

July 7, 2014

Trade, Transportation, and the Environment: Welfare Effects of Emissions Reductions and International Emissions Trading*

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* The authors are grateful to Masahisa Fujita, Keisaku Higashida, Debra Israel, Yoshitaka Kawagoshi, Hiroshi Kurata, Shunsuke Managi, AKM Morshed, Shinozaki Tsuyoshi, and conference/seminar participants at the Research Institute of Economy, Trade and Industry (RIETI), the 53rd Congress of the European Regional Science Association 2013, Tohoku Gakuin University, the Annual Meeting of the Association of Southern European Economic Theorists 2013, the Midwest Economics Association 78th Annual Meeting 2014, the Japan Society of International Economics, NIESG, and Chukyo University for their helpful comments and suggestions. Takarada gratefully acknowledges the partial financial support of a Grant-in-Aid for Scientific Research (C) #26380335. Ogawa gratefully acknowledges the Yamada Academic Fellowship.

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Abstract

Greenhouse gas emissions from international transport are increasing significantly because of the shifting of trade from proximate partners to distant partners under trade liberalization. We examine environmental regulations of international transport in a two-country, two-good general equilibrium model where international transport generates pollution, which is treated as a pure public bad. The main finding is that under a reasonable condition regarding the world demand for international transport, permit trading between the international transport sectors of two countries always benefits an international-transport-importing country but may harm an international-transport-exporting country even if it receives all of the direct gains from permit trading.

JEL Classification: F18; Q56; R41

Keywords: Environmental regulation; Emissions trading system; International trade; Transportation

1. Introduction

There is growing concern about trade-related environmental issues associated with increasing globalization. Most of the concerns are related to how international trade affects the level of greenhouse gases (GHGs) such as carbon dioxide (CO₂) from the production and consumption of goods, while GHG emissions from international shipping and aviation, which are an essential pillar of international trade,¹ tend to be overlooked. The level of GHGs generated by international shipping and aviation has risen sharply in accordance with the expansion of world trade.² According to the International Energy Agency (IEA) (2013), CO₂ emissions from international marine and aviation bunkers in 2011 were both about 80 percent higher than in 1990 (primarily because of significant growth in Asian countries, particularly China), while global CO₂ emissions increased by about 50 percent in the same period.³ In 2011, emissions from international marine and aviation bunkers amounted to about four percent of global emissions, approximately equal to the sum of total emissions in Germany and Italy. In business-as-usual scenarios, emissions from international shipping and aviation are expected to more than triple by 2050.⁴ This is not compatible with the internationally agreed goal of limiting the average global temperature rise to 2°C, required to prevent disruptive climate change, by reducing worldwide emissions by 40–70 percent from 2010 levels by 2050 (IPCC

¹ According to the United Nations (2012, p.44), maritime transport handles over 80 percent of the volume of global trade in goods and accounts for over 70 percent of its value. By contrast, air transportation handles only 2 percent of world trade by weight but about 40 percent by value (see http://files.aea.be/Downloads/AEAcargobrochure_2012.pdf).

² In the period 1970–2012, international trade in goods by maritime transport has grown 4 percent annually and international air cargo has expanded 9 percent annually. See, for example, <http://www.epa.gov/international/trade/transport.html>.

³ Transport accounted for 22 percent of global CO₂ emissions in 2011, making it the second largest emissions-generating sector, after electricity and heat generation (IEA 2013, p.11). About three quarters of transport emissions in 2011 were generated by the road sector, for which emissions had increased by 52% since 1990. It is interesting to note that emissions from international shipping and aviation increased faster than did those from the road sector.

⁴ Emissions from international shipping are expected to rise by 200–300 percent for the period 2007–2050 (International Maritime Organization 2009, p. 106). According to the International Civil Aviation Organization (2013, p. 25), by 2020 international aviation emissions are projected to be 50–70% higher than in 2010 even if fuel efficiency improves by 1.5 percent annually, and by 2050 they could be four to six times higher than the 2010 value.

2014).

Empirical studies have found that a significant volume of trade-related GHG emissions are generated by international transportation, particularly international shipping and aviation, because of the fragmentation of global production and the shifting of trade toward more distant trading partners under the growing importance of cross-regional preferential trade agreements (WTO 2013). Hummels (2009) calculated that if world trade was fully liberalized, CO₂ emissions associated with international transportation would grow by as much as 10 percent, while production-related emissions would not rise. This is because trade would shift from proximate partners to distant partners that could not be reached by land transport, thereby increasing emissions from maritime and air transport. Cristea et al. (2013) found that international transportation is responsible for 33 percent of worldwide trade-related emissions, and over 75 percent of emissions for the major manufacturing categories. They also estimated that full liberalization of tariffs and economic growth concentrated in China and India raise emissions from transport much faster than the value of trade because of the shifting of trade toward distant trading partners.⁵

Emissions from international shipping and aviation are excluded from the present worldwide environmental framework (the United Nations Framework Convention on Climate Change (UNFCCC)) because it is difficult to identify which countries should be responsible for these emissions.⁶ Therefore, the environmental regulation of international shipping and aviation has been entrusted to specialized international organizations such as the International Maritime Organization (IMO) and the International Civil Aviation Organization (ICAO), respectively.⁷

⁵ See also Olsthoorn (2001), Corbett and Winebrake (2008), DeSombre (2008), and Krautzberger and Wetzel (2012) for emissions from international transportation.

⁶ By contrast, the environmental framework of the UNFCCC (the Kyoto Protocol) regulates GHG emissions from international road transport, such as rail and truck, similarly to those from domestic transport.

⁷ The parties included in Annex I of the Kyoto Protocol shall pursue limitation or reduction of GHG emissions not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the ICAO and the IMO, respectively (Article 2.2 of the Kyoto Protocol). See

However, as mentioned above, emissions from international marine and aviation bunkers have significantly increased, despite efforts by the IMO and ICAO to limit this increase through emissions standards and operational improvements.

It is important to restrict more effectively the emissions from international shipping and aviation (hereafter referred to jointly as international transport), which are expected to grow strongly in the absence of intervention. Recently, two notable examples of environmental frameworks for international aviation have emerged. First, the European Union (EU) agreed to apply the EU emissions trading system (ETS) to flights within the European Economic Area (EEA) for the period 2013–2016.⁸ Second, in 2013, the members of the ICAO reached a multilateral agreement to develop, by 2016, a global market-based measure (MBM) such as an ETS to restrict emissions from international aviation, to commence in 2020.⁹ The IMO is also considering the enforcement of a worldwide ETS for international maritime transport as an important MBM option, but the members of the IMO have not yet reached an agreement.¹⁰

The purpose of this paper is to examine the welfare effects of environmental regulations of international transport in a two-country trade model. We focus on two types of environmental regulations: (i) international emissions trading between the international transport sectors of two countries; (ii) one of the two countries unilaterally enforces strict environmental regulation of its international transport sector. The former corresponds to a worldwide ETS for international transport, as considered by international organizations such as the ICAO and IMO. It can also be interpreted as the application of the EU ETS to international aviation if we treat the two countries in our model as countries within the EEA. The latter scenario may correspond to the application of the EU ETS to international aviation if we think of the two “countries” (regions)

http://unfccc.int/methods_and_science/emissions_from_intl_transport/items/1057.php.

⁸ In 2012, the EU was to apply the EU ETS to flights operated from or to non-European countries as well as flights within and between countries in Europe. However, following the recommendation of the ICAO Council, in 2014, the EU agreed to limit the implementation to flights within the EEA. See http://ec.europa.eu/clima/policies/transport/aviation/index_en.htm.

⁹ For details, see <http://www.icao.int/environmental-protection/Pages/default.aspx>.

¹⁰ See <http://www.imo.org/MediaCentre/HotTopics/GHG/Pages/default.aspx>.

as the EEA and the rest of the world. We identify and interpret the conditions for welfare improvement under the regulations. Our study contributes to understanding recent policy discussion on international transport and the environment, particularly a worldwide ETS for international transport.

We construct a two-country, two-good general equilibrium model with an international transport sector in each country. International transport generates pollution, which is treated as a pure global public bad that reduces utility. The two final goods and international transport services are freely traded between the countries so that their prices are set to meet the world market-clearing conditions. Because international transport is indispensable for importing goods, environmental regulations of international transport directly affect international trade flows, thereby changing the terms of trade for both final goods and international transport itself. Thus, it is important to study this issue in a general equilibrium model that can consider interactions between markets. To our knowledge, there exists no such theoretical study rigorously dealing with environmental regulations of international transport in a general equilibrium model.

The main result of this paper is that under a reasonable condition regarding the world demand for international transport, permit trading between the international transport sectors of the two countries benefits an international-transport-importing country, regardless of the world permit price, while an international-transport-exporting country may lose from permit trading overall, even if it receives all of the direct gains from permit trading. The larger the volume of trade in international transport, the higher the possibility of welfare deterioration by permit trading in an international-transport-exporting country. This result suggests that the trade pattern in international transport services is crucial to the welfare effects of permit trading in international transport emissions. Because permit trading improves the efficiency of production by reallocating pollution permits between the two countries, the national income in each country increases as a result of permit trading. This increase in the national income will change the demand for goods and international transport services, thereby causing two terms-of-trade

effects, i.e., for final goods and international transport. The terms of trade for international transport tend to be favorable for an international-transport-importing country because permit trading improves the production efficiency of international transport and increases its world supply. Thus, permit trading makes an international-transport-importing country better off even if it does not receive the direct gains from permit trading. By contrast, an international-transport-exporting country needs to receive large direct gains from permit trading to benefit from international emissions trading because its terms of trade tend to deteriorate.

Our theoretical result seems consistent with empirical observations. A feature of international maritime transport is that fleet ownership is concentrated in a few countries such as Greece and Japan.¹¹ Ship operations are also concentrated in a few firms.¹² This suggests a high degree of market concentration in the maritime transport sector, which suggests large trade imbalances in maritime transport services among countries. A large part of the global market for air cargo used to be provided by a limited number of large carriers such as FedEx and UPS Airlines (OECD 2010, p. 112). However, in recent years, because of developments in emerging economies, many carriers provide international airfreight services, i.e., market concentration is mitigated (IATA 2014). While the EU and the members of the ICAO have reached an agreement on MBMs such as an ETS for environmental regulations of aviation, the members of the IMO have not agreed to implement such measures for maritime transport, as mentioned above. This may be because trade imbalances in maritime transport are larger than that in aviation. A maritime-transport-exporting country is more likely to lose from permit trading under a large volume of exports, thereby reducing its incentive to support the introduction of permit trading.

As for unilateral environmental regulations, we find that a country may benefit from

¹¹ Owners from five countries, Greece, Japan, China, Germany and the Republic of Korea, together accounted for 53 percent of world tonnage in 2013 (UNCTAD 2013, p. 43). An alternative way to consider fleet ownership is in terms of the market value of vessels. According to UNCTAD (2013, p. 42), the top five ship-owning countries controlled about 48 percent of the world fleet by fleet value.

¹² For example, in 2013, the three largest European container ship companies operated one third of the global container carrying capacity (UNCTAD 2013, p. 51).

voluntarily imposing strict environmental regulation of its international transport sector, despite this regulation having the effect of shrinking the international transport sector. This is because the terms of trade for both final goods and international transport can be improved by the regulation.

The existing studies on trade and the environment have mainly examined the relation between pollution emissions and changes in production and consumption caused by trade.¹³ However, few papers have focused on the relation between international transport and the environment because most trade models omit transportation sectors. Some of the trade literature has investigated the role of international transportation, but the focus was not on environmental issues (e.g., Samuelson 1954; Mundell 1957; Herberg 1970; Cassing 1978; Francois and Wooton 2001; Andriamananjara 2004; Behrens and Picard 2011). The exception is Abe, Hattori, and Kawagoshi (2014), who investigated the strategic environmental regulation of international transportation in a two-country oligopolistic trade model, but their focus was on the effects of trade liberalization, not of emissions trading, on international transport.

The introduction of an ETS is believed to minimize abatement costs and yield benefits to both buyers and sellers of permits because it equalizes the marginal abatement costs across emission sources according to textbooks on environmental economics. The existing literature has examined whether this result remains valid even under free trade in emission permits between countries using a general equilibrium model of international trade. Copeland and Taylor (2005) demonstrated that permit trading between countries may harm a participating country, although permit trading improves world welfare. This is because changes in the production of goods through permit trading may cause a negative terms-of-trade effect that cannot be compensated by the direct gains from permit trading. They underscored the importance of considering the effects of permit trading in the presence of international trade.

¹³ See, for example, Copeland and Taylor (2004), Gallagher (2008), Copeland (2012), and Takarada, Ogawa, and Dong (2014) for a survey on trade and the environment.

Marschinski, Flachsland, and Jakob (2012) showed that the linking of ETSs between countries with different types of environmental regulations may make a participating country worse off because of the terms-of-trade effect caused by the linking. These articles found possible welfare improvement/deterioration if emission permits are internationally traded between final goods sectors but did not identify the sufficient condition for the result. In this paper, by considering emissions trading between international transport sectors, we explicitly derive the sufficient condition for welfare improvement. Our paper thus complements the existing studies.

The rest of the article is organized as follows. Section 2 introduces the basic model. Section 3 considers the effects of a unilateral emissions reduction. Section 4 explores the effects of international emissions trading. Section 5 concludes the article.

2. Basic Model

We develop a two-country, two-good general equilibrium model with an international transport sector in each country, to examine the impact of environmental regulations of pollution emissions from international transport. We refer to the two countries as “home” and “foreign”, and use an asterisk (*) to denote foreign variables. The two final goods are labeled as good 1 and good 2, and international transport services are indispensable for trade in goods. To focus on the impact of environmental regulations of international transport, we assume that only international transport services generate pollution emissions. Pollution is treated as a pure global public bad that reduces utility. The final goods and international transport services are freely traded, and all of the markets are completely competitive.

To begin with, we focus on the home country to characterize the production and demand sides and environmental regulations. The structure of the foreign country is similar to that of the home country. We allow for differences in production technologies, consumers’ preferences for goods and environmental quality, and environmental regulations between the two countries. After presenting the basic setting of our model, we describe the equilibrium of the world

economy.

The “production” of international transport services requires specific factors of production (such as aircrafts, marine vessels, airport or port facilities, and engineers) and emits pollution. Although this pollution is a byproduct of output, it is modeled as a productive factor as in Copeland and Taylor (2003, 2005). A firm can produce a certain amount of international transport services with less pollution emissions by increasing its input of the specific factor for abatement activity (i.e., the specific factor and pollution are substitutes in production). In our model, the final goods are produced by employing many factors of production without generating any pollution emissions (i.e., only transportation generates pollution in the model).

To mitigate the damage caused by pollution emissions, the government of each country sets national pollution quotas and implements the pollution target with a marketable permit system. In order to consider a realistic and meaningful situation, we assume that the government initially implements weak environmental regulation of international transport by setting a large pollution quota. A fixed number of pollution permits, Z , are auctioned off to home firms in the international transport sector, and all revenue is redistributed to home consumers in a lump-sum fashion. The price of permits is equalized among firms in the international transport sector through a marketable permit system. Under weak environmental regulation, the marginal damage of pollution to consumers is larger than the permit price.

Let us consider the role of international transport. Despite free trade, the prices of goods are higher in an importing country than in an exporting country because of transportation costs. Without loss of generality, the home country exports good 1 and imports good 2. We assume that transporting one unit of good 1 from the home country to the foreign country requires α units of international transport services, while transporting one unit of good 2 requires β units. The values of the parameters α and β represent the difficulty of international transport, which depends on the properties of the goods. We denote by p the price of good 1 (good 2 is treated as the numeraire) and by t the price of international transport services. Then, the price of good

1 in the foreign country becomes $p + \alpha t$, although it is p in the home country, and the price of good 2 becomes $1 + \beta t$ in the home country.

In our model, differences in the prices of goods between the countries are endogenously determined because the price of international transport must satisfy the world market-clearing condition for international transport. On the one hand price differences are transportation costs for consumers, but on the other hand they are revenue for firms producing international transport services.

We now examine the demand side. The welfare of the home country, denoted by u , is negatively affected by the sum of pollution emissions from the two countries' international transport sectors (i.e., global pollution emissions), $Z_W = Z + Z^*$. The expenditure function with negative externalities is expressed by $E(p, q, Z_W, u)$, where $q = 1 + \beta t$. Because pollution has a negative effect on utility, $E_Z = \partial E / \partial Z_W > 0$ holds. E_Z denotes the marginal damage of pollution to consumers. Assuming that the final goods are normal goods, and choosing $E_u = 1$, we have $E_{pu} > 0$ and $E_{qu} > 0$ (the marginal propensities to consume good 1 and good 2 in the home country are pE_{pu} and qE_{qu} , respectively). The consumption of international transport services itself does not enhance utility. Because international transport is essential for trade in goods, it can be interpreted as an intermediate good. As in Copeland and Taylor (2003, 2005), preferences are assumed to be weakly separable across the set of goods and pollution. This weak separability ensures that the marginal rate of substitution is independent of a change in the amount of pollution. Thus, we obtain $E_{pZ} = E_{pu}E_Z$, which is positive because goods are normal in consumption ($E_{pu} > 0$).

Each country's national income is the sum of income from the production of goods and international transport services. In the home country, income from goods production is expressed using a gross domestic product (GDP) function, $G(p, q)$, where we omit the fixed factor endowment vector. $G(p, q)$ has all the standard properties of a GDP function (e.g., Dixit and Norman, 1980; Wong, 1995). We denote by $F(K, Z)$ the aggregate production function of

international transport in the home country, where K is the endowment of the specific factor, which is inelastically supplied. Then, income from the production of international transport services is given by $tF(K, Z)$. Consequently, the national income of the home country is $G(p, q) + tF(K, Z)$. Similarly, $G^*(p + \alpha t) + tF^*(K^*, Z^*)$ represents the national income of the foreign country.

The equilibrium of the world economy is described by the following system of equations:

$$E(p, q, Z_W, u) = G(p, q) + tF(K, Z), \quad (1)$$

$$E^*(p + \alpha t, Z_W, u^*) = G^*(p + \alpha t) + tF^*(K^*, Z^*), \quad (2)$$

$$E_p(p, q, Z_W, u) - G_p(p, q) + X_p^*(p + \alpha t, Z_W, u^*) = 0, \quad (3)$$

$$\beta X_q(p, q, Z_W, u) + \alpha X_p^*(p + \alpha t, Z_W, u^*) - F(K, Z) - F^*(K^*, Z^*) = 0, \quad (4)$$

where $X_q(p, q, Z_W, u) = E_q(p, q, Z_W, u) - G_q(p, q) > 0$ and $X_p^*(p + \alpha t, Z_W, u^*) = E_p^*(p + \alpha t, Z_W, u^*) - G_p^*(p + \alpha t) > 0$ are the amounts of imports in the home and foreign countries, respectively. (1) and (2) are the budget constraints for the home and foreign countries, respectively. The current account is balanced through trade in the two final goods and international transport services. (3) and (4) are the market-clearing conditions for good 1 and international transport services, respectively. The world market for good 2 clears by Walras' Law.

3. Emission Reductions in International Transport Sectors

In this section, we consider the effects of unilateral enforcement by one country of strict environmental regulation of its international transport sector. Although our model is simple, its equilibrium behavior appears to be complex. To facilitate the exposition, we consider a small reduction in pollution permits by one country when the other country does not change its environmental regulations. In the real world, countries are not allowed to freely generate pollution emissions from international transport because (i) there are national environmental regulations and (ii) international organizations such the ICAO and IMO impose certain

restrictions (e.g., emissions standards) on pollutants from international aviation and shipping, respectively. Thus, even if a country imposes stricter environmental regulations of international transport, other countries are in fact unable to weaken their environmental regulations (i.e., there is no carbon leakage).

First, we examine how a reduction in the number of pollution permits in the international transport sector affects the prices of goods and international transport services. Next, we investigate the effects of emissions reductions on individual welfare and world welfare (the sum of the two countries' welfares).

3.1. Effects of Emissions Reductions on Prices

Totally differentiating (1)–(4), we obtain the following equations:

$$\frac{|H|}{F_z} \frac{dt}{dZ} = (1 - \beta t E_{qu}) \lambda + X_p^* \{E_{pu}(1 - \alpha t E_{pu}^*) - E_{pu}^*(1 - \beta t E_{qu})\} + \kappa t E_{pu}, \quad (5)$$

$$\frac{|H|}{F_z^*} \frac{dt}{dZ^*} = (1 - \alpha t E_{pu}^*) \lambda + X_p^* \{E_{pu}(1 - \alpha t E_{pu}^*) - E_{pu}^*(1 - \beta t E_{qu})\} + \kappa t E_{pu}^*, \quad (6)$$

$$\frac{|H|}{F_z} \frac{dp}{dZ} = \{E_{pu}^*(1 - \beta t E_{qu}) - E_{pu}(1 - \alpha t E_{pu}^*)\} T^* - \mu t E_{pu} - \kappa(1 - \beta t E_{qu}), \quad (7)$$

$$\frac{|H|}{F_z^*} \frac{dp}{dZ^*} = \{E_{pu}^*(1 - \beta t E_{qu}) - E_{pu}(1 - \alpha t E_{pu}^*)\} T^* - \mu t E_{pu}^* - \kappa(1 - \alpha t E_{pu}^*), \quad (8)$$

where $|H|$ is the Jacobian determinant of the system (1)–(4), $\lambda = E_{pp} - G_{pp} + X_{pp}^*$, $\mu = \beta^2 X_{qq} + \alpha^2 X_{pp}^*$, $\kappa = \beta X_{qp} + \alpha X_{pp}^*$, and $T^* = \alpha X_p^* - F^*$. $|H| > 0$ if the equilibrium is locally Hicksian stable (see Appendix A). We assume Hicksian stability in this paper. From the properties of the expenditure and GDP functions, $\lambda < 0$ and $\mu < 0$ hold. $\lambda < 0$ means that an increase in the price of good 1, p , reduces consumption of good 1 and raises production of good 1. $\mu < 0$ indicates that an increase in the price of international transport services, t , reduces the world demand for international transport. T^* is the foreign country's excess demand for international transport services. From the properties of the expenditure function, $pE_{pu} + qE_{qu} = 1$ holds, which can be rewritten as $1 - \beta t E_{qu} = pE_{pu} + E_{qu} > 0$. Similarly,

we have $1 - \alpha t E_{pu}^* > 0$. Assume that environmental regulations are binding in both countries. Then, the output of international transport increases as the number of pollution permits increases ($F_Z > 0$ and $F_Z^* > 0$).

The effects of a small change in the number of pollution permits of the home (foreign) country, $Z^{(*)}$, on the prices of international transport services and good 1 are given by (5) and (7) ((6) and (8)), respectively. The effects on the prices are complicated because there are two terms-of-trade effects, i.e., for final goods and international transport services. To obtain clear-cut results, we impose the following assumption.

Assumption 1 *A change in the price of good 1 has a negligible effect on the world demand for international transport services, i.e., $\kappa = \beta X_{qp} + \alpha X_{pp}^* \cong 0$.*

This assumption is reasonable for the following reason. Suppose that the price of good 1 rises. In the home country, because the price of good 2 (the imported good) becomes relatively lower, consumption of good 2 increases and production of good 2 decreases, which increases the amount of imports. Thus, the home demand for international transport increases ($\beta X_{qp} > 0$). By contrast, in the foreign country, consumption of good 1 (the imported good) decreases and production of good 1 increases, which leads to a reduction in the demand for international transport ($\alpha X_{pp}^* < 0$). The sign of κ depends on the sum of these two opposite effects, and they are nearly offset under Assumption 1. Note that κ is the partial derivative of $\beta X_q + \alpha X_p^*$ with respect to p . Therefore, it simply measures how a change in the relative price of good 1 affects the world demand for international transport, holding all else constant.

We obtain the following proposition for the price of international transport services.

Proposition 1 *Consider Assumption 1. Unilateral enforcement of strict environmental regulation of the international transport sector (a reduction in $Z^{(*)}$) will increase the price of*

international transport services if the preference for good 1 is sufficiently weak in the home country but strong in the foreign country (E_{pu} is small but E_{pu}^* is large).

Proof. The terms on the left-hand side of (5) and (6), $|H|/F_Z^{(*)}$, are positive because $|H| > 0$ and $F_Z^{(*)} > 0$. When E_{pu} is small and E_{pu}^* is large, the term in braces in (5) and (6), $E_{pu}(1 - \alpha t E_{pu}^*) - E_{pu}^*(1 - \beta t E_{qu})$, becomes negative because $1 - \alpha t E_{pu}^* > 0$ and $1 - \beta t E_{qu} > 0$. The first terms of (5) and (6) are negative because $\lambda < 0$. We can neglect the third term under Assumption 1. Therefore, the right-hand sides of (5) and (6) are negative. ■

The intuition behind this result is as follows. Consider the case of a reduction in the number of pollution permits in the home country, Z . There are three effects to be considered. First, a reduction in Z directly decreases the supply of international transport, which raises the price of international transport (the direct effect). Second, this increase in the price has the following indirect effect. In the foreign country, the direct effect enhances income from the international transport sector, which increases the demand for good 1 mainly because the foreign country has a strong preference for good 1 (the imported good). As a result, the foreign demand for international transport (the derived demand for imports) increases to a large extent. In the home country, the rise in the price of international transport services has an ambiguous effect on income from the international transport sector because the output is reduced by a reduction in Z . Therefore, it is ambiguous whether the demand for international transport increases in the home country. The sum of these two effects is the indirect effect. Third, the demand for international transport is also affected by changes in the price of goods. A change in the price of international transport services affects the price of goods by changing the import demand in each country, and this change in the price of goods will further affect the price of international transport services. We can ignore this interaction under Assumption 1. Consequently, the strict regulation will

increase the price of international transport services because the direct effect dominates other effects. We can understand by analogy the case of a reduction in the number of pollution permits in the foreign country.

As for the effects on the price of goods, given by (7) and (8), we cannot obtain clear results by imposing meaningful conditions. Any change in the price of good 1 depends on variables such as preferences, the price of international transport services, and the volume of trade in international transport services. It is ambiguous whether the price of good 1 increases because the effects caused by a reduction in the number of permits interact in a complicated manner through the markets.

3.2. Welfare Effects of Emissions Reductions

Next, we investigate the effects of a unilateral emissions reduction on each country's welfare. Let us focus on an emissions reduction by the home country. We can similarly understand the case of the foreign country. Totally differentiating (1), we obtain

$$du = X_p^* dp + T^* dt + (tF_Z - E_Z) dZ . \quad (9)$$

From (9), the welfare of the home country depends on three effects: (i) the terms-of-trade effect for final goods, $X_p^* dp$; (ii) the terms-of-trade effect for international transport services, $T^* dt$; (iii) the net benefit from an emissions reduction, $(tF_Z - E_Z) dZ$. The home country gains from the terms-of-trade effect for final goods if the price of good 1 increases ($dp > 0$), because the home country exports good 1 ($X_p^* > 0$). If the home country exports international transport services ($T^* > 0$), an increase in the price of international transport ($dt > 0$) will improve welfare. The net benefit is decomposed into a reduction in income from the international transport sector (tF_Z) and consumers' gain associated with a reduction in pollution emissions (E_Z). When environmental regulation is initially weak, the net benefit from an emissions reduction ($dZ < 0$) is positive ($(tF_Z - E_Z) dZ > 0$) because the utility gain dominates the income loss ($tF_Z < E_Z$).

Totally differentiating (1)–(4), we obtain the formal expressions for the welfare effects but they are very complicated (see Appendix B). A reduction in the number of pollution permits directly improves welfare provided that initial environmental regulation is weak. Moreover, it indirectly affects the prices of goods and international transport services by changing the demand and supply of goods and international transport services. We cannot clarify whether an emissions reduction makes countries better off by imposing meaningful conditions, because the reduction has an ambiguous effect on the price of goods, as already mentioned.

Consider world welfare. The effect of an emissions reduction on world welfare is clear, in contrast to the case of individual countries' welfare. Totally differentiating (1) and (2), we have

$$du + du^* = (tF_Z - E_Z - E_Z^*)dZ + (tF_Z^* - E_Z - E_Z^*)dZ^*. \quad (10)$$

When each country's environmental regulation is weak in the initial equilibrium ($tF_Z < E_Z$ and $tF_Z^* < E_Z^*$),¹⁴ both terms in parentheses in (10) are negative. That is, a unilateral emissions reduction improves world welfare, thereby making at least one country better off. This result is straightforward.

Our result suggests that a country may benefit from voluntarily imposing strict environmental regulations of the international transport sector despite these regulations having the effect of shrinking the international transport sector. This is because there is not only the net benefit from an emissions reduction but also a possible improvement in the terms of trade for final goods and international transport services. A country that does not strengthen its environmental regulation is more likely to benefit from voluntary regulation by the other country because the size of the international transport sector is constant.

4. International Emissions Trading in International Transport Sectors

In this section, we consider the effects of international emissions trading on the two countries'

¹⁴ The permit price is equalized between the countries ($tF_Z = tF_Z^* = E_Z + E_Z^*$) when global pollution emissions are optimally regulated.

international transport sectors. In doing this, first, the basic model is modified. Next, we investigate how such emissions trading affects prices and welfare. We examine a small movement toward full free trade in pollution permits, as in Copeland and Taylor (2005), to obtain clear-cut results.

Without loss of generality, we assume that the domestic permit price in the initial equilibrium is higher in the home country than in the foreign country. In each country, the domestic permit price is equal to the marginal value product of pollution permits, $tF_Z^{(*)}$. Therefore, we have $tF_Z^* < tF_Z$ under this assumption. This implies that an environmental regulation of international transport is initially stricter in the home country than in the foreign country. Note that this difference in the permit prices does not always mean that the home country generates less emissions per unit of international transport services than the foreign country does, because production technologies may be asymmetric between the countries. We assume that when the two countries allow international emissions trading, the world permit price, r , will lie between the domestic permit prices of the two countries, i.e., $tF_Z^* \leq r \leq tF_Z$.¹⁵ Thus, once international emissions trading begins, the home country becomes a buyer of pollution permits, while the foreign country becomes a seller of them.

The basic model is modified as follows:

$$E(p, q, Z_W, u) = G(p, q) + tF(K, Z + z) - rz, \quad (11)$$

$$E^*(p + at, Z_W, u^*) = G^*(p + at) + tF^*(K^*, Z^* - z) + rz, \quad (12)$$

$$\beta X_q(p, q, Z_W, u) + \alpha X_p^*(p + at, Z_W, u^*) - F(K, Z + z) - F^*(K^*, Z^* - z) = 0, \quad (13)$$

where z is the number of pollution permits traded between the countries. The third term of (11) represents payment for traded permits by the home country, while the third term of (12) is the revenue of the foreign country from selling permits to the home country. The market-clearing condition for good 1 is the same as in the basic model. Therefore, the equilibrium is described

¹⁵ This relation between the world and domestic prices is typical, as in the case of international factor movement in a competitive market model.

by the system of equations comprising (3) and (11)–(13).

4.1. Effects of International Emissions Trading on Prices

Totally differentiating (3) and (11)–(13), we obtain

$$|H| \frac{dt}{dz} = (tF_z - r)(\kappa\varepsilon - \gamma\lambda) + (F_z - F_z^*)\{t\gamma E_{pu}^* X_p^* + \kappa t E_{pu}^* + (1 - \alpha t E_{pu}^*)(\varepsilon X_p^* + \lambda)\}, \quad (14)$$

$$\begin{aligned} |H| \frac{dp}{dz} = & -(tF_z - r)(\varepsilon\mu - \gamma\kappa) - (F_z - F_z^*)\{\mu t E_{pu}^* + \varepsilon T^*(1 - \alpha t E_{pu}^*)\} \\ & - (F_z - F_z^*)\{\kappa(1 - \alpha t E_{pu}^*) + \gamma t T^* E_{pu}^*\}, \end{aligned} \quad (15)$$

where $\gamma = \beta E_{qu} - \alpha E_{pu}^*$ and $\varepsilon = E_{pu} - E_{pu}^*$.

First, we examine the effect on the price of international transport services, given by (14). We may expect the price to fall because the world supply of international transport will increase through the efficient reallocation of pollution permits between the two countries under international emissions trading. As we will show below, the price tends to fall under certain conditions. $\varepsilon X_p^* + \lambda < 0$ because the equilibrium is locally Hicksian stable (see (A2) in Appendix A). Then, the third term in the braces of (14), $(1 - \alpha t E_{pu}^*)(\varepsilon X_p^* + \lambda)$, is negative. If $\gamma < 0$, $\kappa < 0$, and $\varepsilon > 0$, the right-hand side of (14) is necessarily negative, i.e., the price of international transport services is reduced by international emissions trading ($dz > 0$). We have $\gamma < 0$ and $\kappa < 0$ when the requisite amount of international transport services for transporting one unit of good 1, α , is large and that for transporting one unit of good 2, β , is small. $\varepsilon > 0$ holds under the condition that the preference for good 1 is strong in the home country (large E_{pu}) but weak in the foreign country (small E_{pu}^*).¹⁶ As for the magnitude of the price change, we find that the larger the difference between the domestic permit prices of the two countries ($tF_z - tF_z^*$), the greater the decrease in the price of international transport services.

¹⁶ This condition is not odd. We can show that $E_{pu} > E_{pu}^*$ if the utility functions are identical across the two countries and the sub-utility functions of goods consumption are homothetic. The home country prefers good 1 more than the foreign country does because the domestic price of good 1 is lower in the home country than in the foreign country because of transportation costs.

Remark 1 *The price of international transport services is reduced by international emissions trading between the two countries' international transport sectors if α is large, β is small, and $\varepsilon > 0$.*

The intuition behind this result is as follows. The world supply of international transport services increases despite the fixed global pollution emissions because international emissions trading improves the efficiency of production by reallocating pollution permits between the two countries. This directly reduces the price of international transport services (the direct effect). There are two indirect effects. (i) In the home country, the international transport sector expands through buying permits, which increases the national income despite payment for traded permits because the home country purchases permits at a lower price than its domestic price. The foreign country's national income also rises because the revenue from international emissions trading is large enough to cover the loss associated with a reduction in the size of the international transport sector by selling permits. These increases in the national income of the two countries raise their demand for final goods, thereby increasing the world demand for international transport. However, this increase is small because both countries prefer exported goods rather than imported goods under $\varepsilon > 0$. (ii) The world demand for international transport is affected by a change in the price of goods, p , but the magnitude is small under $\gamma < 0$ and $\kappa < 0$. Because α is large, the price of good 1 in the foreign country, $p + \alpha t$, becomes high, which leads to low consumption of good 1. Therefore, a change in p has a slight effect on the foreign demand for international transport. This can be explained using the analogy that a change in p has an insignificant effect on the home demand for international transport because β is small. Consequently, the direct effect dominates the two indirect effects, and the price of international transport services is lowered by international emissions trading.

Next, consider the effect of international emissions trading on the price of goods, given by

(15). Even if we impose meaningful conditions, we cannot determine the sign of (15). The price of good 1 may be increased or decreased by international emissions trading. Intuitively, this is because there are complicated effects caused by interactions between the markets.

4.2. Welfare Effects of International Emissions Trading

Now, we consider how international emissions trading affects each country's welfare. Interestingly, we obtain clear results despite the changes in the prices of goods and international transport services being generally ambiguous.

The following equations are derived by totally differentiating (3) and (11)–(13):

$$|H| \frac{du}{dz} = (tF_Z - r)\lambda\mu - (F_Z - F_Z^*)\{t\mu X_p^* E_{pu}^* - \lambda T^*(1 - \alpha t E_{pu}^*)\} \\ - \kappa[\kappa(tF_Z - r) + (F_Z - F_Z^*)\{X_p^*(1 - \alpha t E_{pu}^*) - tT^* E_{pu}^*\}], \quad (16)$$

$$|H| \frac{du^*}{dz} = (r - tF_Z^*)\lambda\mu - (F_Z - F_Z^*)\{-t\mu X_p^* E_{pu} + \lambda T^*(1 - \beta t E_{qu})\} \\ - \kappa[\kappa(r - tF_Z^*) + (F_Z - F_Z^*)\{-X_p^*(1 - \beta t E_{qu}) + tT^* E_{pu}\}]. \quad (17)$$

The welfare effects for the home and foreign countries are given by (16) and (17), respectively. For given prices of goods and international transport services, $tF_Z - r$ and $r - tF_Z^*$ represent the direct gains from permit trading in the home and foreign countries, respectively. Given Assumption 1 and assuming that the home country imports international transport services ($T^* < 0$), the sign of (16) is positive, i.e., international emissions trading always causes welfare to rise in the home country. By contrast, if the world permit price is nearly equivalent to the domestic permit price of the foreign country ($r - tF_Z^* \cong 0$), the sign of (17) is negative, i.e., the foreign country is necessarily made worse off by permit trading.

Summing up, we obtain the following proposition.

Proposition 2 *Take as given Assumption 1 and that the home country imports international transport services ($T^* < 0$). Then, international emissions trading between the two countries'*

international transport sectors has the following welfare effects.

(i) The welfare of the home country always improves.

(ii) The welfare of the foreign country necessarily deteriorates if the world permit price is approximately equal to the domestic permit price of the foreign country ($r - tF_z^ \cong 0$).*

This result is of great interest and counterintuitive. Even if the home country (an international-transport-importing country) receives no direct gains from permit trading ($tF_z - r = 0$), it necessarily benefits from it. Further, international emissions trading may make the foreign country (an international-transport-exporting country) worse off even if it enjoys all of the direct gains from permit trading by selling permits at a high price, i.e., tF_z , the current market price of the home country ($tF_z^* < r = tF_z$). The larger the volume of exports of international transport (the smaller the value of T^*), the higher the possibility of welfare deterioration in the foreign country.

To explain why international emissions trading benefits the home country but harms the foreign country, let us review our result on a step-by-step basis. In each country, the national income is increased by permit trading because of an improvement in production efficiency. First, this increase in the national income raises the demand for goods, thereby changing the price of goods (the terms-of-trade effect for final goods). It is ambiguous whether this terms-of-trade effect is favorable to the home country. Second, this change in the price of goods affects the demand for imports, thereby changing the world demand for international transport, which is negligible under Assumption 1. Third, from Remark 1, the terms-of-trade effect for international transport tends to be favorable to the home country. Consequently, the positive effects dominate the negative effects in the home country. By contrast, when the foreign country cannot fully enjoy direct gains from permit trading, it is harmed by permit trading because the terms of trade for international transport tend to deteriorate. This negative terms-of-trade effect is significant when the volume of trade in international transport is large. We know that at least one country

benefits from permit trading because permit trading improves the production efficiency of the world economy.

Our results suggest that the welfare effects of permit trading in international transport sectors are essentially dependent on the trade pattern of international transport. In other words, trade patterns of final goods and emission permits do not affect the welfare effects. Thus, an international-transport-importing country has an incentive to support permit trading regardless of the world permit price. However, an international-transport-exporting country has a great interest in the level of the world permit price. If the direct gains from permit trading are not sufficiently large, an international-transport-exporting country will not participate in the marketable permit system despite the fact that it improves world welfare.

Our theoretical prediction seems in line with real-world observations. Countries such as those in the EU have reached an agreement on MBMs such as an ETS for environmental regulations of international aviation, but the members of the IMO have not yet agreed on such measures for international maritime transport, as mentioned above. This may be because trade imbalances in international maritime transport among countries are greater than that in international aviation. That is, a maritime-transport-exporting country is more likely to be harmed by permit trading, thereby reducing its support against permit trading.

The core contribution of this paper is to show the explicit conditions for the welfare effects of permit trading between countries. By using a general equilibrium model of international trade, Copeland and Taylor (2005, pp. 225–229) considered the welfare effects of international emissions trading between two countries' final goods sectors but did not derive the explicit conditions that determine the welfare effects. In their model, a terms-of-trade effect is created when permit trading alters the production of goods in both countries. This terms-of-trade effect is favorable to only one country and its magnitude is ambiguous although we know that changes in production depend on factor intensity (Rybczynski effect). Marschinski et al. (2012) investigated international emissions trading between the final goods sectors of two countries

with different types of environmental regulations, such as partial emissions coverage and an economy-wide cap-and-trade system. They found that the welfare effects from the linking of ETSs between countries are ambiguous because of the terms-of-trade effect caused by the linking.

In our model, permit trading benefits both countries by expanding the volume of trade in goods because permit trading increases the world supply of international transport services. In other words, permit trading reduces trade impediments (transportation costs) and works similarly to trade liberalization. Thus, both countries can gain from permit trading, particularly an international-transport-importing country. An international-transport exporting country may be made better off by permit trading if it enjoys a large share of the direct gains from permit trading.

5. Concluding Remarks

In this paper, we developed a two-country, two-good general equilibrium model with an international transport sector in each country to examine how environmental regulations of international transport affect welfare. The novelty of our analysis is that it sheds light on the effects of worldwide emissions trading in international transport sectors, which have attracted public attention in recent years.

We demonstrated that a unilateral reduction in the number of pollution permits in the international transport sector has ambiguous effects on individual countries' welfares because of the terms-of-trade effects for final goods and international transport services caused by emissions reductions. By contrast, the welfare effects of international emissions trading between the two countries' international transport sectors are clear, although permit trading also creates the two terms-of-trade effects. Under a reasonable condition regarding the world demand for international transport, an international-transport-importing country always benefits from permit trading, regardless of whether it enjoys any direct gains, while permit trading necessarily harms

an international-transport-exporting country if it cannot enjoy the direct gains.

The important implications of our results are as follows. (i) A country that has significant environmental awareness and exports international transport is likely to benefit from a unilateral reduction in the number of pollution permits, because consumers' gain associated with the reduction in emissions is large and the terms of trade for international transport tend to improve. (ii) Without raising global pollution emissions, international emissions trading increases the world supply of international transport, thereby facilitating international trade. Therefore, it is quite important to establish a worldwide marketable permit system not only to protect the environment at lower cost but also to increase the gains from trade. (iii) Both countries can be made better off by permit trading if an international-transport-exporting country enjoys the direct gains from permit trading. However, a country's share of the direct gains is determined by bargaining between buyers and sellers. Thus, international income transfers (side payments) are generally required to attract support for international emissions trading from all countries.

For future research, it would be worthwhile building alternative models in order to better understand the mechanism underlying the effects of environmental regulations of international transport. Marketable permit systems for final goods and international transport can be integrated into a single worldwide marketable permit system to reduce global pollution emissions more efficiently. It would be interesting to construct an oligopoly model of international trade in order to consider strategic interactions between firms with respect to international emissions trading in the international transport sector.

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Appendix A: Stability Conditions

Taking $Z^{(*)}$ as an exogenous variable and totally differentiating (1)–(4), we obtain

$$H \begin{bmatrix} du \\ du^* \\ dp \\ dt \end{bmatrix} = \begin{bmatrix} tF_Z - E_Z & -E_Z \\ -E_Z^* & tF_Z^* - E_Z^* \\ -E_{pu}E_Z - E_{pu}^*E_Z^* & -E_{pu}E_Z - E_{pu}^*E_Z^* \\ F_Z - \beta E_{qu}E_Z - \alpha E_{pu}^*E_Z^* & F_Z^* - \beta E_{qu}E_Z - \alpha E_{pu}^*E_Z^* \end{bmatrix} \begin{bmatrix} dZ \\ dZ^* \end{bmatrix}, \quad (A1)$$

where

$$H = \begin{bmatrix} 1 & 0 & E_p - G_p & \beta X_q - F \\ 0 & 1 & X_p^* & \alpha X_p^* - F^* \\ E_{pu} & E_{pu}^* & \lambda & \kappa \\ \beta E_{qu} & \alpha E_{pu}^* & \kappa & \mu \end{bmatrix}.$$

We consider the dynamic system consisting of (1) and (2) and the following two equations:

$$\dot{p} = E_p(p, q, Z_W, u) - G_p(p, q) + X_p^*(p + \alpha t, Z_W, u^*),$$

$$\dot{t} = \beta X_q(p, q, Z_W, u) + \alpha X_p^*(p + \alpha t, Z_W, u^*) - F(K, Z) - F^*(K^*, Z^*).$$

Linearizing the system at the equilibrium values of the variables, we derive

$$\begin{bmatrix} d\dot{p} \\ d\dot{t} \end{bmatrix} = \begin{bmatrix} E_{pu}u_p + E_{pu}^*u_p^* + \lambda & E_{pu}u_t + E_{pu}^*u_t^* + \kappa \\ \beta E_{qu}u_p + \alpha E_{pu}^*u_p^* + \kappa & \beta E_{qu}u_t + \alpha E_{pu}^*u_t^* + \mu \end{bmatrix} \begin{bmatrix} dp \\ dt \end{bmatrix},$$

where $u_p = -(E_p - G_p)$, $u_t = -(\beta X_q - F)$, $u_p^* = -X_p^*$, and $u_t^* = -(\alpha X_p^* - F^*)$. Then, the

Hicksian perfect stability conditions are as follows:

$$E_{pu}u_p + E_{pu}^*u_p^* + \lambda < 0, \quad \beta E_{qu}u_t + \alpha E_{pu}^*u_t^* + \mu < 0, \quad (\text{A2})$$

$$\det \begin{bmatrix} E_{pu}u_p + E_{pu}^*u_p^* + \lambda & E_{pu}u_t + E_{pu}^*u_t^* + \kappa \\ \beta E_{qu}u_p + \alpha E_{pu}^*u_p^* + \kappa & \beta E_{qu}u_t + \alpha E_{pu}^*u_t^* + \mu \end{bmatrix} > 0. \quad (\text{A3})$$

Rewriting $|H|$, we find that $|H|$ is equivalent to the left hand side of (A3).

Appendix B: Welfare Effects of Emissions Reductions

From (A1), we derive the formal expressions of the welfare effects of emissions reductions in each country as follows:

$$|H| \frac{du}{dZ} = \begin{vmatrix} tF_Z - E_Z & E_p^* - G_p^* & -F^* \\ tF_Z E_{pu}^* + (E_{pu} - E_{pu}^*)E_Z & \lambda & \kappa - \alpha\lambda \\ -\alpha E_{pu} E_Z - F_Z + \beta E_{qu} E_Z & \kappa - \alpha\lambda & \mu - 2\alpha\kappa + \alpha^2\lambda \end{vmatrix},$$

$$|H| \frac{du^*}{dZ} = \begin{vmatrix} -E_Z^* & E_p^* - G_p^* & -F^* \\ (E_{pu} - E_{pu}^*)E_Z^* - tF_Z E_{pu} & \lambda & \kappa - \alpha\lambda \\ F_Z - (tF_Z - E_Z^*)(\beta E_{qu} - \alpha E_{pu}) & \kappa - \alpha\lambda & \mu - 2\alpha\kappa + \alpha^2\lambda \end{vmatrix},$$

$$|H| \frac{du}{dZ^*} = \begin{vmatrix} -E_p & E_p - G_p & F^* \\ -tF_Z^* E_{pu} - (E_{pu} - E_{pu}^*)E_Z & \lambda & \kappa - \alpha\lambda \\ F_Z^* - \beta E_{qu} E_Z + \alpha E_{pu} E_Z & \kappa - \alpha\lambda & \mu - 2\alpha\kappa + \alpha^2\lambda \end{vmatrix},$$

$$|H| \frac{du^*}{dZ^*} = \begin{vmatrix} tF_Z^* - E_Z^* & E_p - G_p & F^* \\ tF_Z^* E_{pu} - (E_{pu} - E_{pu}^*)E_Z^* & \lambda & \kappa \\ F_Z - \alpha E_{pu} E_Z^* + (tF_Z^* - E_Z^*)\beta E_{qu} & \kappa & \mu \end{vmatrix}.$$