Trade, Pollution Policy, and Environmental Technology*

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Abstract

We examine gains from trade in a small open economy model with the inter-industry interaction caused by pollution. In our model, the economy is diversified in the trading equilibrium so that it cannot avoid the negative impact of pollution through the spatial separation of production. First, we show that free trade may harm the economy depending on the trade pattern and the level of a pollution tax. Second, unless a pollution tax is optimal, the introduction of new pollution-reducing technology can harm the economy even if it is costless. We also derive a similar result under tariff policy.

JEL classification: F13; Q55; Q56

Keywords: Gains from trade; Pollution externality; Pollution tax; Tariff policy; Environmental technology

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1 Introduction

In recent years, there has been growing concern with the effects of international trade on the environment (e.g., Copeland and Taylor, 2003; Bhagwati, 2004). International trade results in changes in the location of production of goods between countries. This change is one of the important sources of gains from trade. On the other hand, there is concern about trade leading to spatial concentration of polluting industries. We face trade-off between damage from an increase in domestic pollution and conventional gains from trade if countries have comparative advantage in polluting goods. In such a case, it is important for countries to implement environmental policy (e.g., a pollution tax and the introduction of new pollution-reducing technology) so as to benefit from trade. However, if all pollution externalities are not internalized, it is controversial whether trade liberalization improves welfare and the environment.

In this paper, we develop a small open economy model with domestic pollution externality. The present model has three features. First, pollution generated by production in the Smokestack manufacturing industry deteriorates the productivity of an environmentally sensitive sector (e.g., agriculture) instead of affecting utility directly.[1] This depicts a situation that recent increases in green-house gases (GHGs) alter each country's climate, and droughts and floods caused by climate change may negatively affect agricultural production (e.g., OECD, 2001; IPCC, 2001).[2] Technically, the amount of pollution determines comparative advantage in this framework. A country which discharges a small (large) amount of pollution will have comparative advantage in the clean (polluting) sector. Second, a country is diversified in the

[1]There are numerous studies on trade and the environment when environmental pollution deteriorates welfare directly instead of affecting production of goods. See, for example, Barrett (1994), Copeland and Taylor (1994), Ludema and Wooton (1994), Copeland and Taylor (1995), Copeland (1996), and Copeland and Taylor (2003).

[2]Empirical evidence has linked industrial pollution to reduced fishing, damaged crops and forests, and beach closures, which have negative effects on tourism. See Copeland and Taylor (1999, p.138).

trading equilibrium so that it cannot avoid the negative impact of pollution through the spatial separation of production. Third, our model using duality is tractable so that we can clarify the effects of policy intervention. In this framework, we investigate gains from trade with and without pollution policy and show under what conditions a country benefits from trade. We also examine the effects of improvement in environmental technology under pollution and tariff policy.

Our main results are the following. First, we show that a small open economy can gain from trade even if the government *subsidizes* production of the polluting good, regardless of the trade pattern. In our model, the economy is diversified in the trading equilibrium so that there is trade-off between conventional gains from trade and productivity losses caused by pollution. Under the absence of pollution policy, free trade is likely to harm a small country if it exports the polluting good. Thus, we consider that the economy should impose a pollution tax when it exports the polluting good. However, there is the possibility that the standard gains from trade are large enough to outweigh the negative impact of lax pollution policy. This result implies that free trade can be welfare improving for countries not implementing optimal environmental policy.

Second, we show that contrary to conventional wisdom, welfare of a small open economy can deteriorate by the introduction of new pollution-reducing technology unless a pollution tax (or a tariff) is optimal, even if the cleaner technology is costless. This occurs because when a pollution tax is sufficiently high, the introduction of the cleaner technology may intensify the tax-induced production distortion. This result implies that interest in environmental technology depends on a country's policy.

We consider a pollution tax and a tariff on Smokestack in this paper. The standard theory of distortions implies that policy intervention should target a distortion directly (e.g., Bhagwati, 1971). In the present model, since pollution is generated by domestic production, tariff policy is not the first best policy. Therefore, the pollution tax can attain a higher level of welfare than the tariff can. However, the analysis of tariff policy in the context of trade and the environment is significant in countries, especially in developing countries, which have difficulty in taking positive measures to deal with environmental pollution. In such countries, pollution policy is considered to be an obstacle to economic development and costly to monitor.[3]

A seminal study is Copeland and Taylor (1999) who examined gains from trade under the inter-industry interaction caused by domestic pollution.[4] Copeland and Taylor showed that free trade is always welfare improving for a small open economy despite the absence of pollution policy, which sharply differs from our result although the basic structure of our model is based on their model. In Copeland and Taylor's model, a small country completely specializes in Smokestack or Farming because their model behaves like a Ricardian model. Therefore, a small country can avoid the negative impact of pollution through the spatial separation of production. Our study complements Copeland and Taylor's analysis and shows that gains from trade in a small country are dependent on its trade pattern in general production structure. Benarroch and Thille (2001) and Unteroberdoerster (2001) extended the Copeland and Taylor's model by allowing for the possibility of transboundary pollution. In these papers, transboundary pollution serves the same role as diversified production in the present paper. By using a trade model with

[3]For example, the third Conference of Parties to the United Nations Framework Convention on Climate Change (COP3) held in Kyoto at the end of 1997 adopted, so-called, the Kyoto Protocol. The protocol includes an important agreement that the targets of reduction in GHGs in developed countries were explicitly set. However, developing countries have no obligation to the reduction of GHGs emission.

[4]See also Herberg and Kemp (1969) and Herberg et al. (1982) for the literature about externalities on production in trade models.

the inter-industry interaction caused by pollution, Rauscher (1997, Ch.5) examined the effects of trade liberalization (i.e., a reduction in the tariff rate) when the government implements environmental policy but did not investigate gains from trade. By using a two-country model that has the same features in this paper, Takarada (2005) studied the welfare effects of a transfer of pollution abatement technology in the absence of pollution policy. The existing literature did not thoroughly analyze gains from trade under policy intervention and the effects of the introduction of new pollution-reducing technology.

The remainder of this paper is organized as follows. We present a trade model with pollution externality in Section 2. In Section 3, we study gains from trade with and without environmental policy. We examine the effects of a change in environmental technology in Section 4. Finally, we provide concluding remarks.

2 The Model

We develop a small open economy model to show gains from trade under pollution externality. There are two industries denoted M and A. Industry M (or Smokestack manufacturing) is a dirty industry that discharges pollution as a joint product of output. The production function of M is $Q_M = F^M(v^M)$, where v^M is the vector of factors employed in industry M. $F^M(\cdot)$ is increasing, concave, and linearly homogeneous in inputs. We assume that one unit of M generates λ units of pollution, i.e., $D = \lambda Q_M$, where D is the volume of pollutant. It is assumed that the type of pollution is local.

Industry A is an environmentally sensitive industry (e.g., agriculture). Pollution generated by industry M negatively affects the productivity of A. The production function of A is given by the following multiplicatively separable form:

$$Q_A = m(D)F^A(v^A), \tag{1}$$

where v^A is the vector of factors employed in industry A. $F^A(\cdot)$ is increasing, concave, and linearly homogeneous in inputs. $m = m(D)$ is the degree of production externality. We assume that $0 < m(D) \leq 1$ and $m'(D) < 0$. We assume that a representative firm in industry A treats the amount of pollution, D, as exogenously given. Diseconomies of scale are external to the firm but internal to the industry.

The markets of goods and factors of production are competitive. The goods are tradeable at the fixed world price. The government imposes a production tax, τ, on M. Thus, the producer price of M is $p = p^W - \tau$, where p^W is the world relative price of M. τ is positive (negative) if the government imposes a tax on M (subsidizes production of M).[5] Tax revenue is distributed to the households in a lump-sum fashion.

We define the gross domestic product (GDP) function with production externality as

$$\widetilde{G}(p, m, v) = \max_{v} \left\{ pF^M(v^M) + m(D)F^A(v^A) \mid v^M + v^A = v \right\}, \tag{2}$$

where v is the factor endowment vector.[6] It is positively linear homogeneous in p and m (e.g., Helpman, 1984, p.334). Let us define the following function:

$$\widetilde{R}(q, v) = \max_{v} \left\{ qF^M(v^M) + F^A(v^A) \mid v^M + v^A = v \right\}, \tag{3}$$

where $q \equiv \frac{p}{m(D)}$. The value of $\widetilde{R}(\cdot)$ is the 'virtual' national income because it denotes the national income under the 'virtual' price, q. $\widetilde{R}(\cdot)$ behaves like the standard GDP function with

[5] We do not consider a consumption tax on M in this paper. A consumption tax does not affect the amount of pollution because pollution is generated by production and not by consumption.

[6] We can show that the production transformation locus is downward-sloping. The curvature of the production possiblity frontier may be entirely concave, entirely convex, or it may have convex and concave parts because there are inter-industrial externalities. See Herberg et al. (1982) for details.

constant returns to scale technologies. Since $\widetilde{G}(p,m,v)$ is linearly homogeneous in p and m, we can rewrite it as follows:

$$\begin{aligned}\widetilde{G}(p,m,v) &= \max_{v} m(D)\left\{\frac{p}{m(D)}F^M(v^M)+F^A(v^A)\mid v^M+v^A=v\right\}\\ &= m(D)\max_{v}\left\{qF^M(v^M)+F^A(v^A)\mid v^M+v^A=v\right\}\\ &= m(D)\widetilde{R}(q,v). \qquad (4)\end{aligned}$$

Henceforth, we delete the fixed factor endowment vector, i.e., $G(p,m)\equiv\widetilde{G}(p,m,v)$ and $R(q)\equiv\widetilde{R}(q,v)$. Thus, $G(p,m)=m(D)R(q)$. Note that the GDP function, $G(p,m)$, includes information of production externality. From the properties of the GDP function, $G_p(p,m)=Q_M$, where a subscript indicates differentiation, i.e., $G_p\equiv\frac{\partial G(p,m)}{\partial p}$ (e.g., Helpman, 1984). Thus, we obtain $G_p=m(D)R_q(q)\frac{\partial q}{\partial p}=R_q=Q_M$.

The model can be characterized by the following equations:

$$E(p^W,u)=G(p,m)+T, \qquad (5)$$

$$D=\lambda R_q(q), \qquad (6)$$

$$T=\tau R_q(q), \qquad (7)$$

where $E(p^W,u)$ and T are the expenditure function with the level of utility, u, and the lump-sum subsidy, respectively. The budget constraint of the economy is given by equation (5). Equation (6) denotes the endogenous level of pollution discharged by production of M. Equation (7) is tax revenue that can be positive or negative depending on the sign of τ.

Totally differentiating equations (5), (6), and (7), we have

$$E_u du+NdD=-(E_p-R_q-\frac{\tau R_{qq}}{m})dp^W-\frac{\tau R_{qq}}{m}d\tau, \qquad (8)$$

$$\left(1+\frac{\lambda R_{qq}pm'}{m^2}\right)dD=\frac{\lambda R_{qq}}{m}dp^W-\frac{\lambda R_{qq}}{m}d\tau+R_q d\lambda, \tag{9}$$

where $N\equiv\frac{m'}{m}(pR_q-mR)+\frac{\tau R_{qq}pm'}{m^2}$. N is positive under $\tau<0$ because of $pR_q-mR=-Q_A$ but N can be negative if τ is sufficiently large.

From equations (8) and (9), we can derive the following basic equations. The effect of a price change on welfare is given by

$$\Delta\left(\frac{du}{dp^W}\right)=-\left(1+\frac{\lambda R_{qq}pm'}{m^2}\right)(E_p-R_q)+\frac{\tau R_{qq}}{m}+\frac{\lambda R_{qq}m'}{m^2}Q_A, \tag{10}$$

where $\Delta\equiv E_u\left(1+\frac{\lambda R_{qq}pm'}{m^2}\right)=E_u\left(1+\epsilon_q\epsilon_D\right)$. We define $\epsilon_q\equiv q\frac{R_{qq}}{Q_M}$ and $\epsilon_D\equiv D\frac{m'}{m}$. ϵ_q and ϵ_D indicate the virtual price elasticity of the output of M and the pollution elasticity of productivity losses, respectively. ϵ_q is positive and ϵ_D is negative.

We assume that an increase in the output of M leads to a less increase in its own output, i.e., $1+\epsilon_q\epsilon_D>0$ (see the Appendix A). Δ is positive if and only if $1+\epsilon_q\epsilon_D>0$. The amount of pollution increases if the output of M increases. This increase in pollution increases the virtual price. Thus, the output of M will increase further. To stop this linkage, we must make the assumption. If the assumption does not hold, the economy will completely specialize in M if once the output of M increases.

The intuition behind the assumption for $\Delta>0$ is that the response of outputs to a change in the relative price is normal. We can show by simple calculation that the output of M (A) decreases (increases) if the domestic relative price of M decreases. Moreover, from equation (9), we can derive

$$\frac{dD}{d\lambda}=R_q\left(1+\frac{\lambda R_{qq}pm'}{m^2}\right)^{-1}. \tag{11}$$

$\Delta>0$ implies that the amount of pollution increases if the emission rate increases. Thus, an increase in the emission rate creates additional damage to the productivity of A.

In order to observe the change in pollution induced by a price change, using equations (8) and (9), we have

$$\Delta\left(\frac{dD}{dp^W}\right) = E_u\frac{\lambda R_{qq}}{m} > 0. \tag{12}$$

It denotes that a decrease in the price of M reduces pollution. A decrease in pollution implies a decrease in the output of M because there is no transboundary pollution.

3 Gains from Trade under Pollution

3.1 Free trade without pollution policy

We consider the effects of free trade without pollution policy (i.e., $\tau = 0$). It is convenient for considering two cases according to the trade pattern.

First, from equation (10), welfare improves as a result of a decrease in the price of M (i.e., $\frac{du}{dp^W} < 0$) when a small country imports M (i.e., $E_p - R_q \geq 0$). A country imports M after opening the market if it faces the lower price of M than in autarky, i.e., $p^A \geq p^W$, where p^A is the price of M in autarky. From equation (12), trade decreases the amount of pollution. There are both conventional gains from trade and an increase in the productivity of A as long as A is produced. Thus, a small country benefits from free trade when it imports M.

Second, the welfare effect as a result of a change in the price is ambiguous when a small country exports M (i.e., $E_p - R_q < 0$). An increase in the price of M implies improvement in the terms of trade and an increase in pollution (equation (12)). From equation (10), welfare deteriorates if the volume of trade in M is relatively small and production externality is relatively large. However, an increase in the price of M leads to welfare improvement (i.e., $\frac{du}{dp^W} > 0$) if the volume of export of M becomes relatively large and the production of A shrinks. We find that an increase in the price of M is welfare improving if the output of A is zero. A small country exports M if $p^A < p^W$. Thus, gains from trade depend on the relative size of the effects regarding production externality and the volume of trade. It is possible for a country to lose from free trade when it exports M.

Then, we obtain the following proposition.

Proposition 1. *Under the absence of pollution policy, free trade is welfare improving for a small country if it imports Smokestack. However, free trade may harm a small country if it exports Smokestack.*

We show that with no pollution policy, gains from trade are conditional on the trade pattern.[7] Our result is different from proposition 3 in Copeland and Taylor (1999) although the type of pollution in this paper is the same as their model.[8] Copeland and Taylor showed that free trade is always welfare improving for a small open economy, despite the absence of pollution policy. In Copeland and Taylor's model, but not in our model, a country immediately specializes in Farming or Smokestack after trade because their model behaves like a Ricardian model.[9] Therefore, production of the dirty good never affects the productivity of the clean good. By employing a Ricardian framework, they illustrated the possibility of beneficial separation. However, in our model, by introducing more than one factor of production, a country will continue producing both the dirty and clean goods even after trade occurs. Thus, free trade causes productivity

[7] A similar result is derived when pollution affects utility directly. See, for example, Copeland and Taylor (2003).

[8] The equilibrium in our small open economy model essentially replicates the steady state in Copeland and Taylor (1999) that modeled pollution as a stock in a dynamic model.

[9] In Copeland and Taylor (1999), there are two factors of production, labor and the stock of environmental capital. Labor is employed in both industries but the stock of environmental capital is only used for production of Farming. The level of the stock of environmental capital is given at any moment in time, but may change over time, depending on the flow of pollution. Thus, their model has the feature of a Ricardian model.

losses. Copeland and Taylor (1999) also showed that in a two-country framework, welfare of the exporter of Smokestack goods may deteriorate.[10] Our analysis complements Copeland and Taylor's analysis.

3.2 Suboptimal pollution policy

We examine gains from trade when a pollution tax is not optimally chosen by the government. The economy always gains from trade under the optimal pollution tax (i.e., Pigovian tax) because pollution externality is internalized (see the Appendix B).[11] There are three reasons for us to investigate suboptimal pollution policy: (i) the government may continue to impose the pollution tax which is optimal in autarky even after free trade because of the adjustment costs of a change in environmental policy; (ii) the government may implement too strict pollution policy if there are interest groups that insist on the cleaner environment (e.g., environmentalists and producers in the clean sector that benefit from improvement of productivity); (iii) some countries, especially developing countries, tend to subsidize production of the manufacturing industry, which usually uses a large amount of energy and discharges pollution, for economic development.

It is convenient for considering two cases according to the trade pattern. First, we investigate the case in which the economy imports M. We already know that despite the absence of pollution policy, a country benefits from free trade if it imports the dirty good (Proposition 1). However, production externality is not internalized without pollution policy. We will clarify whether the

[10] Very similar results are obtained in the increasing returns to scale and trade literature where Ethier (1982) had a small open economy always gaining from trade, but in the two-country version with diversified production a country could lose.

[11] Using a model with external output-generated economies and diseconomies of scale, Panagariya (1981) obtained a similar result. He showed that welfare maximization for a small country requires a permanent tax subsidy scheme encouraging expansion of the increasing returns to scale industry and contraction of the decreasing returns to scale industry. Note that his production externality in an industry is induced by its total output and does not depend on the other industry's level of output.

imposition of a suboptimal pollution tax improves welfare.

From equation (10), a small country suffers from improvement in the terms of trade (i.e., $\frac{du}{dp^W} > 0$) if the government imposes a sufficiently high pollution tax. This implies that although the government implements pollution policy, a country may suffer from importing M. The necessary and sufficient condition for this result is that the right hand side of equation (10) is positive. Therefore, a production tax on M must satisfy the following inequality:

$$\underline{\tau}_M > \theta_M \equiv \frac{m}{R_{qq}} \left\{ \left(1 + \frac{\lambda R_{qq} p m'}{m^2}\right) (E_p - R_q) - \frac{\lambda R_{qq} m'}{m^2} Q_A \right\} \geq 0. \tag{13}$$

We obtain the implication of $\underline{\tau}_M$ by rewriting θ_M as follows:

$$\begin{aligned} \theta_M &= \frac{p}{Q_M} \frac{Q_M}{q R_{qq}} \left\{ (1 + \epsilon_q \epsilon_D)(C_M - Q_M) - \frac{D m'}{m} \frac{R_{qq}}{m} \frac{Q_A}{Q_M} \right\} \\ &= \frac{p}{\epsilon_q Q_M} \left\{ (1 + \epsilon_q \epsilon_D)(C_M - Q_M) - \epsilon_D \frac{Q_M}{p} \frac{q R_{qq}}{Q_M} \frac{Q_A}{Q_M} \right\} \\ &= \frac{1}{\epsilon_q Q_M} \left\{ p(1 + \epsilon_q \epsilon_D)(C_M - Q_M) - \epsilon_q \epsilon_D Q_A \right\}, \end{aligned} \tag{14}$$

where $C_M \equiv E_p$. C_M denotes the compensated demand for M. Equation (14) implies that $\underline{\tau}_M$ becomes large if the output of M decreases or if the output of A increases. We know that the economy benefits from trade under the optimal pollution tax, $\tau^* = -\frac{\lambda m'}{m} Q_A \geq 0$ (see the Appendix B). Thus, it is clear that $\tau^* < \theta_M$. That is, the pollution tax, $\underline{\tau}_M$, is *above* the optimal level (i.e., too stringent pollution policy compared to the optimal pollution policy).

We can explain this result as follows. From equations (8) and (9), we have

$$\Delta \left(\frac{dD}{d\tau} \right) = -E_u \frac{\lambda R_{qq}}{m} < 0. \tag{15}$$

It denotes that an increase in a tax rate unambiguously reduces the amount of pollution, which implies that the output of M decreases. A high production tax extremely shrinks the industry of M and expands the industry of A. There is tax-induced production distortion. A decrease in the price of M after trade decreases the output of M and then pollution decreases. The reduction of pollution expands the industry of A (productivity gains). However, it exaggerates the tax-induced production distortion. Hence, a country suffers from trade although there are the standard gains from trade and the productivity gains.

It is straightforward that a country benefits from importing M if the government imposes the pollution tax, $\widehat{\tau}_M$, which satisfies $\widehat{\tau}_M \leq \theta_M$. This implies that the economy can be better off even when there is a *subsidy* on M. Intuitively, a subsidy for M will increase pollution. However, a decrease in the domestic price of M after trade reduces pollution, which results in productivity gains. The productivity gains and the standard gains from trade outweigh the productivity losses caused by the subsidy. Thus, a country benefits from importing M although the government subsidizes production of M.

Second, we examine the case in which the economy exports M. We already know that the economy may suffer from exporting M under the absence of environmental policy (Proposition 1). This implies that the government should implement environmental policy to internalize pollution externality. However, we will show the possibility that the economy benefits from exporting M even if the government *subsidizes* production of M.

Using a similar method as in the former case, we can show that the economy benefits from exporting M if the government imposes the pollution tax, $\underline{\tau}_E$, which satisfies $\underline{\tau}_E \geq \theta_E$, where

$$\theta_E \equiv \frac{m}{R_{qq}} \left\{ \left(1 + \frac{\lambda R_{qq} p m'}{m^2}\right)(E_p - R_q) - \frac{\lambda R_{qq} m'}{m^2} Q_A \right\}. \tag{16}$$

The implication of θ_E is similar to that of θ_M. Note that θ_E is positive if the volume of the export of M is sufficiently small but it is negative if the volume of the export of M becomes large. Thus, $\underline{\tau}_E$ can be negative (i.e., a subsidy) when θ_E is negative. However, the economy suffers from exporting M if the government imposes the pollution tax, $\widehat{\tau}_E$, which satisfies $\widehat{\tau}_E < \theta_E$.

This result is counter-intuitive because we consider that the government should impose a pollution tax on M to mitigate the increase in pollution caused by exporting M. Intuitively, the economy is better off because the standard gains from trade are large enough to outweigh the negative impact of such lax pollution policy. On the other hand, under $\widehat{\tau}_E$, the economy is worse off because of too lax environmental policy compared to the optimal environmental policy.

Summing up, we obtain the following proposition.

Proposition 2. *A small country suffers from importing Smokestack if the government imposes the pollution tax, $\underline{\tau}_M$, but it benefits from trade if the pollution tax is $\widehat{\tau}_M$. On the other hand, when a small country exports Smokestack, it is worse off under $\widehat{\tau}_E$ but it is better off under $\underline{\tau}_E$.*

This proposition implies that the relation between the trade pattern and the level of a pollution tax determines gains from trade. Note that free trade can be welfare improving even if a pollution tax is below the optimal level, regardless of the trade pattern. Of course, the optimal pollution tax can attain a higher level of welfare than a suboptimal pollution tax can.

4 Environmental Technology

In this section, we consider the possibility that pollution generated per unit of M, λ, is reduced by advanced abatement technology. It is assumed that a change in the emission rate does not require costs in order to make its effects clear.

4.1 The case of pollution policy

From equations (8) and (9), the effect of a change in the emission rate on welfare is given by

$$\Delta\left(\frac{du}{d\lambda}\right) = -R_q N. \tag{17}$$

Equation (17) shows that a decrease (an increase) in λ harms (enriches) a small country if the government imposes a sufficiently high pollution tax. Recall that N can be negative under a high production tax on M. We should note that this result holds although new pollution-reducing technology is costless. The result is counter-intuitive because we know that an increase in λ increases pollution and so the productivity of A deteriorates.

The necessary and sufficient condition for the result is $-R_q N > 0$. Thus, a production tax on M must satisfy the following inequality:

$$\widetilde{\tau} > \frac{mQ_A}{R_{qq}p} \geq 0. \tag{18}$$

Let us consider the implication of $\widetilde{\tau}$. We can rewrite the inequality as follows:

$$\begin{aligned}
\widetilde{\tau} &> \frac{mQ_A}{R_{qq}p} = -\frac{m}{R_{qq}p}(pQ_M - mR) \\
&= -p\left(\frac{1}{q}\frac{Q_M}{R_{qq}} - \frac{1}{q}\frac{Q_M}{R_{qq}}\frac{R}{qQ_M}\right) \\
&= -p\left(\frac{1}{\epsilon_q} - \frac{1}{\epsilon_q}\frac{mR}{pQ_M}\right) \\
&= -\frac{p}{\epsilon_q}\left(1 - \frac{1}{\eta}\right) \geq 0,
\end{aligned} \tag{19}$$

where $\eta \equiv \frac{pQ_M}{mR}$. η indicates the proportion of industry M's output value to the national income. Equation (19) implies that the smaller η and ϵ_q are, the larger $\widetilde{\tau}$ becomes.

Reasoning of the result is the following. M is undersupplied and A is overproduced under $\widetilde{\tau}$, which implies that the domestic production is distorted. A decrease in pollution caused by the introduction of new pollution-reducing technology improves the productivity of A and so the output of A increases (productivity gains). However, the increase in the output of A intensifies the tax-induced production distortion. The expansion of the distortion outweighs the productivity gains. Thus, a country suffers from the introduction of new pollution-reducing technology under a sufficiently high pollution tax.

Such a counter-intuitive result never occurs if the government imposes the optimal production tax, τ^*, on M. Substituting τ^* for τ in equation (17), we obtain

$$\Delta\left(\frac{du}{d\lambda}\right)\Big|_{\tau=\tau^*} = R_q\frac{m'Q_A}{m}\left(1+\frac{\lambda R_{qq}pm'}{m^2}\right) \leq 0. \tag{20}$$

The right hand side of equation (20) is negative when A is produced. Thus, a decrease in λ improves welfare under the optimal pollution tax.

We can also obtain a similar result under $\overline{\tau} \leq \frac{mQ_A}{R_{qq}p}$. Such a pollution tax is likely to be *below* the optimal level because $\tau^* < \frac{mQ_A}{R_{qq}p}$ when the economy is diversified in production. Intuitively, when a pollution tax is below the optimal level (e.g., a subsidy on M), M is overproduced and A is undersupplied. A decrease in pollution induced by the reduction of the emission rate enhances the productivity of A and so its output increases. This alleviates the production distortion induced by lax environmental policy compared to the optimal environmental policy.[12]

Summing up, we obtain the following proposition which is independent of the trade pattern.

Proposition 3. *A small open economy always gains from the introduction of new pollution-reducing technology if the government imposes the optimal pollution tax, τ^*, or the pollution tax, $\overline{\tau} \leq \frac{mQ_A}{R_{qq}p}$, but suffers from it if the pollution tax satisfies the inequality, $\widetilde{\tau} > \frac{mQ_A}{R_{qq}p}$.*

[12]There is the possibility that $\overline{\tau}$ is above the optimal level. In this case, there is tax-induced production distortion. However, productivity gains caused by the introduction of new pollution-reducing technology outweigh the negative impact of the distortion.

The effect of a change in environmental technology in terms of a country as a whole has not been thoroughly studied in the existing literature although it contains important policy implications.[13] Our result implies that contrary to conventional wisdom, a technology with lower pollution per unit of output is not always good for a country. The government may impose a high pollution tax when the government imposes the pollution tax which was optimal before the introduction of the cleaner technology or when there are interest groups that insist on the cleaner environment (e.g., environmentalists and producers in the clean sector that benefit from improvement of productivity). In such a country, the introduction of new pollution-reducing technology deteriorates welfare. Therefore, a country may not develop and adopt new environmental technology. The paradoxical outcome is avoidable not only when the government imposes the optimal pollution tax but also when the government implements suboptimal environmental policy (e.g., a subsidy on M). Of course, the level of welfare under the optimal pollution tax is higher than that under a suboptimal pollution tax.

The welfare loss due to the introduction of new pollution-reducing technology is related to the argument of immiserizing growth. The welfare impact of growth can be reduced because growth may give rise to distortions that increase the welfare loss, causing it to outweigh the primary gain from growth (see Bhagwati et al., 1998). In our model, the cleaner technology operates like technological progress but, in analogy to the argument of immiserizing growth, it may harm the economy.

[13] Benarroch and Thille (2001) examined how the initial difference in environmental technology (i.e., one country discharges pollution but the other country generates no pollution) affects gains from trade in section 4.1. However, they did not investigate the effect of the introduction of new pollution-reducing technology under the presence of pollution and tariff policy.

4.2 The case of tariff policy

In this subsection, we consider the effect of the introduction of the cleaner technology in a model under tariff policy. The substance of the model is same as the model with a production tax in Section 2.

First, we develop a small open economy model when the government imposes a specific tariff, t, on M. Thus, the domestic relative price of M is $p^D = p^W + t$. Tariff revenue is distributed to the households in a lump-sum fashion. Substituting p^D for p in the GDP function, $G(\cdot)$, we obtain the GDP function under a tariff, $G(p^D, m) = m(D)R(r)$, where $R(\cdot)$ is the virtual national income and the virtual price, r, is defined as $r \equiv \frac{p^D}{m(D)}$. The GDP function has the property, $G_p = R_r = Q_M$. Hence, the model can be characterized by the following equations:

$$E(p^D, u) = G(p^D, m) + \widetilde{T}, \tag{21}$$

$$D = \lambda R_r(r), \tag{22}$$

$$\widetilde{T} = t\left\{E_p(p^D, u) - R_r(r)\right\}, \tag{23}$$

where $\widetilde{T}$ is the lump-sum subsidy.

Second, we examine the effect of a change in the emission rate on welfare. Totally differentiating equations (21), (22), and (23), we obtain

$$\Delta' \left(\frac{du}{d\lambda}\right) = R_r \left(\frac{m'}{m} Q_A + \frac{tR_{rr} p^D m'}{m^2}\right), \tag{24}$$

where $\Delta' \equiv (E_u - tE_{pu}) \left(1 + \frac{\lambda R_{rr} p^D m'}{m^2}\right)$. In this subsection, we assume that all goods are normal in consumption. Thus, $E_u - tE_{pu} = (E_u - p^D E_{pu}) + p^W E_{pu} > 0$. Using a similar method as in the case of a production tax, we can show that Δ' is positive if $1 + \sigma_r \sigma_D > 0$, where $\sigma_r \equiv r\frac{R_{rr}}{Q_M}$

and $\sigma_D \equiv D\frac{m'}{m}$ are the virtual price elasticity of the output of M and the pollution elasticity of productivity losses, respectively.

Equation (24) shows that a decrease (an increase) in λ harms (benefits) a small country if the tariff rate is sufficiently small. The necessary and sufficient condition is given by

$$\widetilde{t} < -\frac{mQ_A}{R_{rr}p^D} \leq 0. \tag{25}$$

It is similar to equation (18). The implication of $\widetilde{t}$ is similar to that of $\widetilde{\tau}$ in equation (19).

Reasoning of the result is the following. A is overproduced by the negative tariff, $\widetilde{t}$, which implies a subsidy for A. Thus, the domestic production is distorted by the tariff. A decrease in pollution caused by the introduction of new pollution-reducing technology results in an increase in the output of A (productivity gains). However, this intensifies the tariff-induced production distortion. The expansion of the distortion outweighs the productivity gains. This reasoning is similar to the reasoning under a pollution tax.

We can show that such a paradoxical result never occurs if the government imposes the optimal tariff, t^*, as follows:

$$t^* = -\frac{\lambda R_{rr}m'}{m^2}Q_A\left\{E_{pp}\left(1+\frac{\lambda R_{rr}p^D m'}{m^2}\right)-\frac{R_{rr}}{m}\right\}^{-1} \leq 0. \tag{26}$$

In this paper, the productivity of A is negatively influenced by the production of M. Therefore, it is optimal for the government to impose t^* (i.e., an export tax or an import subsidy) encouraging contraction of industry M and expansion of industry A (see the Appendix C). Substituting t^* for t in equation (24), we obtain

$$\Delta'\left(\frac{du}{d\lambda}\right)\Big|_{t=t^*} = -Z\frac{R_r m' Q_A}{m}\left(1+\frac{\lambda R_{rr}p^D m'}{m^2}\right)\left\{E_{pp}\left(1+\frac{\lambda R_{rr}p^D m'}{m^2}\right)-\frac{R_{rr}}{m}\right\}^{-1}, \tag{27}$$

where $Z \equiv -\left(E_{pp} - \frac{R_{rr}}{m}\right) > 0$. The right hand side of equation (27) is negative when A is produced. Thus, a decrease in λ improves welfare under the optimal tariff.

We can also derive a similar result in the case of $\overline{t} \geq -\frac{mQ_A}{R_{rr}p^D}$. Such a tariff rate can be *below* (or *above*) the optimal level because $t^* > -\frac{mQ_A}{R_{rr}p^D}$ when the economy is diversified in production. This case includes a positive tariff on M and free trade. Intuitively, under a positive tariff, M is overproduced and A is undersupplied because of $p^D > p^W$, which implies that the domestic production is distorted by the tariff. A decrease in pollution induced by the introduction of new pollution-reducing technology enhances the productivity of A and so its output increases. This alleviates the tariff-induced production distortion. This reasoning holds under free trade as long as A is produced.

Summing up, we obtain the following proposition which is independent of the trade pattern.

Proposition 4. *A small open economy always gains from the introduction of new pollution-reducing technology if the government imposes the optimal tariff, t^*, or the tariff rate, $\overline{t} \geq -\frac{mQ_A}{R_{rr}p^D}$, but suffers from it if the tariff rate satisfies the inequality, $\widetilde{t} < -\frac{mQ_A}{R_{rr}p^D}$.*

This result is similar to Proposition 3. A technology with lower pollution per unit of output is unlikely to be desired by a small country with a sufficiently low negative tariff rate compared to the optimal level despite a decrease in pollution. This paradoxical outcome does not take place when the government imposes the optimal tariff or when the government protects industry M by imposing a positive tariff.

5 Concluding Remarks

We developed a small open economy model to examine gains from trade under pollution externality. The production in one industry generates pollution as a joint product of output, which reduces the productivity of an environmentally sensitive sector. The main contribution of this paper is to investigate implications of environmental policy intervention when a small country faces the inter-industry interaction caused by pollution. We extended previous work by introducing more than one factor of production. Under this scenario, the economy is always diversified in the trading equilibrium so that it cannot avoid the negative impact of pollution through the spatial separation of production. Thus, environmental policy is important to mitigate damage caused by pollution.

In this framework, we showed the possibility that free trade can be welfare improving when a pollution tax is below the optimal level. For example, the economy may be better off even if the government subsidizes the production of Smokestack. This is informative for policy makers in countries subsidizing the production of manufacturing industries for economic development. Our theoretical result implies that free trade can be welfare improving for countries not implementing optimal environmental policy.

We also showed that the welfare of a small open economy can paradoxically deteriorate by the introduction of a new technology with lower pollution per unit of output under the presence of a pollution tax and a tariff, even if the technology is costless. Such a counter-intuitive result has not been observed in the existing literature. The essence of the result under a pollution tax is similar to that under a tariff although a pollution tax can attain a higher level of welfare than a tariff can. This result implies that a country imposing an import tariff to protect the Smokestack manufacturing industry tends to introduce new pollution-reducing technology. However, when a country implements strict pollution policy compared to the optimal pollution policy, it is unlikely to adopt new environmental technology. Such stringent environmental policy may arise when the government imposes the pollution tax which was optimal before the introduction of the cleaner technology or when there are interest groups that insist on the cleaner environment (e.g., environmentalists and producers in the clean sector that benefit from improvement of productivity). Hence, a country's concern with the technology of environmental cleanup depends on its policy.

We can discuss the effect of transboundary pollution in the present model (see the Appendix D). Since our model is a small open economy model, the effect of a change in the level of transboundary pollution is substantially similar to that in the domestic incidence of pollution. A country suffers from an increase in cross-border pollution under the optimal pollution tax (or the optimal tariff), but may benefit from it unless pollution policy (or tariff policy) is optimal.

The following extensions can be considered for future research. First, we can examine gains from trade and pollution policy in a two-country framework. This analysis provides meaningful results which are different from the present results. Second, we can consider costs for the introduction of new pollution-reducing technology. In this paper, such costs are not explicitly considered in order to clarify the effects of a change in environmental technology. The free new abatement technology can be interpreted as technology transfer. The substance of our outcome is unlikely to change even if we consider costs of environmental technology.

Appendix A

In this Appendix, we consider the implication of $1+\epsilon_q\epsilon_D$. Recall that $Q_M = R_q(q)$. Partially differentiating the right hand side with respect to Q_M, we obtain

$$\begin{aligned} dR_q &= R_{qq}dq = R_{qq}\frac{-pm'}{m^2}dD \\ &= -\frac{\lambda R_{qq}pm'}{m^2}dQ_M = -\epsilon_q\epsilon_D dQ_M. \end{aligned}$$

To make sure that an increase in the output of M leads to a less increase in its output, we must assume $\frac{\partial R_q}{\partial Q_M} < 1$. Thus, $-\epsilon_q\epsilon_D < 1$. This implies that at least one absolute value of the elasticity must be smaller than unity.

Appendix B

In this appendix, we examine gains from trade when the government optimally chooses a production tax on M. First, let us derive the optimal pollution tax. From equations (8) and (9), we obtain

$$\Delta\left(\frac{du}{d\tau}\right) = -\frac{R_{qq}}{m}\tau - \frac{\lambda R_{qq}m'}{m^2}Q_A.$$

It is optimal for the socially planning government to impose the production tax, $\tau^* = -\frac{\lambda m'}{m}Q_A \geq 0$, on M. Using $\lambda = \frac{D}{Q_M}$, we can rewrite the optimal pollution tax as $\tau^* = -\epsilon_D\frac{Q_A}{Q_M}$. It implies that τ^* is large if ϵ_D is small and the relative supply of A (i.e., $\frac{Q_A}{Q_M}$) is large.

Second, we consider gains from trade under the optimal pollution tax. Substituting τ^* for τ in equation (10), we obtain

$$\Delta\left(\frac{du}{dp^W}\right)\Big|_{\tau=\tau^*} = -\left(1+\frac{\lambda R_{qq}pm'}{m^2}\right)(E_p - R_q).$$

It implies that under the optimal pollution tax, a small country unambiguously benefits from free trade.

Appendix C

In this appendix, we investigate an optimal tariff on M. Totally differentiating equations (21), (22), and (23), the effect of a tariff on welfare is given by

$$\Delta' \left(\frac{du}{dt} \right) = t \left(E_{pp} - \frac{R_{rr}}{m} \right) \left(1 + \frac{\lambda R_{rr} p^D m'}{m^2} \right) + \frac{\lambda R_{rr}}{m} \left(\frac{m'}{m} Q_A + \frac{t R_{rr} p^D m'}{m^2} \right). \qquad \text{(A.1)}$$

From equation (A.1), it is optimal for the socially planning government to impose the tariff rate, t^*, regardless of the trade pattern. We can consider the implication of t^* by rewriting equation (26) as follows:

$$\begin{aligned} t^* &= -\frac{\lambda R_{rr} m'}{m^2} Q_A \left\{ E_{pp} \left(1 + \frac{\lambda R_{rr} p^D m'}{m^2} \right) - \frac{R_{rr}}{m} \right\}^{-1} \\ &= -\frac{D}{Q_M} \frac{R_{rr} m'}{m^2} Q_A \left\{ \frac{E_p}{p^D} p^D \frac{E_{pp}}{E_p} \left(1 + \frac{D}{Q_M} \frac{R_{rr} p^D m'}{m^2} \right) - \frac{R_{rr}}{m} \right\}^{-1} \\ &= -\frac{Q_A}{Q_M} D \frac{m'}{m} \frac{Q_M}{p^D} r \frac{R_{rr}}{Q_M} \left\{ \frac{C_M}{p^D} \sigma_p \left(1 + D \frac{m'}{m} r \frac{R_{rr}}{Q_M} \right) - \frac{Q_M}{p^D} r \frac{R_{rr}}{Q_M} \right\}^{-1} \\ &= -\frac{Q_A}{Q_M} \sigma_D \frac{Q_M}{p^D} \sigma_r \left\{ \frac{C_M}{p^D} \sigma_p \left(1 + \sigma_r \sigma_D \right) - \frac{Q_M}{p^D} \sigma_r \right\}^{-1} \\ &= -\sigma_r \sigma_D Q_A \left\{ \sigma_p \left(1 + \sigma_r \sigma_D \right) C_M - \sigma_r Q_M \right\}^{-1}, \end{aligned} \qquad \text{(A.2)}$$

where $\sigma_p \equiv p^D \frac{E_{pp}}{E_p}$ denotes the price elasticity of compensated demand for M and is negative. Equation (A.2) implies that t^* becomes small if the output of A increases or the output of M decreases.

Totally differentiating equations (21), (22), and (23), we have

$$\Delta' \left(\frac{dD}{dt} \right) = \frac{\lambda R_{rr}}{m} \left(E_u - t E_{pu} \right) > 0.$$

It denotes that a decrease in a tariff rate unambiguously reduces the amount of pollution, which implies a decrease in the output of M. The optimal tariff induces productivity gains of A.

Appendix D

In this Appendix, we only examine the effect of transboundary pollution in the context of a pollution tax because the essence of the result is similar to the result under a tariff.

With cross-border pollution, b, the total level of pollution, $\widetilde{D}$, affecting a small country is given by $\widetilde{D} = \lambda R_q(q) + b$. By using this instead of equation (6), we obtain the effect of transboundary pollution on welfare as follows:

$$\Delta \left(\frac{du}{db} \right) = -N.$$

It is similar to equation (17). A country suffers from an increase in b under the optimal pollution tax, but may benefit from it unless a pollution tax is optimal.

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