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Market Integration and Competition in Environmental and Trade Policies

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Abstract

Recent empirics suggest the relevance of transport cost reductions for world trade growth along with eliminations in protectionist trade barriers. To address the welfare effects of trade cost reductions in a context of 'trade and the environment,' we develop a two-stage game model where governments choose environmental and trade policies and firms play a Cournot-Nash game. We show that reductions in transport costs lead to lower emission taxes and higher tariffs. And, we find that the degree of pollution damage plays a central role in whether market integration is welfare-improving relative to autarky.

Key words: market integration, oligopoly, pollution tax, tariff, gains/losses from trade

JEL classification: F12, F18, L13, Q56

1 Introduction

Over the last decades, multilateral market integration has led to rapid growth in world trade. While it is obvious that such growth in world trade has improved welfare of each country and the world, it simultaneously brings new concerns, e.g., protection of intellectual property rights, and trade and labor standard.[1]

Among others, 'trade and the environment' has received much attention in both international and environmental economics, which has brought a large literature.[2] One of the central interests in this field is what consequences follow from a noncooperative setting of environmental policies. Early contributions include Conrad (1993), Kennedy (1994a,b), Rauscher (1994), Ulph (1996) and Tanguay (2001), wherein each country is motivated to use laxer environmental policies as a tacit protectionist trade policy called 'eco-dumping.' In contrast, a Bertrand-Nash model of Barrett (1994, Section 5) shows that the noncooperatively determined environmental policy is tougher than the environmentally optimal level. Based on the above body of literature, Walz and Wellisch (1997), Burguet and Sempere (2003), and Baksi and Chaudhuri (2009) consider welfare effects of trade liberalization, i.e., multilateral reductions in protectionist trade policies, under noncooperative choices of environmental policies.[3]

On the driving forces of growing world trade flows, Baier and Bergstrand (2001, p. 19) empirically show that 'income growth, tariff rate reductions, and transport-cost declines all contributed nontrivially to the real growth of world trade.'[4] Despite these evidences, to our knowledge, there is no study except for Straume (2006) that addresses the effects of transport cost reductions.[5] Straume (2006) examines the effects of transport cost reductions in a two-stage game model in which governments choose emission taxes and then oligopolistic firms choose output and abatement levels, taking the taxes as given. One of his novel results is that market integration can reduce the need for inter-country policy coordination.

The purpose of this paper is to develop a two-country, two-stage game model to consider the impact of market integration, i.e., transport cost reductions, on the optimal tariff and emission tax, and welfare. While we are partly common with Straume (2006) in interests, this paper is greatly differentiated. First, we allow for not only emission taxes but also tariffs as policy instruments.[6] Second, we pay much attention to welfare effects of market integration whereas Straume's (2006) aim is to analyze policy coordination. We establish two main results. First, market integration leads each country to impose a laxer environmental policy (lower emission tax) and a tougher trade policy (higher tariff). Second, we find three patterns of the dependence of the Nash equilibrium welfare on trade costs. Whether freer trade is beneficial highly depends on the degree of pollution damage.

The rest of this paper is organized as follows. Section 2 formulates a two-stage game model in which the government in two trading countries noncooperatively chooses emission taxes and tariffs in the first stage and firms play a Cournot-Nash game in the second stage. The subgame perfect Nash equilibrium is characterized. Section 3 explores welfare effects of transport cost reductions. Section 4 concludes the paper.

2 A Model

2.1 FUNDAMENTALS

Consider a reciprocal market model of intra-industry trade in homogeneous goods.[7] There are two symmetric countries (Home and Foreign), two goods (Goods 1 and 2) and one factor (labor). The Foreign variables are asterisked to distinguish them from the Home variables. The market of Good 1 in each country is segmented and duopolized by a Home firm (firm X) and a Foreign firm (firm Y). Without loss of generality, one unit of labor produces one unit of Good 2, which is the numareire, so that the wage rate is internationally fixed to unity. Production of Good 1 is nationally monopolized under a constant marginal cost $c \geq 0$, and emits a proportional emission, which is transboundary. Letting x (resp. y) and x^* (resp. y^*) be the Home (resp.

Foreign) firm's supply into the Home and Foreign markets, pollution in Home is measured by $x + x^* + \theta(y + y^*)$ where $\theta \in [0, 1]$ is a fraction of Foreign emission arriving in Home.[8] Analogously, pollution in Foreign is $\theta(x + x^*) + y + y^*$.

Assume a representative consumer in each country whose preference is

$$u = aC_1 - \frac{C_1^2}{2} + C_2 - sZ, \quad a > c, \quad s > 0, \tag{1}$$

where u is utility, $C_i, i = 1, 2$ is the consumption of Goods 1 and 2, and s is marginal damage from pollution.[9] Utility maximization under the budget constraint yields linear inverse demand functions: $p = a - x - y$ and $p^* = a - x^* - y^*$.

Two policy instruments are available to each country's government: emission taxes τ and τ^* and import tariffs t and t^*. Moreover, we assume that exporting involves a per-unit transport cost $T \geq 0$. While transportation involves a certain pollutant as Colvile et al. (2001) empirically argue, we do not model it throughout our analysis. Summarizing these assumptions, the profit of the Home and Foreign firms is defined by

$$\text{Home firm}: (a - c - \tau - x - y)x + (a - c - \tau - t^* - T - x^* - y^*)x^* \tag{2}$$

$$\text{Foreign firm}: (a - c - \tau^* - t - T - x - y)y + (a - c - \tau^* - x^* - y^*)y^*, \tag{3}$$

where the first term in these equations represents the profit from serving in the Home market and the second term is the counterpart in the Foreign market.[10]

Let us consider the following two-stage game. The Home and Foreign governments choose emission taxes and tariffs to maximize welfare in the first stage. Taking these policy choices as given, the Home and Foreign firms play a Cournot-Nash game in the second stage. We will solve this game with backward induction.

2.2 A COURNOT-NASH GAME

This subsection solves the second stage of the game: a quantity-setting game. Solving the system of the first-order conditions for profit maximization yields the Cournot-Nash equilibrium outputs:[11]

$$x = \frac{a-c-2\tau+\tau^*+t+T}{3} \tag{4}$$

$$x^* = \frac{a-c-2\tau+\tau^*-2t^*-2T}{3} \tag{5}$$

$$y = \frac{a-c+\tau-2\tau^*-2t-2T}{3} \tag{6}$$

$$y^* = \frac{a-c+\tau-2\tau^*+t^*+T}{3}. \tag{7}$$

Making use of (4)-(7), consumer surplus in Home denoted by CS (resp. Foreign denoted by CS^*) is given by $CS = (x+y)^2/2$ (resp. $CS^* = (x^*+y^*)^2/2$) and the equilibrium profit of each firm, denoted by π and π^*, is simply expressed by $\pi = x^2 + x^{*2}$ and $\pi^* = y^2 + y^{*2}$, respectively. Assuming that the Home government distributes the emission tax revenue $\tau(x+x^*)$ and the tariff revenue ty to the consumer in a lump-sum fashion, Home's welfare to be maximized in the first stage is defined as follows.

$$\begin{aligned} V &= CS + \pi + \tau(x+x^*) + ty - sZ \\ &= \frac{(x+y)^2}{2} + x^2 + x^{*2} + \tau(x+x^*) + ty - s\left[x + x^* + \theta(y+y^*)\right] \\ &= \frac{1}{2}\left[\frac{2(a-c)-\tau-\tau^*-t-T}{3}\right]^2 \\ &\quad + \left(\frac{a-c-2\tau+\tau^*+t+T}{3}\right)^2 + \left(\frac{a-c-2\tau+\tau^*-2t^*-2T}{3}\right)^2 \\ &\quad + \tau \cdot \frac{[2(a-c)-4\tau+2\tau^*+t-2t^*-T]}{3} + t \cdot \frac{(a-c+\tau-2\tau^*-2t-2T)}{3} \\ &\quad - s \cdot \frac{[2(a-c)-4\tau+2\tau^*+t-2t^*-T] + \theta\left[2(a-c)+2\tau-4\tau^*-2t+t^*-T\right]}{3} \\ &\equiv V(\tau, \tau^*, t, t^*, T). \end{aligned} \tag{8}$$

Applying the same procedure to Foreign, the Foreign government's payoff is defined by $V(\tau^*, \tau, t^*, t, T)$ due to the symmetry assumption between countries.

2.3 A POLICY GAME

Having derived the Cournot-Nash equilibrium in the second stage, let us turn to the first stage and derive the subgame perfect Nash equilibrium. Each government seeks to maximize welfare by choosing emission taxes and tariffs. Then, the first-order conditions are

$$\begin{aligned}
\frac{\partial V}{\partial \tau} &= \frac{-7\tau - \tau^* + 3t + 2t^* + 2T - 4(a-c) + 6s(2-\theta)}{9} = 0 \\
\frac{\partial V}{\partial t} &= \frac{\tau - \tau^* - 3t - T + a - c - s(1-2\theta)}{3} = 0 \\
\frac{\partial V^*}{\partial \tau^*} &= \frac{-\tau - 7\tau^* + 2t + 3t^* + 2T - 4(a-c) + 6s(2-\theta)}{9} = 0 \\
\frac{\partial V^*}{\partial t^*} &= \frac{-\tau + \tau^* - 3t^* - T + a - c - s(1-2\theta)}{3} = 0.
\end{aligned}$$

These conditions allow us to find that both governments choose the same level of emission taxes and tariffs, each of which is explicitly derived as

$$\tau^N = \frac{-7(a-c) + T + s(31-8\theta)}{24} \tag{9}$$

$$t^N = \frac{a - c - T - s(1-2\theta)}{3}, \tag{10}$$

where superscript N refers to the subgame perfect Nash equilibrium. Substituting these into (4)-(7) and using the definition of pollution, the domestic emission (the total supply of a firm) and the pollution level in each country are

$$\begin{aligned}
\text{emission} &= x + x^* = y + y^* = \frac{3(a-c-s) - T}{4} \\
\text{pollution} &= x + x^* + \theta(y + y^*) = \theta(x + x^*) + y + y^* = \frac{(1+\theta)[3(a-c-s) - T]}{4}.
\end{aligned}$$

Thus, the degree of transboundary pollution θ has no impact on the individual firm's emission and a positive impact on pollution in each country.

Eqs. (9) and (10) immediately lead to:

Proposition 1. *Market integration, i.e., a reduction in transport costs, lowers the emission tax and raises the tariff determined in the subgame perfect Nash equilibrium.*

(Table 1 around here)

Employing Straume's (2006) decomposition, let us consider the intuitions behind Proposition 1. As shown in Appendix and Table 1 in detail, the effect of a change in transport costs on consumer utility is $U_{\tau T} = U_{tT} = -1/9$. These negative signs imply that transport cost reductions increase each country's marginal benefit from taxation and thus higher taxes are chosen. The reason is simply that reduced transport costs promote competition and thus the distortion associated with under-supply becomes weaker, namely, there is less need to under-tax to tackle the under-supply problem.

The second welfare component is considered by examining the effect on net trade surplus, S_τ and S_t. Appendix shows that $S_{\tau T} > 0$ and $S_{tT} < 0$, which, in turn, implies that market integration strengthens (resp. weakens) the rent-shifting motive through an emission tax (resp. a tariff). As Straume (2006, p. 544) states, 'lower trade costs make it easier to capture rents from the foreign market.' Therefore, each government chooses a lower emission tax and a higher tariff so as to shift more rents from the trading country.

The third and fourth components relate to the effects on production costs and damages from pollution. As is inferred from the linear specification of production cost and pollution damage, there is no effect of transport cost reductions on these terms, i.e., $C_{\tau T} = C_{tT} = D_{\tau T} = D_{tT} = 0$. In other words, 'only incentives for rent-shifting and increasing consumer utility are affected.' (Straume, 2006, p. 544)

The total effect of reduced transport costs on the equilibrium emission tax and tariff is determined by the above effects. If transport cost reductions favorably affect the change in marginal benefit from emission taxes and tariffs, governments will raise these taxes. As Table 1 summarizes, since the positive effect on net trade surplus outweighs the negative effect on consumer utility, the total effect becomes positive and hence market integration induces a higher emission tax. In contrast, both the effect on consumer utility and net trade surplus are negative in the case of tariffs. Consequently, the total effect also becomes negative and a lower tariff is induced by market integration.

Before proceeding, let us mention the difference between Burguet and Sempere (2003) and us regarding the response of the optimal emission tax to reductions in trade barrier. Burguet and Sempere (2003, p. 35) find that 'environmental policies are tougher after the reduction in tariffs,' which is seemingly contradictive to our result. This discrepancy stems from the difference in the assumption on trade barriers. Because Burguet and Sempere (2003) assume an import tariff as an exogenous trade barrier, governments have an incentive to compensate for reduced tariff revenue by raising emission taxes. On the other hand, such a motive does not exist in our model since we have assumed that an exogenous trade barrier takes a form of transport costs.

3 Gains/Losses from Trade

This section considers the relationship between the welfare level determined in the subgame perfect Nash equilibrium and transport costs. To this end, we need to compute a prohibitive trade cost over which exports are zero and the resulting equilibrium coincides with the autarkic equilibrium. Substituting (9) and (10) into either (5) or (6), each firm's export becomes

$$x^* = y = \frac{5(a-c) - 11T - s(5+8\theta)}{24}.$$

Thus, setting this to zero, the prohibitive transport cost $\overline{T}$ is

$$\overline{T} = \frac{5(a-c) - s(5+8\theta)}{11}. \tag{11}$$

From an economic point of view, this must be non-negative and thus we need a restriction that $s \leq 5(a-c)/(5+8\theta)$.

Let us next compute the welfare level in the subgame perfect Nash equilibrium. Substituting (9) and (10) into (8) and rearranging terms yield

$$\begin{aligned} W(T) &\equiv V\left(\tau^N, \tau^N, t^N, t^N, T\right) \\ &= \frac{41T^2 - 2[13(a-c) - s(13+28\theta)]T + 9(a-c-s)[5(a-c) - s(5+8\theta)]}{96}. \end{aligned} \tag{12}$$

The rest of our task is to closely examine the properties of $W(T)$. Our finding is summarized in:

Proposition 2. *There are three possibilities on the locus of* $W(T)$ *depending on* s. *They are classified as follows.*

Case 1 (Figure 1) with $s < \frac{9(a-c)}{9+32\theta}$ *:* $W(0) > W\left(\overline{T}\right), W'(0) < 0,$ *and* $W'\left(\overline{T}\right) > 0$

Case 2 (Figure 2) with $\frac{9(a-c)}{9+32\theta} < s < \frac{13(a-c)}{13+28\theta}$ *:* $W(0) < W\left(\overline{T}\right), W'(0) < 0,$ *and* $W'\left(\overline{T}\right) > 0$

Case 3 (Figure 3) with $s > \frac{5(a-c)}{5+8\theta}$ *:* $W(0) < W\left(\overline{T}\right), W'(0) > 0,$ *and* $W'\left(\overline{T}\right) > 0$.

(Figures 1-4 around here)

Proof: We begin by comparing the welfare levels at zero transport cost and the prohibitive transport cost. Evaluating (12) at $T = 0$ and $T = \overline{T}$, welfare in these two polar cases is respectively

$$\begin{aligned} W(0) &= \frac{3(a-c-s)[5(a-c)-s(5+8\theta)]}{32} \\ W\left(\overline{T}\right) &= \frac{3[5(a-c)-s(5+8\theta)][7(a-c)+s(2\theta-7)]}{242}. \end{aligned}$$

Taking the ratio between these two, we have

$$\frac{W(0)}{W\left(\overline{T}\right)} = \frac{121(a-c-s)}{16[7(a-c)+s(2\theta-7)]},$$

which exceeds one if and only if $s < 9(a-c)/(9+32\theta)$. That is, if the damage from pollution is small enough, welfare at zero transport cost is higher than that at the prohibitive transport cost, i.e., welfare under autarky.

The next task is to compute the slope of $W(T)$. Differentiating (12) once and twice yields

$$W'(T) = \frac{41T - [13(a-c) - s(13+28\theta)]}{48}, \quad W''(T) = \frac{41}{48}. \qquad (13)$$

At this stage, we easily see that the locus of $W(T)$ is strictly convex since the second derivative is positive. Evaluating $W'(T)$ at $T=0$ and $T=\overline{T}$, we obtain

$$W'(0) = \frac{-13(a-c)+s(13+28\theta)}{48} \quad (14)$$

$$W'\left(\overline{T}\right) = \frac{31(a-c)-s(31+10\theta)}{264}. \quad (15)$$

Accordingly, we see that $W'(0)<0$ if and only if $s<13(a-c)/(13+28\theta)$ and that $W'\left(\overline{T}\right)>0$ if and only if $s<31(a-c)/(31+10\theta)$.

However, the upper bound of s should be replaced from $31(a-c)/(31+10\theta)$ to $5(a-c)/(5+8\theta)$ because of the restriction that $\overline{T}\geq 0$ made above. Therefore, the three thresholds that determine three inequalities in Proposition 2 have a unique ranking such that

$$\frac{5(a-c)}{5+8\theta} > \frac{13(a-c)}{13+28\theta} > \frac{9(a-c)}{9+32\theta}.$$

This ranking is depicted in Figure 4. Based on it, we can divide three possibilities as follows. First, if $s<9(a-c)/(9+32\theta)$, we have $W(0)>W(\overline{T})$, $W'(0)<0$ and $W'\left(\overline{T}\right)>0$, which gives Figure 1. Second, if s falls between $9(a-c)/(9+32\theta)$ and $13(a-c)/(13+28\theta)$, $W(0)<W\left(\overline{T}\right)$, $W'(0)<0$ and $W'\left(\overline{T}\right)>0$ follow, from which we can get Figure 2. Finally, we have $W(0)<W\left(\overline{T}\right)$, $W'(0)>0$ and $W'\left(\overline{T}\right)>0$ for $13(a-c)/(13+28\theta)<s<5(a-c)/(5+8\theta)$. These observations provide us with Figures 1-3. **Q.E.D.**

Part of the underlying intuitions for Proposition 2 is well-recognized in the trade literature. Market integration increases total supply in each country, i.e., promotes competition, and thus favorably affects welfare (procompetitive effect). In contrast, increased imports associated with reductions in transport costs can have a negative welfare effect since the less efficient foreign firm's market share expands in each country.[16] In addition to these effects, transport cost reductions unambiguously expand both domestic and global pollution.

The overall welfare effect is determined by the interplay among these three effects. If s is small enough, the pollution expansion effect is negligible and the result in trade theory is reestablished; welfare depends on T in a U-shaped and $T = 0$ ensures higher welfare than autarky (Figure 1). This is because 'aggregate trade costs are largest for intermediate values of' T. (Haufler et al., 2005, p. 292) Indeed, the total transport costs in the subgame perfect Nash equilibrium are calculated as

$$Ty = Tx^* = \frac{T[5(a-c) - 11T - s(5+8\theta)]}{24},$$

which is inverted-U-shaped in T and becomes highest when $T = [5(a-c) - s(5+8\theta)]/22$. Accordingly, the above argument of Haufler et al. (2005) survives our model even though we allow for pollution damages as long as s is too small.

In contrast, the larger s is, the more significant the pollution expansion effect is. This is illustrated in Case 2: autarky yields higher welfare than trade with any non-prohibitive transport cost (Figure 2). The situation is much worse if s is sufficiently large. In this case, reductions in transport costs monotonically reduce welfare since pollution expansion and the associated welfare losses are considerable. To summarize, the welfare effects of reduced transport costs crucially depend on how the country cares about pollution damages.

At this stage, it is useful to address the local pollution case in light of comparison with some existing studies such as Walz and Wellisch (1997) and Burguet and Sempere (2003) both of which focus on local pollution. In this extreme case, we can state:

Corollary. *When pollution is local, only Case 1 arises.*

Proof: Under $\theta = 0$, we have

$$\begin{aligned} \frac{W(0)}{W(\overline{T})} &= \frac{121}{112} \\ W'(0) &= -\frac{13(a-c-s)}{48} < 0, \quad W'(\overline{T}) = \frac{31(a-c-s)}{264} > 0, \end{aligned}$$

which immediately leads to the result. **Q.E.D.**

Both Walz and Wellisch (1997, Proposition 3, p. 284) and Burguet and Sempere (2003), Proposition, p. 31) commonly prove that trade liberalization is welfare-improving.[17] While the above result is seemingly inconsistent with their result, the reason is that we suppose transport costs as a trade barrier. As mentioned earlier, freer trade is inevitably associated with wasteful resources of transport costs. In contrast, this effect is absent in the gains-from-trade proposition of Walz and Wellisch (1997) and Burguet and Sempere (2003) because tariff revenue fully compensates the losses from wasteful resources.

4 Concluding Remarks

Formulating a two-stage game model of strategic environmental and trade policies, we have explored the effects of reductions in transport costs on the equilibrium policies and welfare. The first result shows that market integration induces each country to choose a lower emission tax and a higher tariff. The second result identifies that whether freer trade benefits each country highly depends on the degree of pollution damage.

Two advantages of this paper are that we endogenize both environmental policies and trade policies and that we take into account transport costs. The first point is relevant since trade policies as well as environmental policies are available and are noncooperatively determined by self-interested governments in light of reality. The second point is also important in view of the empirical assessment of the literature cited in Introduction.

However, our results admittedly rest on a number of simplifying assumptions such as linear demand, cost and pollution damage. Although all of these restrictions are frequently made to facilitate analysis in the existing literature as well, it is important to reconsider the robustness of our results by relaxing them. Furthermore, we assume away abatement activities. It is our future research agenda to reexamine our results in more general settings.

Notes

1. See Bagwell and Staiger (2003) for an excellent review of these newly emerging issues surrounding world trade. Bhagwati (2004) also provides a non-technical review of recent discussions of these issues.

2. Focusing on the perfectly competitive product markets, Copeland and Taylor (2003) comprehensively survey the state-of-the-art of theoretical and empirical researches on trade and the environment.

3. Employing a third-market (resp. reciprocal market) model, Walz and Wellisch (1997) (resp. Burguet and Sempere (2003)) regard reductions in export subsidies (resp. import tariffs) as a scheme of trade liberalization. Both papers commonly assume local pollution, but Baksi and Chaudhuri (2009) allow for transboundary pollution.

4. Anderson and Wincoop (2004) also make clear the empirical significance of reductions in transport costs.

5. Regarding this, Krugman (1995, p. 328) states that 'international economists, however, tend to view much, though not all, of the growth of trade as having essentially political causes, seeing its great expansion after World War II largely as a result of the removal of the protectionist measures $\cdots$.'

6. Kennedy (1994b), Walsh and Wellisch (1997) and Tanguay (2001) also examine the interaction between environmental and trade policies, but their focus substantially differs from ours.

7. See Brander (1981), Brander and Krugman (1983) and Helpman and Krugman (1985, pp. 104-111) for the details of this model. Bernhofen (1998) and Friberg and Ganslandt (2006) demonstrate that the Brander-Krugman model provides an important insight empirically.

8. While it is possible to allow for different values of θ between countries, our assumption that θ is internationally equal is plausible given the observation that environmental degradations are mostly global in the modern world, namely, both countries suffer from the environmental damage equally.

9. The preference parameter a is assumed equal between countries. And, following the existing literature, we use an additively-separable utility function

for convenience.

10. Instead of assuming a per-unit transport cost, Tanguay (2001) assumes that profits from exporting are multiplied by $k < 1$, where k measures the cost of exporting.

11. Thus, the assumption of market segmentation and positive values of y and x^* imply intra-industry trade in a homogeneous product. See, for instance, Brander (1981) and Brander and Krugman (1983).

12. We follow Kennedy (1994a, b) and Haufler et al. (2005) in using these terminologies.

13. This is confirmed in Haufler et al. (2005) and Straume (2006) as well.

14. Haufler et al. (2005) call this the rent shifting effect.

15. While Kennedy (1994b) assumes a production subsidy instead of an import tariff as a protectionist instrument, most of his arguments apply to our case with little modification. Looking at Eqs. (9.23) and (9.24) in Kennedy (1994b, p. 206), we can confirm that emission taxes have four effects but that production subsidies have three effects.

16. Note that untaxed marginal cost of domestic production is c while that of exporting is $c + T$. This intriguing result is first established by Lahiri and Ono (1988).

17. Walz and Wellisch (1997) (resp. Burguet and Sempere (2003)) model trade liberalization as a marginal reduction in export subsidies (resp. import tariffs).

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Appendix

This appendix shows that welfare of each country has four components and how each of them is affected by a reduction in transport costs. Under our specification of the functions of utility, production cost, and pollution damage, Home's welfare is

$$\begin{aligned} V &= a(x+y) - \frac{(x+y)^2}{2} - p\cdot(x+y) + px + p^*x^* - c\left(x+x^*\right) - \tau\left(x+x^*\right) - t^*x^* - Tx^* \\ &\quad +\tau\left(x+x^*\right) + ty - sZ \\ &= a(x+y) - \frac{(x+y)^2}{2} + \left(p^* - t^* - T\right)x^* - (p-t)y - c\left(x+x^*\right) - sZ \\ &= \underbrace{\frac{(2a-x-y)(x+y)}{2}}_{U} + \underbrace{\left(p^* - t^* - T\right)x^* - (p-t)y}_{S} - \underbrace{c(x+x^*)}_{C} - \underbrace{sZ}_{D} \\ &\equiv U + S - C - D, \end{aligned} \tag{16}$$

where U, S, C, and D respectively denote consumer utility, net trade surplus, production cost, and environmental damage. Substituting (4)-(7) into (16), each component becomes a function of emission taxes, tariffs, and the transport cost:

$$U = \frac{(4a+2c+\tau+\tau^*+t+t)[2(a-c)-\tau-\tau^*-t-T]}{18} \tag{17}$$

$$\begin{aligned} S &= \frac{(a+2c+\tau+\tau^*-2t^*-2T)(a-c-2\tau+\tau^*-2t^*-2T)}{9} \\ &\quad -\frac{(a+2c+\tau+\tau^*-2t+T)(a-c+\tau-2\tau^*-2t-2T)}{9} \end{aligned} \tag{18}$$

$$C = \frac{c[2(a-c)-4\tau+2\tau^*+t-2t^*-T]}{3} \tag{19}$$

$$D = \frac{s\{2(a-c) - 4\tau + 2\tau^* + t - 2t^* - T + \theta[2(a-c) + 2\tau - 4\tau^* - 2t + t^* - T]\}}{3}. \tag{20}$$

Differentiating (17)-(20) with respect to τ and t, we have

$$U_\tau = U_t = \frac{-a - 2c - \tau - \tau^* - t - T}{9} \tag{21}$$

$$S_\tau = \frac{-3a - 6c - 6\tau + 4t + 2t^* + 3T}{9}, \quad S_t = \frac{2(2a + c + 2\tau - \tau^* - 4t - T)}{9} \tag{22}$$

$$-C_\tau = \frac{4c}{3}, \quad -C_t = -\frac{c}{3} \tag{23}$$

$$-D_\tau = \frac{2s(2-\theta)}{3}, \quad -D_t = -\frac{s(1-2\theta)}{3}, \tag{24}$$

where subscripts τ and t stand for a partial derivative. The emission tax and tariff in the subgame perfect Nash equilibrium are determined to aggregate these effects, i.e., $U_\tau + S_\tau - C_\tau - D_\tau = 0$ and $U_t + S_t - C_t - D_t = 0$.

	emission tax	tariff
consumer utility	$U_{\tau T} = -\frac{1}{9}$	$U_{tT} = -\frac{1}{9}$
net trade surplus	$S_{\tau T} = \frac{1}{3}$	$S_{tT} = -\frac{2}{9}$
production cost	$-C_{\tau T} = 0$	$-C_{tT} = 0$
environmental damage	$-D_{\tau T} = 0$	$-D_{tT} = 0$
total	$\partial \tau^N / \partial T > 0$	$\partial t^N / \partial T < 0$

Table 1: Effects of transport cost reductions on taxation

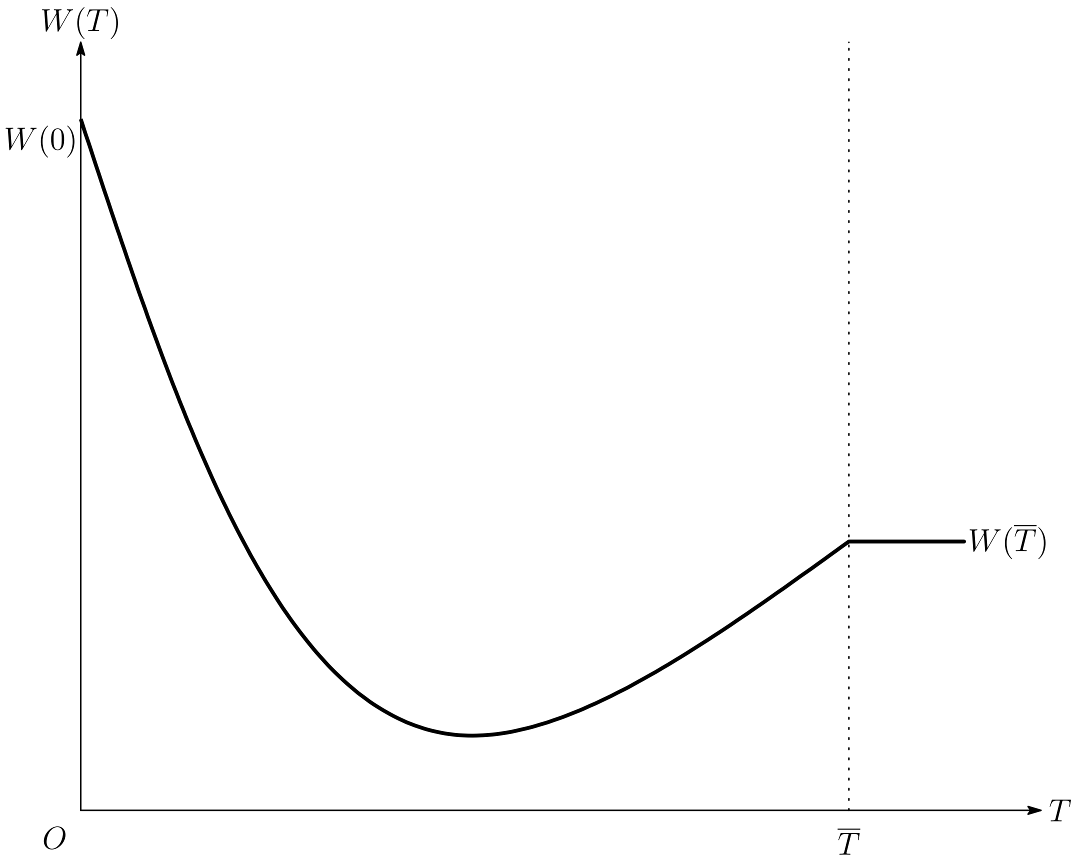

Figure 1: Case 1

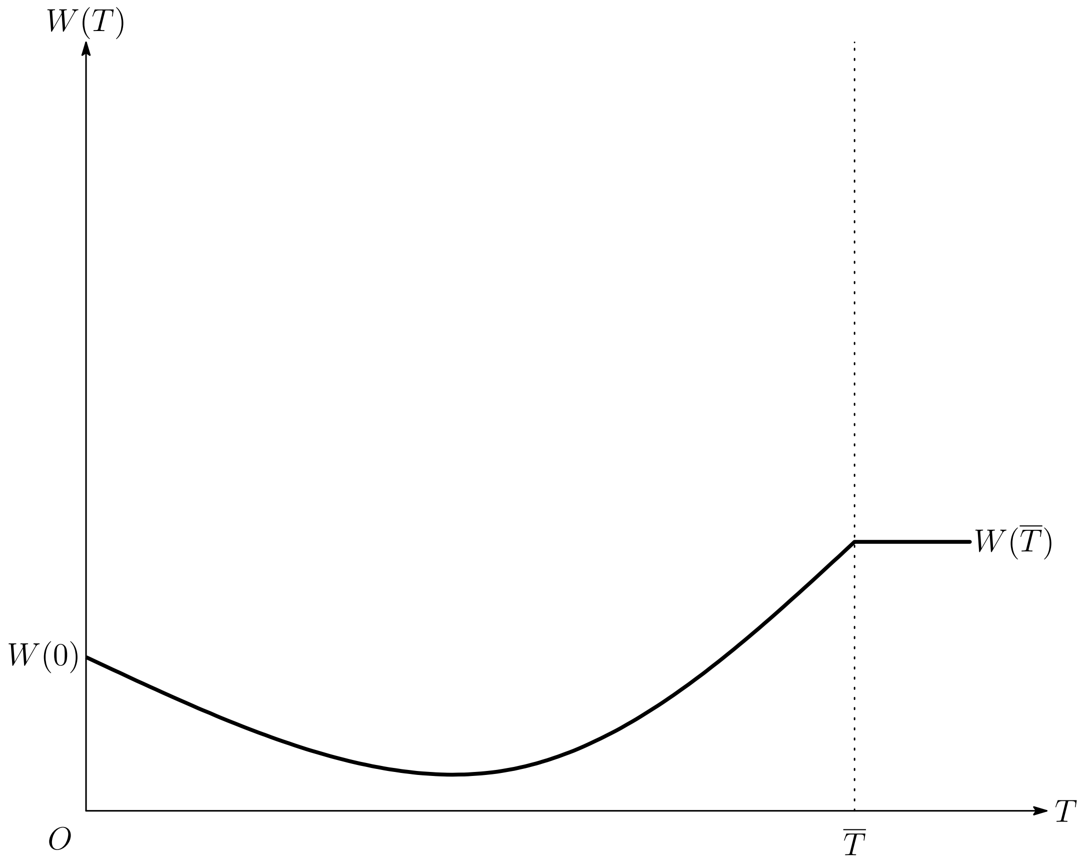

Figure 2: Case 2

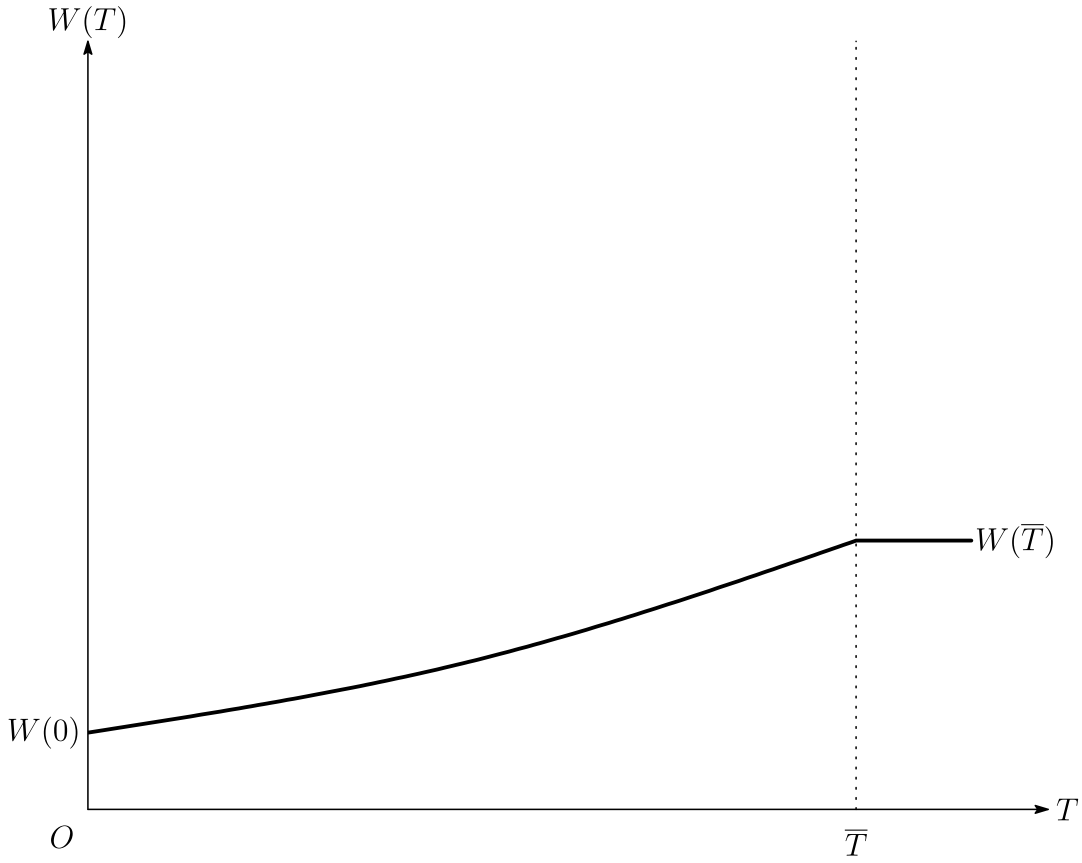

Figure 3: Case 3