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Gains from trade in a polluting product in the presence of transboundary stock pollution

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Abstract

This paper examines how the opening of trade affects a country's welfare in the context of an international polluting duopoly model with transboundary stock pollution. In this framework, we show that trade liberalization can have quite different welfare implications, depending on the mode of international competition and the magnitudes of international transportation coefficients of pollutant emissions and decay rates of pollutant stocks in respective countries, as well as on the values of other environmental and economic variables.

Keywords: gains from trade, international duopoly, Cournot-Nash competition, Stackelberg competition, transboundary stock pollution.

JEL Classification: F10, F12, Q20.

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1 Introduction

The large literature on the gains-from-trade proposition initiated by Samuelson (1939) generally asserts that free trade is beneficial to all the participating nations. Moreover, the so-called 'new trade theory' which incorporates imperfect competition and/or increasing returns has found new sources of gains from trade. Among others, Markusen (1981) makes it clear that the opening of trade promotes competition, from which all trading countries can gain.

To the best of our knowledge, however, the existing literature on gains from trade under imperfect competition has not fully investigated into cross-border and long-term environmental issues associated with increased economic activities,[1] whereas in reality the concerns over 'transboundary stock pollution' problems, such as global warming, stratospheric ozone-layer depletion and acid rain, seem to play increasingly important parts in recent negotiations over more liberalized trade regimes at both global and regional scales. Such a trend is exemplified in the debates over NAFTA where freer commercial interactions in North America were frequently opposed partly on the ground of environmental protection. Similar arguments have also been repeatedly made by citizen groups who persistently resist so-called globalization, as was symbolically manifested in their feverish oppositions towards the World Trade Organization (WTO) Round Talk in Seattle in 1999.[2]

This paper aims to explore how the possible existence of gains from international trade in a polluting product can be affected by different modes of international duopolistic competition, namely, Stackelberg and Cournot-Nash types of competition. In addition, more significantly, we show that, when the pollution issue is transboundary and persistent by nature, the existence of gains from trade liberalization depends upon the following two physical characteristics of the pollution problem, the magnitudes of international

[1] There exist game-theoretic studies which investigate into the welfare implications of transboundary stock pollution problems. Important examples of such studies are Long (1992) and Dockner and Long (1993) for global pollution issues and Kaitala, Pohjola and Tahvonen (1992) and Mäler and de Zeeuw (1998) for regional transboundary pollution issues. However, these studies do not account for the effects of international trade.

[2] Discussing various alleged rationals for the resistance to globalization, Bhagwati (2004) critically evaluates each one of them from a viewpoint of the international trade theory.

transportation coefficients of pollutant emissions and decay rates of pollutant stocks in respective countries, as well as on the values of other environmental and economic variables, such as discount rates and marginal damage costs of pollution.

This paper is structured as follows. Section 2 presents our basic model of an economy with transboundary stock pollution and derives its autarkic outcome. By extending the model to a two-country world, the next section characterizes the free trade outcomes in two different modes of international competition. Then, Section 4 compares these results and discusses how the welfare implications of trade liberalization can be influenced by the environmental characteristics surrounding the pollution problem. The last section contains brief concluding remarks.

2 Autarky

This section develops our basic model and describes its autarkic outcome. The model is comprised of two countries (Home and Foreign), two goods (Goods 1 and 2), and one primary factor (labor). We assume that both countries share the identical preferences and production technologies, and produce both goods. In the following description of our model, we focus on the Home country since the Foreign country can be described symmetrically. We denote each Foreign variable by attaching an asterisk (*). Furthermore, Good 2 serves as a numeraire and is produced with a unitary input coefficient so that the wage rate is internationally equalized and fixed at unity. In the autarkic case, Good 1 is monopolistically supplied by a single domestic firm and $c > 0$ units of labor are required to produce one unit of Good 1. Hence, the marginal cost of its production is assumed to be constant at c. In addition, we suppose that the production of one unit of Good 1 entails one unit of pollutant emissions.

Now, let us assume that the utility function of a representative consumer in Home can be specified by[3]

$$V = \int_0^\infty e^{-rt} \left[AC_1 - \frac{C_1^2}{2} + C_2 - sZ \right] dt, \quad A > c, \quad r, s > 0, \tag{1}$$

where V is the consumer's utility level, r is the discount rate, $C_i,\ i = 1, 2$, is the consump-

[3]For simplicity, we suppose that the population of consumers in each country is normalized to one.

tion of each good, s is the constant marginal damage cost of the pollutant stock, and Z is the pollutant stock level in this country. We assume, furthermore, that the generation of the pollutant emissions associated with the consumption of Good 1 is treated as a negative externality by this consumer and, therefore, out of its control. Hence, the consumer maximizes its utility by ignoring the adverse effects of the stock pollution completely. This is essentially the same as the case where the consumer maximizes its instantaneous utility without considering the environmental damage cost.

Letting p denotes the price of Good 1 measured by the price of Good 2, this consumer's utility maximization problem subject to the budget constraint yields the demand function of Good 1:

$$C_1 = A - p.$$

Under autarky, the market-clearing condition is

$$A - p = x,$$

where x is the output of Good 1. Hence, the inverse demand function and the monopoly firm's profit at each time instant are respectively defined by

$$p = A - x, \tag{2}$$

$$\pi \equiv (A - c - x)x. \tag{3}$$

Using (2) and (3), the long-term social welfare of the nation, U, which is the sum of the consumer surplus, the monopolist's profit, and the environmental damage cost of the pollution over the infinite time horizon, can be expressed as

$$U = \int_0^\infty e^{-rt} \left[\frac{(A-p)^2}{2} + \pi - sZ \right] dt. \tag{4}$$

In the subsequent analysis, (4) determines the intertemporal social welfare of the country in each situation.

As for the transboundary effects of the pollutant emissions, we assume that one unit of Foreign's (resp. Home's) pollutant emissions x^* (resp. x) increases Home's (resp. Foreign's) current pollutant flow level by the fraction of $\alpha \in [0, 1]$ (resp. α^*) while one unit of domestic emissions increases its own pollutant flow by one unit. In the literature of environmental economics, α and α^* are sometimes referred to as 'transportation coefficients', but we call them 'pollutant import coefficients' here in order to emphasize the directions of the pollutant flow. In the case of a global pollutant, such as CO_2 that is a culprit of the global warming problem, we have $\alpha = \alpha^* = 1$, while at least one of α and α^* is strictly smaller than one and they normally take different values in so-called regional environmental issues, such as the transboundary acid rain problem in Northern Europe and East Asia. When $\alpha = \alpha^* = 0$, on the other hand, the pollution problem is completely localized. In sum, the pollution levels in the respective countries are described as

$$\dot{Z} = x + \alpha x^* - kZ, \tag{5}$$

$$\dot{Z}^* = x^* + \alpha^* x - k^* Z^*, \tag{6}$$

where $\dot{Z}$ and $\dot{Z}^*$ respectively denote the time derivatives of the pollutant stocks, and k and k^* are so-called decay rates of the pollutant stocks in the respective countries. Thus, we suppose that the pollutant stocks in these countries are subject to the pattern of an exponential decay as in Kaitala *et al.* (1992) and Dockner and Long (1993). We also assume in this article that, while the preference-related variables of the consumers, such as discount rates and marginal costs of the pollution, and firms' production costs are exactly symmetric across the two countries, the environmental variables, such as pollutant import coefficients and decay rate of the pollutants can be diverse, and mainly focus on the impacts of the latter variables on the long-term social welfare.

Let us now formulate the profit maximization problem of each country's firm. For the simplicity of expositions, we write the behaviors of the firms in both countries in a completely static fashion although the firms' actual behaviors would not change at all if they maximized their respective long-term profits intertemporally since the firms do not care about the stock pollution issue, quite similarly to a consumer who disregards the pollution problem as an externality. Again, we focus on the Home firm since its Foreign counterpart acts in exactly the same fashion. Specifically, the Home firm solves the following problem in the autarkic case:

$$\max_{x} \ (A - c - x)x,$$

whose solution can be immediately obtained as

$$x^A = \frac{A-c}{2}, \tag{7}$$

where the superscript A represents the autarkic outcome. Also, the autarkic price is derived from the demand function as

$$p^A = \frac{A+c}{2}. \tag{8}$$

Under autarky, hence, the firm essentially acts as a monopolist in each domestic market of the polluting product.

Substituting (7) into (5), we have[4]

$$\dot{Z}^A = (1+\alpha)\frac{A-c}{2} - kZ^A,$$

where Z^A is the pollutant stock in Home under autarky. This is a simple first-order linear ordinary differential equation, which can be easily solved and yields the following path of the pollutant stock over time in Home:

$$Z^A = e^{-kt}Z_0 + (1-e^{-kt})\frac{(1+\alpha)(A-c)}{2k}, \tag{9}$$

where Z_0 is the initial pollutant stock level in the Home country.

Now, we are ready to compute the intertemporal social welfare of this nation. Throughout this paper, let us express the value of social welfare of each country by excluding the influence of the initial pollutant stock level. This is acceptable for our main purpose here, i.e., to analyze the welfare implications of trade liberalization by comparing the relative payoffs of an individual nation under the respective situations, mainly because the marginal damage cost of the pollution is assumed constant. If the damage cost function were nonlinear, the initial pollutant stock level would certainly matter.

By substituting the time-path of the pollutant stock in (9) except the term involving Z_0, as well as (3) and (8) into (4), the intertemporal social welfare of the Home country

[4]Note that the firm in Foreign produces the same amount of Good 1 as Home's firm in the autarkic case by our symmetry assumptions on the characteristics of the firms as well as the representative consumers across the countries.

in the autarkic outcome can be written as

$$U^A = \frac{3}{8}(A-c)^2 \int_0^\infty e^{-rt} dt - \frac{s(1+\alpha)(A-c)}{2k} \int_0^\infty e^{-rt} \left[1 - e^{-kt}\right] dt$$
$$= \frac{3}{8r}(A-c)^2 - \frac{s(1+\alpha)}{2r(r+k)}(A-c). \tag{10}$$

It should be noted that, even under autarky, the welfare of Home is affected by the production level in Foreign through the transboundary pollution flow in (5). Hence, there exists a negative externality associated with the production of Good 1 across the two countries. The next section extends this model to an international duopoly in two different modes of competition.

3 International duopoly

When the two domestic markets of Good 1 described above is fully integrated internationally, the new market-clearing condition becomes

$$C_1 + C_1^* = 2(A-p) = x + x^*,$$

which is inverted to yield

$$p = A - \frac{x + x^*}{2}. \tag{11}$$

This defines the inverse demand function for Good 1 in the international market and each firm's profit function becomes

$$\pi = \left(A - c - \frac{x + x^*}{2}\right) x.$$

First, we consider the case where the two firms are engaged in a Cournot-Nash competition in this aggregated market. In essence, these firms determine their respective output supply levels concurrently. Specifically, these two firms respectively attempt to solve the following maximization problems:

$$\max_{x} \ \pi = \left(A - c - \frac{x + x^*}{2}\right) x,$$
$$\max_{x^*} \ \pi^* = \left(A - c - \frac{x + x^*}{2}\right) x^*.$$

We can immediately obtain the first-order conditions:

$$A - c - \frac{x^*}{2} - x = 0,$$
$$A - c - \frac{x}{2} - x^* = 0,$$

which lead to their respective reaction functions:

$$x = A - c - \frac{x^*}{2}, \tag{12}$$
$$x^* = A - c - \frac{x}{2}. \tag{13}$$

Solving these equations simultaneously, we can obtain the Cournot-Nash equilibrium levels of output supply for the respective firms:

$$x^C = x^{*C} = \frac{2(A - c)}{3}. \tag{14}$$

Furthermore, the equilibrium price becomes

$$p^C = \frac{A + 2c}{3}. \tag{15}$$

Comparing (8) and (15), we can easily confirm $p^C < p^A$, which implies that the pro-competitive effect of the opening of international trade emerges under the Cournot-Nash competition.

Moreover, the long-term social welfare of the Home country can be obtained in the exact same way as in the autarkic case above. Consequently, we have the Home country's intertemporal social welfare except the effect of the initial pollutant stock level as

$$U^C = \frac{4}{9r}(A - c)^2 - \frac{2s(1 + \alpha)}{3r(r + k)}(A - c). \tag{16}$$

As another possible mode of international duopoly under free trade, we also consider the case where the two firms are engaged in a Stackelberg type competition. In a Stackelberg duopoly, the leader firm is somehow able to make a credible commitment with respect to the supply level of Good 1 prior to its follower. In order to simplify the descriptions, as a possible form of Stackelberg-type competition, we focus on the case where Home's firm is the Stackelberg leader and Foreign's firm is the follower in this possible international Stackelberg market. It should be noted that exactly the same argument holds even when the roles in a Stackelberg equilibrium are reversed between the two firms.

Substituting the reaction function of the Foreign's firm, (13), into the definition of π above, the Home firm's profit function, when it acts as the Stackelberg leader, can be described as

$$\begin{aligned}\pi &= \left(A - c - \frac{x + x^*}{2}\right) x \\ &= \left(\frac{A - c}{2} - \frac{x}{4}\right) x.\end{aligned}$$

Thus, from the profit maximization problem of this Stackelberg leader, we can easily derive the following levels of output supply in the Stackelberg equilibrium:

$$x^L = A - c, \tag{17}$$

$$x^F = \frac{A - c}{2}, \tag{18}$$

where x^L and x^F respectively denote the output levels of the leader and the follower. Furthermore, the equilibrium price, p^S, becomes

$$p^S = A - \frac{x^L + x^F}{2} = \frac{A + 3c}{4}. \tag{19}$$

Comparing (15) and (19), we can observe $p^S < p^C$, i.e., the price of Good 1 is even lower under the Stackelberg competition than under the Cournot-Nash competition. Hence, the procompetitive effect of international trade is strengthened further in the Stackelberg outcome.

In a similar way to the autarkic case above, substituting (17) and (18) into (5) and (6), we can obtain the path of the respective nations' pollutant stocks over time. Then, by substituting this time-path of the pollutant stock as well as (3) and (19) into (4), we have the levels of the intertemporal social welfare of the countries with the leader firm and the follower firm, respectively, as

$$U^L = \frac{17}{32r}(A - c)^2 - \frac{s(2 + \alpha)}{2r(r + k)}(A - c), \tag{20}$$

$$U^{*F} = \frac{13}{32r}(A - c)^2 - \frac{s(1 + 2\alpha^*)}{2r(r + k^*)}(A - c). \tag{21}$$

Once again, these values of intertemporal social welfare are described by excluding the effects of the initial pollutant stocks just for the simplicity of exposition.

4 Gains from trade

In this section, we examine how the possible existence of gains from international trade in a polluting product can be affected not only by the mode of international duopolistic competition but also by the magnitudes of certain environmental variables. Especially, we focus upon the two physical characteristics of the environment, i.e., k, the decay rate of the pollutant stock, and α, the transboundary pollutant import coefficient, and suppose that the two countries are completely symmetric in all the economic aspects as well as in the other environmental aspects than expressed by these variables.

Our first main result is concerned with the welfare aspect of trade liberalization under the Cournot-Nash type competition.

Proposition 1. *The Cournot-Nash equilibrium outcome under free trade brings net gain from trade to each country if and only if*

$$k + r > \frac{12s(1+\alpha)}{5(A-c)}, \tag{22}$$

$$k^* + r > \frac{12s(1+\alpha^*)}{5(A-c)}. \tag{23}$$

Proof. Given U^C in (16) and U^A in (10), we can easily verify that the inequality $U^C > U^A$ is equivalent to (22) after some calculations. An exactly parallel argument to Foreign yields (23). **Q.E.D.**

Graphically, the condition (22) implies that, if the actual values of the relevant variables fall in the shaded region C in Figure 1 with α on the horizontal axis and $(k+r)$ on the vertical axis,[5] the Cournot-Nash competition in the international market can bring net gain from trade to the Home country.

(Figure 1 around here)

Thus, given a particular value of the pollutant import coefficient, α, as well as the values of other variables such as the discount rate and the marginal cost of the pollution,

[5]Since k and r virtually play the same roles in our results, we mainly express them in such a combination.

the decay rate of the pollutant stock, k, needs to take a sufficiently high value in order for the country to gain from international trade with the Cournot-Nash competition. On the other hand, if the pollutant possesses such a prolonged adverse effect in a country that, at least, one of (22) and (23) is violated and, therefore, the values of the variables fall within the unshaded region A in Figure 1, the government of this country would, quite legitimately, attempt to disallow the international trade in the Cournot-Nash fashion and the trade in this polluting product might not materialize between the countries. In other words, if a country is sufficiently vulnerable to the pollution issue, in terms of a slow decay process of the pollutant stock, it rationally opts for remaining in autarky for the fear of the long-term effect of the pollution, even though free trade in the good itself could be mutually gainful. We can also understand that the environmental proximity, in the sense of a higher value of the pollutant import coefficient, requires the country's environment to assimilate the pollutant more quickly, i.e., to have a higher value of the pollutant decay rate, in order for this country to be able to gain from trade liberalization.

However, the Cournot-Nash type competition is not the only possible mode of an international duopoly market. In fact, even though either one of the conditions, (22) and (23), is violated, a Stackelberg-type competition might be able to provide an additional opportunity for both countries to benefit from the international trade in this polluting good. As for the Stackelberg equilibrium outcome under free trade, we have the following two results concerning the effect of the opening of trade on each country's intertemporal social welfare:

Proposition 2. *The Stackelberg equilibrium outcome under free trade brings net gain from trade to Home, whose firm is the leader, if and only if*

$$k + r > \frac{16s}{5(A-c)}. \tag{24}$$

Proof. Given U^L in (20) and U^A in (10), the inequality $U^L > U^A$ immediately leads to (24). **Q.E.D.**

Proposition 3. *The Stackelberg equilibrium outcome under free trade brings net gain* *from trade to Foreign, whose firm is the follower, if and only if*

$$k^* + r > \frac{16s\alpha^*}{A-c}. \tag{25}$$

Proof. Given U^{*F} in (21) and U^{*A} given in (10), we can easily show that the inequality $U^{*F} > U^{*A}$ is equivalent to (25). **Q.E.D.**

These last two propositions can be expressed graphically in Figure 2.

(Figure 2 around here)

In the upper diagram of Figure 2, if the actual values of the variables fall in the shaded region S, the Stackelberg type competition in the international market can bring net gain from trade to the Home country whose firm assumes the role of the Stackelberg leader in the international duopoly. In the lower diagram, on the other hand, the shaded region S^* corresponds to the values of the variables where the Foreign country can benefit from the trade in the polluting product when its firm acts as the Stackelberg follower. Interestingly, the value of α does not play any role in the condition (24) and, as a consequence, the region S is demarcated by a horizontal straight line. This is due to the specific structure of our model which leads to $x^F = x^A$, namely, the amount of good 1 produced by the Foreign firm does not change at all by moving from autarky to the international duopoly in the Stackelberg fashion. In other words, Home is affected to an exactly identical extent by the Foreign firm's pollutant emissions both in the autarkic case and in the Stackelberg outcome.

As in the case of the Cournot-Nash type competition, the Stackelberg outcome is beneficial to Foreign as well as Home if its decay rate of the pollutant stock takes a sufficiently high value. For Foreign, if its environment does not get affected significantly by the transboundary flow of the pollutant, or put differently, if the value of α^* is quite small, it might be still better off by having its firm in the international Stackelberg market than by remaining in autarky even though the pollutant has a very persistent adverse impact, i.e., the value of k^* is extremely small. This is because, when α^* is very small, the country with the follower firm does not have to suffer too significantly from the emission expansion in the other country under international trade while it can benefit from the procompetitive effect.

Concerning this Stackelberg outcome, we can further observe that:

Proposition 4. *Suppose that the two countries possess exactly the same values of* α *and* k. *Then, if the following inequality is satisfied, the Home country whose firm is the first-mover in the international Stackelberg duopoly benefits relatively more than the Foreign country whose firm is the second mover, and, otherwise, the country with the second mover has a relative advantage*:

$$k + r > \frac{4s(1-\alpha)}{A-c}. \tag{26}$$

Proof. We have the case where the country with the first mover benefits relatively more from international trade in the Stackelberg fashion if $U^L > U^{*F}$, given U^L in (20) and U^{*F} in (21) with $\alpha = \alpha^*$ and $k = k^*$. We can easily confirm that this condition can be transformed into (26). **Q.E.D.**

In the context of our model, therefore, there exists cases where a country would prefer to have its own firm become the Stackelberg follower in the international duopoly rather than the Stackelberg leader. Such a situation occurs when $k + r < \frac{4s(1-\alpha)}{A-c}$ holds, namely, when the pollutant decay rate is sufficiently small or the pollutant import coefficient is sufficiently large. Combined with the condition in Proposition 3, where the Stackelberg-type competition under free trade brings net gains to the country with the follower firm, $\frac{16s\alpha}{A-c} < k + r < \frac{4s(1-\alpha)}{A-c}$ is needed for this country to benefits from the trade and, at the same time, to be better off than the country with the leader firm. Hence, from the restriction that there is a non-empty interval of $k + r$ that satisfies the last condition, we can see that such a case is possible only when $\alpha < \frac{1}{3}$, i.e., the pollution issue must be sufficiently localized.

The four propositions above have interesting implications for the welfare impacts of trade liberalization. For the simplicity of expositions, we focus on the two limiting cases in the following discussion. First, let us set $\alpha = \alpha^* = 0$ under which pollution is fully localized within each country. Then, (22) reduces to

$$k + r > \frac{12s}{5(A - c)}. \tag{27}$$

Therefore, in order for a country to gain from trade in the Cournot-Nash equilibrium in the presence of a completely localized pollution problem, the pollutant decay rate must be sufficiently large so that the procompetitive effect outweighs the losses from the adverse impact of domestic pollution expansion under free trade.

Concerning the gains/losses from trade in the Stackelberg case, (25) is trivially satisfied since the right-hand side diminishes to zero in a completely localized pollution issue, which, in turn, implies that Foreign necessarily gains from trade under the Stackelberg type competition. In contrast, whether Home gains from trade in the Stackelberg equilibrium is contingent on the scale of the pollutant decay rate as is expressed in (24). These observations stems from a special feature of a Stackelberg-type competition, i.e., the Home firm produces more than the Foreign firm as can be easily observed in (17) and (18). Moreover, in our specific model we have $x^F = x^A$, namely, the Foreign output amount does not change at all by moving from autarky to free trade in the Stackelberg fashion. Hence, the Foreign's pollutant emission level remains the same under these two regimes. Therefore, Foreign can enjoy only the procompetitive gains from trade under the Stackelberg-type competition.[6]

In contrast, Home may lose from trade due to the overwhelming pollution expansion effect by moving from autarky to having its firm become the Stackelberg leader. Indeed, if the marginal damage cost is large enough, or the pollutant decay rate is small enough, to violate the condition (24), the pollution expansion effect plays a dominant role and more than offsets the procompetitive gain of international trade. As a result, Home can possibly lose from trade under the Stackelberg competition while Foreign can benefit from it.

According to Proposition 4, moreover, the Foreign country with its firm acting as the Stackelberg follower in the international market is relatively better off than the Home

[6] In fact, the Foreign firm's profit necessarily declines as the price of the good gets lower with trade liberalization in the Stackelberg manner. However, this loss is overwhelmed by the increase in the consumer surplus.

country with the leader firm if

$$k + r, k^* + r < \frac{4s}{A - c}. \tag{28}$$

Therefore, whereas both Home and Foreign benefit from trade in the Stackelberg outcome if (24) and (28) simultaneously hold, it is the Foreign country with the follower firm that benefits relatively more from international trade.

Other interesting insights can be obtained for the other limiting case of $\alpha = \alpha^* = 1$, i.e., the case of global pollution. In this case, free trade with the Cournot-Nash type competition concurrently benefits both countries if and only if

$$k + r, k^* + r > \frac{24s}{5(A - c)}. \tag{29}$$

While we can interpret (29) in an analogous manner to that of (27), it should be noted that the condition (29) is more restrictive than (27). This is because the procompetitive effect is more likely to dominate the losses from pollution expansion under localized pollution than under transboundary pollution. Accordingly, the pollutant decay rate must be much larger in a global pollution issue than in a completely localized pollution issue for both countries to gain from international trade in the Cournot-Nash fashion.

On the other hand, the conditions of the Stackelberg outcome's benefiting both nations in the presence of a global pollution problem can be obtained as follows. The Home country gains from trade if and only if (24) holds as is also the case for any other values of α, while the Foreign counterpart is

$$k^* + r > \frac{16s}{A - c}. \tag{30}$$

From (24) and (30), we can conclude that, for the symmetric case where $k = k^*$, (i) both countries gain from trade in the Stackelberg manner if $k > \frac{16s}{A-c} - r$, (ii) Home gains and Foreign loses if $\frac{16s}{5(A-c)} - r < k < \frac{16s}{A-c} - r$, and (iii) both lose from trade if $k < \frac{16s}{5(A-c)} - r$. That is, whether trade liberalization with global stock pollution is gainful for each country, as well as for the whole world, highly depends on the magnitude of the pollutant decay rate. When the pollutant decay rate is so large that $k + r > \frac{16s}{A-c}$ holds, free trade in the Stackelberg fashion benefits both countries. This is because the procompetitive gains dominate the pollution expansion losses when the pollutant stock depreciates sufficiently fast. The opposite holds when k is sufficiently small to satisfy $k + r < \frac{16s}{5(A-c)}$. As a matter of fact, qualitatively similar results always emerge, irrespective of the value of the pollutant import coefficient.

In the case of global pollution, furthermore, only Home gains from trade and Foreign loses if k is insufficiently large and belongs to the open interval, $(\frac{16s}{5(A-c)} - r, \frac{16s}{A-c} - r)$. In fact, as opposed to the case of a completely localized pollution problem, the Home country is always relatively better off by moving from autarky to the Stackelberg outcome than the Foreign country in the case of a global pollution problem, as the right hand side of the condition (26) collapses to zero and, therefore, for any value of k, Home with its firm being the Stackelberg leader in the international market benefits relatively more from trade liberalization. In other words, in a global pollution issue, Home enjoys larger procompetitive gains which originates from its firm's taking the leadership in the international Stackelberg duopoly, while Foreign loses by the overwhelming pollution expansion effect which originates solely from the other country. As a result, the Stackelberg competition under free trade can results in such a biased distribution of trade gains in the presence of a global pollution problem, such as the global warming and the stratospheric ozone depletion.

5 Concluding remarks

Our analytical findings might provide some new insights into practical policymaking issues surrounding trade liberalization when a transboundary stock pollution problem is one of each government's important concerns. Trade liberalization in a good whose production generates transboundary pollutant emissions has two opposing effects: procompetitive effect and pollution-expansion effect. The welfare implications of these effects of international trade are contingent on certain environmental characteristics of the pollution problem, among other things.

In particular, the results of our analysis indicate that decay rates of pollutant stocks and transportation coefficients of transboundary pollution might play significant roles in determining the existence of net gains from trade, along with the type of competition in the potential international market of such an product. Although the country tends to lose from the international trade when the stock pollution inflicts larger damages upon its environment, smaller pollutant import coefficients and larger pollutant decay rates might nevertheless create an opportunity to bring net gain from trade to the country. Hence, the government needs to pay due attention to these environmental characteristics concerning transboundary stock pollution issues in identifying the country's potential gain from trade liberalization.

Admittedly, our model is very simple and there would still be many possible directions of extension. For instance, we have not allowed for the role of government intervention. It might be fruitful to examine what kinds of welfare consequences emerge if not only the duopolistic firms but also each country's government acts strategically in choosing its environmental policy as in Barrett (1994) and Ulph (1996).

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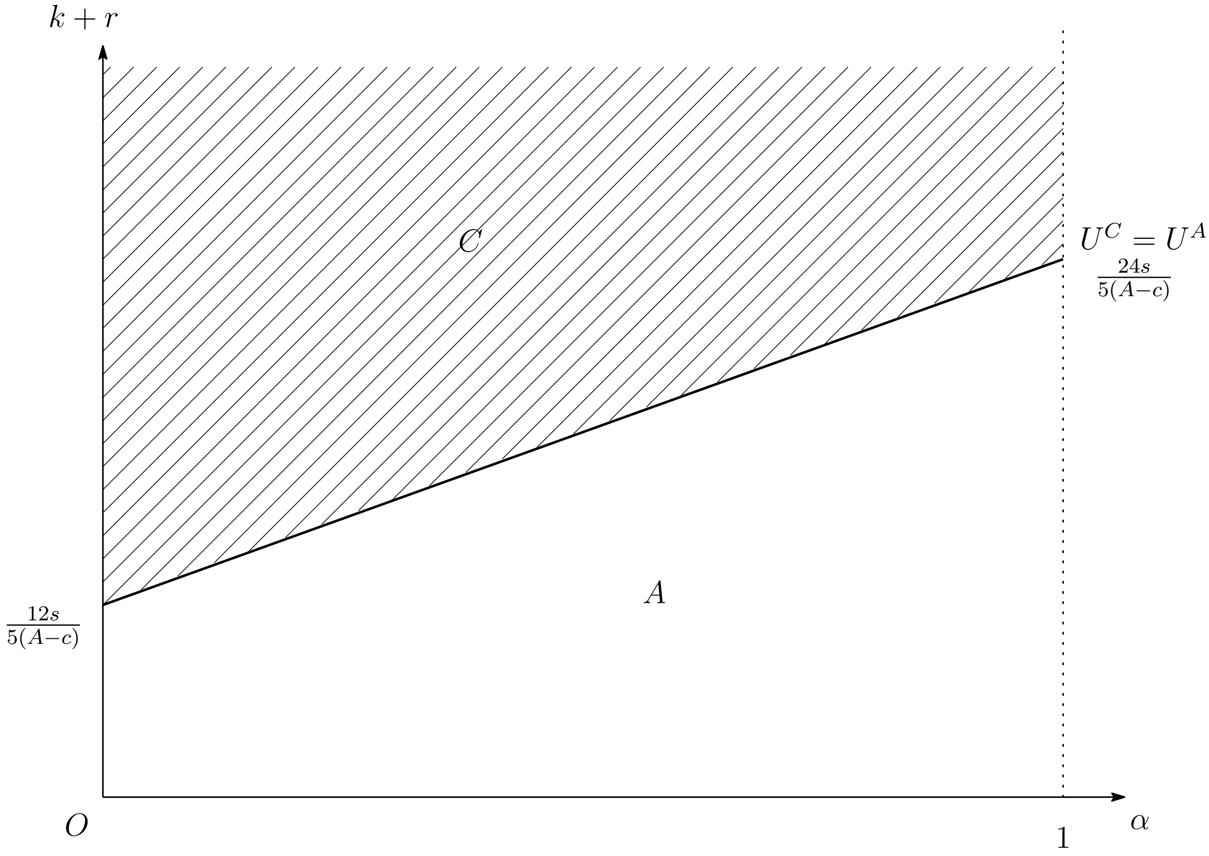

Figure 1: The case of Cournot-Nash competition

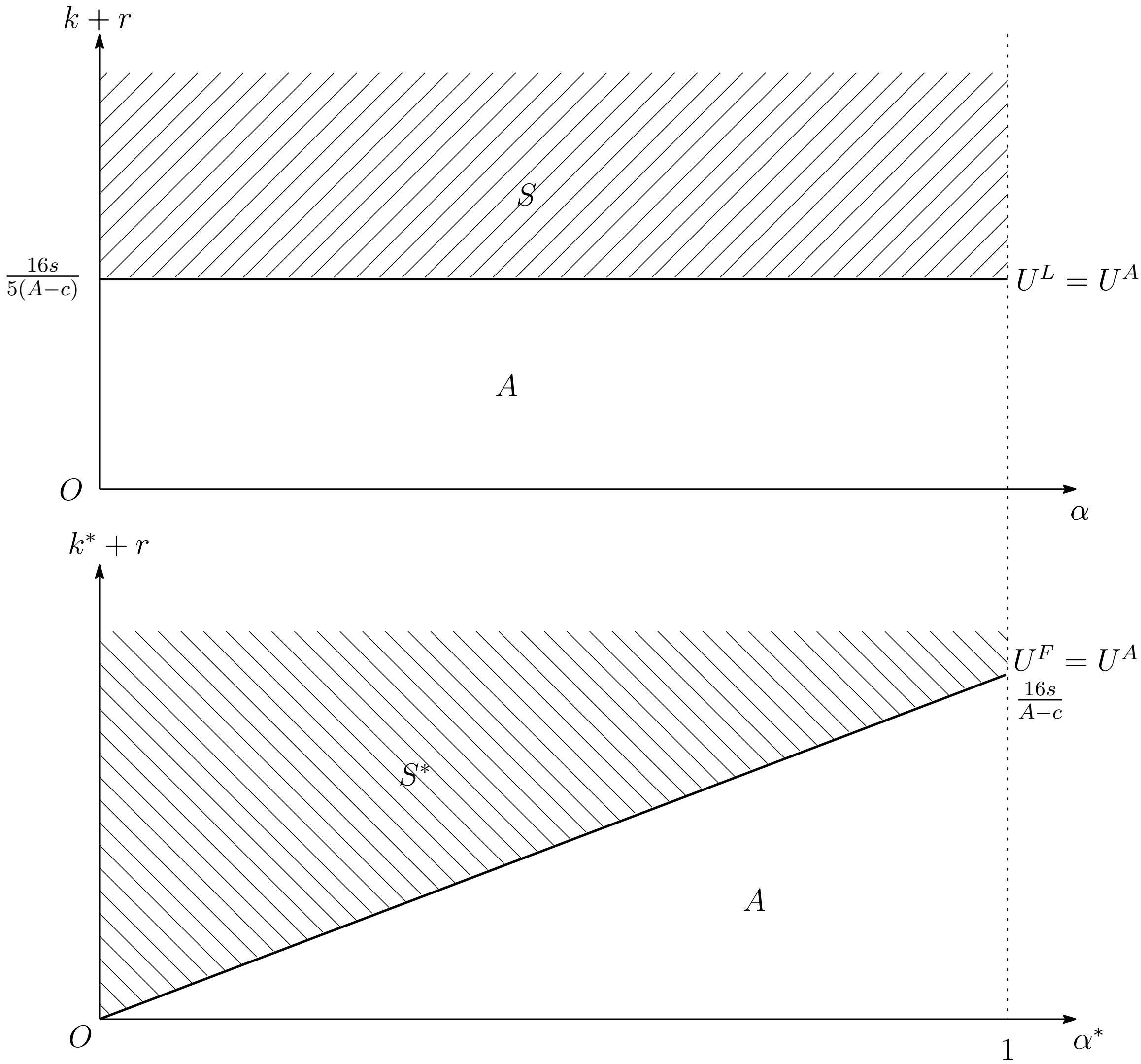

Figure 2: The case of Stackelberg competition