and Kiyono (1987), in our model, the implicit tariff effect encompasses not only a deterioration of terms of trade but also a reduction in the real income, so that the importing country loses from trade in shipping services.

Appendix A: A prohibitive tariff on foreign shipping services

Consider that the home country imposes a uniform, ad valorem tariff $\tau > 0$ on foreign shipping services. In this case, the home unit cost to supply its export goods by using foreign shipping services should be changed from $wa(z) + \theta^* w^* a^*(z)$ to $wa(z) + (1+\tau)\theta^* w^* a^*(z)$. On the other hand, the other unit costs in Section 3 remain intact. Accordingly, a borderline shipping service t^* exists such that

$$\omega = \widetilde{T}(t^*, \theta, \theta^*, \tau) := (1+\tau)T(t^*, \theta, \theta^*),$$

and the home country purchases both home shipping services $z \in [0, t^*]$ and foreign shipping services $z \in [t^*, 1]$. The foreign country purchases both home shipping services $z \in [0, t]$ and foreign shipping services $z \in [t, 1]$. Moreover, the foreign country produces goods $z \in \widetilde{\Omega}^*(\tau) =$

$\{z' \mid \omega \geq \widetilde{\Psi}_T(z', \theta, \theta^*, \tau)\}$, where

$$\widetilde{\Psi}_T(z, \theta, \theta^*, \tau) = \begin{cases} \tilde{\psi}_F(z, \theta^*, \tau) := \max\{[1 - \theta^*(1+\tau)]A(z),\ 0\} & \text{if } z \in [t^*, 1], \\ \psi_H(z, \theta) = \dfrac{A(z)}{1+\theta} & \text{if } z \in [0, t^*], \end{cases}$$

and the home country produces $z \in \Omega = \{z' \mid \omega \leq \Psi_T^*(z', \theta, \theta^*)\}$.

Suppose now that the home country imposes a positive, uniform tariff

$$\tau = \tilde{\tau}(\theta, \theta^*) := \frac{\theta - \theta^*(1+\theta)}{\theta^*(1+\theta)}.$$

on foreign shipping services. For a given relative wage ω, the schedule $\omega = \psi_F^*(m^*, \theta^*)$ characterizes the set of goods produced at home as $[A^{-1}(\omega/(1+\theta^*)), 1]$. On the other hand, since $\widetilde{T}(z, \theta, \theta^*, \tilde{\tau}(\theta, \theta^*)) = \tilde{\psi}_F(z, \theta^*, \tilde{\tau}(\theta, \theta^*)) = \psi_H(z, \theta)$ for any $z \in (0, 1]$, the set of goods that the home country produces is identical to the set of home shipping services that the home country uses to export goods, that is, $[0, A^{-1}((1+\theta)\omega)] = [0, t^*]$. Hence, the home country does not import any shipping services from the foreign country under $\tau = \tilde{\tau}(\theta, \theta^*)$. This implies that the FT economy is equivalent to the NS economy if the import tariff $\tau = \tilde{\tau}(\theta, \theta^*)$ is imposed on foreign shipping services.

Appendix B

Proof of Lemma 2

First, we prove the existence of the fixed points. It is straightforward to verify $\widetilde{B}(0, m^*, \theta, \theta^*) \in (0, \infty)$ and $\lim_{\omega \to \infty} \widetilde{B}(\omega, m^*, \theta, \theta^*) \in (0, \infty)$. In addition, it follows from Assumption 1 and the properties of f_2 and f_3 that $\lim_{m^* \to 0} \widetilde{B}(\omega, m^*, \theta, \theta^*) = 0$ and $\lim_{m^* \to 1} \widetilde{B}(\omega, m^*, \theta, \theta^*) = \infty$. Moreover, differentiating

$\widetilde{B}$ with respect to ω, we obtain

$$\frac{\partial \widetilde{B}}{\partial \omega} = \frac{\int_{f_2(m^*,\theta,\theta^*)}^{f_3(m^*,\theta^*)} \frac{\theta^* b^*(z)A(z)}{(\omega+\theta^* A(z))^2} dz}{\int_{m^*}^1 b(z)dz} > 0, \quad \lim_{\omega\to\infty} \frac{\partial \widetilde{B}}{\partial \omega} = 0, \quad \text{and} \quad \frac{\partial^2 \widetilde{B}}{\partial \omega^2} = -\frac{2\int_{f_2(m^*,\theta,\theta^*)}^{f_3(m^*,\theta^*)} \frac{\theta^* b^*(z)A(z)}{(\omega+\theta^* A(z))^3} dz}{\int_{m^*}^1 b(z)dz} < 0.$$

Let us define the difference between $\widetilde{B}$ and ω as $G(\omega, m^*, \theta, \theta^*) := \widetilde{B}(\omega, m^*, \theta, \theta^*) - \omega$. This function satisfies $G(0, m^*, \theta, \theta^*) \in (0, \infty)$ and $\lim_{\omega\to\infty} G(\omega, m^*, \theta, \theta^*) < 0$, which implies that $G(\omega, m^*, \theta, \theta^*) < 0$ for a sufficiently large ω. Therefore, by the intermediate value theorem, a relative wage $\tilde{\omega}$ exists, which satisfies $G(\tilde{\omega}, m^*, \theta, \theta^*) = 0$.

Next, we prove the uniqueness of $\tilde{\omega}$. Suppose first that $(\partial/\partial\omega)G(0, m^*, \theta, \theta^*) \leq 0$. In this case, $G(\omega, m^*, \theta, \theta^*)$ is monotonically decreasing in ω, because it is strictly concave in ω. Thus, $\tilde{\omega}$ is unique. Suppose next that $(\partial/\partial\omega)G(0, m^*, \theta, \theta^*) > 0$. It is easy to observe that $\lim_{\omega\to\infty}(\partial G/\partial\omega) = -1 < 0$. Accordingly, there is a unique $\bar{\omega}$ such that $(\partial/\partial\omega)G(\bar{\omega}, m^*, \theta, \theta^*) = 0$. Since $\omega > \bar{\omega} \Leftrightarrow (\partial G/\partial\omega) < 0$ because of the strict concavity of $G(\bar{\omega}, m^*, \theta, \theta^*)$ in ω, there is a unique relative wage $\tilde{\omega} \geq \bar{\omega}$. **Q.E.D.**

Proof of Proposition 6

First, we prove that the foreign country gains from trade. Let us define $\Delta^* := V^*(\theta + \Delta\theta, \theta^*; T) - V^*(\theta + \Delta\theta, \theta^*; A)$; in other words,

$$\begin{aligned}
\Delta^* &= \int_{t^{FT}}^{m^{FT}} b(z) \ln \frac{A(z)}{\omega^{FT} + \theta^* A(z)} dz + \int_0^{t^{FT}} b(z) \ln \frac{\psi_H(z, \theta + \Delta\theta)}{\omega^{FT}} dz + \int_0^{m^{NS}} b(z) \ln \frac{\omega^{NS}}{\psi_H(z, \theta + \Delta\theta)} dz, \\
&> \int_{t^{FT}}^{m^{FT}} b(z) \ln \frac{A(z)}{\omega^{FT} + \theta^* A(z)} dz + \int_0^{t^{FT}} b(z) \ln \frac{\psi_H(z, \theta + \Delta\theta)}{\omega^{FT}} dz + \int_0^{m^{NS}} b(z) \ln \frac{\omega^{FT}}{\psi_H(z, \theta + \Delta\theta)} dz,
\end{aligned} \tag{14}$$

where the inequality comes from Proposition 5. Suppose first that $t^{FT} \geq m^{NT}$. It follows from $\omega^{FT} = \psi_F(m^{FT}, \theta^*)$ and $(\partial/\partial z)\psi_F(z, \theta^*) < 0$ that $\psi_F(z, \theta^*) - \omega^{FT} = A(z) - \left(\omega^{FT} + \theta^* A(z)\right) > 0$ for $z \in (t^{FT}, m^{FT})$. In addition, it follows from $\omega^{FT} = T(t^{FT}, \theta + \Delta\theta, \theta^*)$, $(\partial/\partial z)\psi_H(z, \theta + \Delta\theta) < 0$, and

Lemma 1 that $\psi_H(z, \theta + \Delta\theta) > \omega^{FT}$ for $z \in (0, t^{FT})$. Thus, inequality (14) is rewritten as

$$\begin{aligned}
\Delta^* &> \int_{t^{FT}}^{m^{FT}} b(z) \ln \frac{A(z)}{\omega^{FT} + \theta^* A(z)} dz + \int_0^{m^{NS}} b(z) \ln \frac{\psi_H(z, \theta + \Delta\theta)}{\omega^{FT}} \cdot \frac{\omega^{FT}}{\psi_H(z, \theta + \Delta\theta)} dz, \\
&= \int_{t^{FT}}^{m^{FT}} b(z) \ln \frac{A(z)}{\omega^{FT} + \theta^* A(z)} dz, \\
&> 0.
\end{aligned}$$

Suppose next that $t^{FT} < m^{NS}$. It follows from $\omega^{FT} = T(t^{FT}, \theta + \Delta\theta, \theta^*)$ and $(\partial/\partial z)T(z, \theta + \Delta\theta, \theta^*) < 0$ that for $z \in (t^{FT}, m^{NS})$,

$$\frac{A(z)}{\omega^{FT} + \theta^* A(z)} - \frac{\psi_H(z, \theta + \Delta\theta)}{\omega^{FT}} = \frac{\theta A(z) \left(\omega^{FT} - T(z, \theta + \Delta\theta, \theta^*)\right)}{(1 + \theta)\omega^{FT} (\omega^{FT} + \theta^* A(z))} > 0.$$

Using this inequality, we obtain

$$\begin{aligned}
\Delta^* &> \int_{m^{NS}}^{m^{FT}} b(z) \ln \frac{A(z)}{\omega^{FT} + \theta^* A(z)} dz + \int_0^{m^{NS}} b(z) \ln \frac{\psi_H(z, \theta + \Delta\theta)}{\omega^{FT}} dz + \int_0^{m^{NS}} b(z) \ln \frac{\omega^{FT}}{\psi_H(z, \theta + \Delta\theta)} dz, \\
&= \int_{m^{NS}}^{m^{FT}} b(z) \ln \frac{A(z)}{\omega^{FT} + \theta^* A(z)} dz, \\
&> 0.
\end{aligned}$$

Thus, the foreign country enjoys the gains from trade in shipping services.

Finally, we prove that there are no gains from trade in shipping services for the home country. The difference $\Delta := V(\theta + \Delta\theta, \theta^*; FT) - V(\theta + \Delta\theta, \theta^*; NS)$ is

$$\begin{aligned}
\Delta &= -\left[(\ln \omega^{NS}) \left(\int_{m^{*NS}}^1 b(z) dz \right) - (\ln \omega^{FT}) \left(\int_{m^{*FT}}^1 b(z) dz \right) \right] + \int_{m^{*NS}}^{m^{*FT}} b(z) \ln \psi_F^*(z, \theta^*) dz, \\
&< -(\ln \omega^{NS}) \left(\int_{m^{*NS}}^{m^{*FT}} b(z) dz \right) + \int_{m^{*NS}}^{m^{*FT}} b(z) \ln \psi_F^*(z, \theta^*) dz, \\
&= \int_{m^{*NS}}^{m^{*FT}} b(z) \ln \frac{\psi_F^*(z, \theta^*)}{\omega^{NS}} dz.
\end{aligned}$$

Here, $\omega^{NS} > \psi_F^*(z, \theta^*)$ holds for $z \in (m^{*NS}, m^{*FT})$, since $\omega^{NS} = \psi_F^*(m^{*NS}, \theta^*)$ and $(\partial/\partial z)\psi_F^*(z, \theta^*) < 0$. Hence, we obtain $\Delta < 0$. **Q.E.D.**

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