International Trade and Renewable Resources under Asymmetries of Resource Abundance and Resource Management

Naoto Jinji*

Hitotsubashi University

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Abstract

I extend a two-country trade model with various resource management regimes developed by Brander and Taylor (1997b) by allowing the relative resource abundance to differ between two countries. I show that when differences in the resource abundance are small, the relative resource abundance determines trade patterns if the relative demand for the resource good is medium. Otherwise, differences in the resource management regime determine trade patterns. With large differences in the resource abundance, the relative resource abundance determines trade patterns unless the resource abundant country is in the open-access regime and the relative demand for the resource good is high. Welfare effects of trade liberalization are also examined.

Keywords: international trade; renewable resources; relative resource abundance; resource management regime.

JEL classification: F10; Q20.

*Graduate School of Economics, Hitotsubashi University, 2-1 Naka, Kunitachi, Tokyo 186-8601, Japan. Phone: +81-42-580-8505. Fax: +81-42-580-8882. E-mail: njinji@econ.hit-u.ac.jp

1 Introduction

In the theory of international trade, it is well known that differences in the relative abundance of factor endowments determine trade patterns in the standard Heckscher-Ohlin model. Recently, Brander and Taylor (1998) have shown that a similar result holds when two countries with open-access renewable resources trade with each other, while their model is of Ricardian type rather than Heckscher-Ohlin type. On the other hand, Brander and Taylor (1997b) and Chichilnisky (1993, 1994) have demonstrated that differences in the management regime of natural resources determine trade patterns when two trading countries are identical except for the resource management regime. That is, when property rights over the natural resources are well-defined in one country and ill-defined in another country, these differences create a motive a motive for trade with each other. These findings imply that when renewable resources are traded internationally, either relative resource abundance or the difference in the resource management regime determines trade patterns.

The different driving forces of international trade have different implications on welfare effects of trade liberalization. When the relative resource abundance determines trade patterns, the relatively resource scarce country gains from trade and the relatively resource abundant country loses from trade (Brander and Taylor, 1998). When the difference in the resource management regime determines trade patterns, on the other hand, the country with optimally managing the renewable resource gains from trade and the country without optimally managing the renewable resource may lose from trade (Brander and Taylor, 1997b; Chichilnisky, 1993, 1994).

In the real world, countries generally differ both in relative resource abundance and in resource management regime. The country with optimally managing its renewable resources may or may not be endowed with relatively abundant natural resources. Thus, it is important to see how trade patterns and gains from trade are determined when countries differ in both of these two respects. To the best of my knowledge, however, this issue has not been examined yet in the literature. This paper tries to fill this gap.

In this paper, I investigate this issue by extending Brander and Taylor's (1997b) model of trade between "consumer" and "conservationist" countries. In Brander and Taylor's model, the relative resource abundance is the same in the two countries. I allow the two trading countries to differ in the relative resource abundance. The relative resource abundance is determined by the difference in the intrinsic growth rate of the renewable resource. Thus, the relatively resource abundant country is endowed with a renewable source with faster growth. In the original Brander and Taylor's (1997b) model, one country (called "conservationist" country) optimally manages its renewable resource and the other country (called "consumer" country) allows its renewable resource to be subject to open-access. I consider both possibilities that the relatively resource abundant country adopts the conservationist regime and that is adopts the open-access regime (and the other country adopts opposite management regime). As in Brander and Taylor (1997b), I mainly focus on the analysis of steady states.

The main results are as follows. First, I show that when the resource abundance is similar in the two countries, trade patterns are determined by the difference in the resource management regime if the relative demand for the resource good is high or

low. If the relative demand is low, the country in the open-access regime exports the resource good and imports the numeraire. If the relative demand is high, on the other hand, the country in the conservationist regime exports the resource good. In these cases, the relative resource abundance does not affect trade patterns. If the relative demand is at a medium level, by contrast, trade patterns are determined by the relative resource abundance rather than by the difference in the resource management regime. The relatively resource abundant country exports the resource good, regardless of the resource management regime. While the results in the cases of high and low relative demand are generally the same as those in Brander and Taylor (1997b), the case of medium relative demand is new to the literature.

Second, when the resource abundance is quite different between the two countries, if the relatively resource abundant country is in the conservationist regime it always exports the resource good, regardless of the level of the relative demand. This possibility is also not seen in Brander and Taylor (1997b) because they focus on the case of symmetric resource abundance. Despite the large difference in the resource abundance, however, the relatively resource scarce country still has a possibility of exporting the resource good if it is in the conservationist regime and the partner country is in the open-access regime and if the relative demand is sufficiently high.

Third, with respect to welfare effects of trade liberalization, if the resource abundance is similar in the two countries and if the relative demand for the resource good is at a medium level, the relatively resource scarce country gains from trade, irrespective of the resource management regime, while the relatively resource abundant country loses from

trade if it is in the open-access regime. Similar welfare implications are obtained when the resource abundance is quite different in the two countries.

In the literature, Emami and Johnston (2000) is closely related to this paper. Similar to me, Emami and Johnston (2000) introduce a difference in the relative resource abundance in Brander and Taylor's (1997b) model and consider the case in which two trading countries differ in both relative resource abundance and resource management regime.[1] However, their focus is on the effects of unilateral resource management by comparing the case in which two countries with open-access resource freely trade with each other with the case in which one of the two countries manages its natural resource. They do not investigate the effects of trade liberalization when two countries differ in both relative resource abundance and resource management regime.

The rest of the paper is organized in the following way. Section 2 sets up the model. Section 3 investigates trade patterns and welfare effects after trade is liberalized between two countries. Section 4 concludes.

2 The Model

2.1 Resource dynamics

The model in this paper is a Ricardian general equilibrium model with renewable resource developed by Brander and Taylor (1997a, b, 1998). I first describe the basic structure of renewable resource dynamics. Let $S(t)$ be the stock of the renewable resource at time t.

[1] Emami and Johnston (2000) analyze a simplified version of Brander and Taylor's model in the sense that they exclude the dynamics of the renewable resource.

The net change in the resource stock at time t is determined by

$$dS/dt = G(S(t)) - H(t), \tag{1}$$

where $G(S(t))$ denotes the natural growth rate and $H(t)$ is the harvest rate. I omit the time argument hereafter. As in Brander and Taylor, I use a specific functional form for $G(S)$, which is given by

$$G(S) = rS(1 - S/K), \tag{2}$$

where r is the intrinsic growth rate and K is the maximum possible size or "carrying capacity" for the resource stock.

2.2 Production and supply

There are two goods: the harvest of the renewable resource, H, and manufactures, M. Good M is taken as a numeraire and hence its price is normalized to 1. Labour, L, is the only primary factor of production, besides the resource stock. One unit of good M is simply produced by one unit of labour:

$$M^P = L_M, \tag{3}$$

where L_M denotes the amount of labour employed in manufacturing and the superscript P indicates variables in the production side. The harvest of the renewable resource is, on the other hand, carried out by the Schaefer production function:

$$H^P = \alpha S L_H, \tag{4}$$

where α is a positive constant and L_H is amount of labour used in the harvesting sector. The full employment condition is given by

$$L = L_H + L_M. \tag{5}$$

Substitute (3) and (4) into (5) to yield the Ricardian production possibility frontier (PPF):

$$H^P = \alpha S(L - M^P). \tag{6}$$

A steady state emerges when $dS/dt = 0$, or equivalently $G(S) = H$. Equate $G(S)$ as given by (2) with H as given by (4) and solve for S to yield $S = 0$ or $S_{ss} = K(1-\alpha L_H/r)$. If the steady state stock level is not zero, the harvest of the renewable resource in steady state is given by substituting S_{ss} into (4), which yields

$$H^P_{ss} = rS_{ss}(1 - S_{ss}/K). \tag{7}$$

Substitute (7) and S_{ss} into (6) to obtain production of manufactures in steady state:

$$M^P_{ss} = L - (r/\alpha)(1 - S_{ss}/K). \tag{8}$$

Dividing (7) by (8) yields the steady state relative supply of the resource good to manufactures:

$$\left(\frac{H^P}{M^P}\right)_{ss} = \frac{rS_{ss}(1 - S_{ss}/K)}{L - (r/\alpha)(1 - S_{ss}/K)} \equiv RS_{ss}. \tag{9}$$

As I will show below, in order to express the relative supply as a function of the price of the resource good, the resource management regime should be taken into account.

2.3 Utility and demand

Identical households are assumed. A representative household is endowed with one unit of labour. The instantaneous utility function of the representative household is given by $u = h^{\beta}m^{1-\beta}$, where h and m are consumption levels of the resource good and manufactures, respectively. Denote the price of good H as p. Then, the instantaneous budget constraint is given by $ph + m = I$, where I is the household's total income, which includes wage income w and a share of any government revenues raised by regulating the access to the resource, if any. From the representative household's utility maximization, aggregate demands for goods H and M are given by

$$H^D = \beta IL/p, \qquad M^D = (1-\beta)IL, \tag{10}$$

where the superscript indicates variables in the demand side. The relative demand of the resource good to manufactures is then given by

$$H^D/M^D = \beta/(1-\beta)p. \tag{11}$$

Note that the relative demand is independent of both I and L, because preferences are homothetic.

2.4 Resource management regimes

There are two resource management regimes: *open-access* and *conservationist*. In Brander and Taylor (1997b), the *consumer country* is in the open-access regime and the *conservationist country* is in the conservationist regime.[2] When a country is in the open-access regime, there is no property right over the renewable resource that limits access

[2] As for the detailed discussion on the two regimes, see Brander and Taylor (1997a, b, 1998).

to the resource. The harvest of the resource is hence determined by profit-maximization under free-entry conditions, which requires current-period profits for the representative harvester to be zero. The current-period zero-profit condition yields

$$p = w/\alpha S, \tag{12}$$

where w is the wage. Since labour is freely mobile between the harvesting and manufacturing sectors, the wage must be the same in the two sectors as long as both goods are produced in the economy. When manufactures are produced, $w = 1$ and hence (12) can be rewritten as $p = 1/\alpha S$. This determines the steady state stock level in the open-access regime for a given p as

$$S^o = 1/\alpha p. \tag{13}$$

The conservationist regime is, on the other hand, defined by the regulatory regime that maximizes steady state utility of the representative domestic household. Following Brander and Taylor (1997b), the government's problem in the conservationist regime is expressed as choosing the resource stock level S to maximize an aggregate instantaneous utility function $u(H, M) = H^{\beta}M^{1-\beta}$ subject to (7) and (8). The first-order condition yields the optimal steady state stock level in the conservationist regime for a given p as

$$S^c = 2/K + 1/2\alpha p. \tag{14}$$

The steady state relative supply in the open-access regime is obtained by substituting (13) into (9):

$$\left(\frac{H^P}{M^P}\right)^{open} = \frac{r(\alpha K p - 1)}{p\{\alpha K(\alpha L - r)p + r\}} \equiv RS^o(p). \tag{15}$$

Similarly, the steady state relative supply in the conservationist regime is obtained by

substituting (14) into (9):

$$\left(\frac{H^P}{M^P}\right)^{conserve} = \frac{r(\alpha Kp+1)(\alpha Kp-1)}{2p\{\alpha K(2\alpha L-r)p+r\}} \equiv RS^c(p). \tag{16}$$

3 Trade Liberalization

I now consider trade between two countries that are different in two respects: relative resource abundance and resource management. I call the two countries as home and foreign countries. Without loss of generality, I assume the foreign country is relatively resource abundant in the following sense:

$$r < r^*, \tag{17}$$

where an asterisk (*) indicates foreign variables.[3]

As discussed in the previous section, there are two possible resource management regimes: open-access and conservationist. I assume the two countries conduct the different management regimes and consider both of the two possible cases, i.e., the case in which the home (resp. foreign) country is in the open-access (resp. conservationist) regime and the case in which the home (resp. foreign) country is in the conservationist (resp. open-access) regime. Except for these two points, the two countries are identical.

As in Brander and Taylor (1997b), I focus on the case in which both countries are diversified in the free-trade steady-state equilibrium. As Brander and Taylor (1997b) have shown, the possibility of either country specializing in the resource good can be ruled out by assuming $L > r^*/\alpha$.

[3]Since $L = L^*$ in my model, (17) is equivalent to the condition for the resource abundance in Brander and Taylor (1998).

3.1 Trade patterns

I first examine patterns of trade. As in Brander and Taylor (1997b), relative demand is the same in each country and hence world relative demand is also the same. Thus, patterns of trade are determined by the common relative demand and the difference in the relative supply.

I determine patterns of trade by taking several steps. The first step is to compare the steady state resource stock levels in the two resource management regimes after trade is liberalized. I obtain the following lemma:

Lemma 1 *In the free trade steady state, the resource stock in the conservationist regime is necessarily higher than in the open-access regime, regardless of the value of* r*.*

(Proofs of Lemmas and Propositions are presented in the Appendix.)

This lemma implies that after trade is liberalized, the resource stock in steady state is higher in each country when the country is in the conservationist regime than when it is in the open-access regime.

The next step is to compare the relative supplies in the two countries, given the resource management regime. The following result is obtained:

Lemma 2 *For any* $p > 1/\alpha K$*, the steady state relative supply in each management regime is larger in the foreign country than in the home country.*

This lemma determines the locus of the steady state relative supply curves in each management regime. Note that the relative supply in either management regime is zero for $p \leq 1/\alpha K$ in either country. Lemma 2 simply tells me that for $p > 1/\alpha K$ the

relative supply curve of the foreign country lies outside that of the home country in each management regime.

Let $RS^i(p)$, $i = c, o$, be the relative supply in the home country and $RS^{*i}(p)$, $i = c, o$, be the relative supply in the foreign country. The following lemma then determines the locus of these four relative supply curves.

Lemma 3 *(i) If* $2r > r^*$, $RS^o(p)$ *and* $RS^{*c}(p)$ *intersect once at* $p = p^{x1} > 1/\alpha K$*; (ii) If* $2r < r^*$, $RS^o(p) < RS^{*c}(p)$ *holds for any* $p > 1/\alpha K$*; (iii)* $RS^c(p)$ *and* $RS^{*o}(p)$ *intersect once at* $p = p^{x2} > 1/\alpha K$ *for any* r *and* r^* *with* $r < r^*$*; and (iv)* $p^{x1} < p^{x2}$ *holds.*

The first and second parts of the lemma imply that when the home country is in the open-access regime and the foreign country is in the conservationist regime, the relative supply of the home country can partly exceed that of the foreign country if the difference in the relative resource abundance is not too large. If the difference is sufficiently large, then the relative supply of the home country never exceeds that of the foreign country. I call the former case as the "small difference" case and the latter as the "large difference" case. The third part of the lemma implies that when the home country is in the conservationist regime and the foreign country is in the open-access regime, the relative supply of the foreign country exceeds that of the home country for lower values of p for all r and r^* with $r < r^*$. The fourth part simply tells me that $RS^c(p)$ and $RS^{*o}(p)$ intersect at a price higher than the price at which $RS^o(p)$ and $RS^{*c}(p)$ intersect.

The relative supply curves in the small difference case are illustrated in Figure 1. As shown in the figure, $RS^o(p)$ and $RS^{*c}(p)$ intersect at price p^{x1} and $RS^c(p)$ and $RS^{*o}(p)$ intersect at price p^{x2}. The relative supply curves in the large difference case are depicted

in Figure 2. While $RS^c(p)$ and $RS^{*o}(p)$ intersect at price p^{x2}, $RS^{*c}(p)$ lies outside of $RS^o(p)$ for all $p > 1/\alpha K$ and hence there is no intersection between $RS^{*c}(p)$ and $RS^o(p)$ except for $RS^{*c}(1/\alpha K) = RS^o(1/\alpha K) = 0$.

3.1.1 Small differences

I first examine the small difference case, i.e., $2r > r^*$. With a small difference, there exist three possible cases, depending on the level of the common world relative demand, as shown in Figure 3. The relative supply curves in Figure 3 are the same as those in Figure 1. RD_i, $i = 1, 2, 3$, are the relative demand curves in three different cases. RD_1 corresponds to a low relative demand and RD_3 indicates a high relative demand. Following Brander and Taylor (1997b), I call the former case as the "mild overuse" case and the latter case as the "severe overuse" case. Finally, RD_2 illustrates a medium relative demand. I call this case as the "medium overuse" case. Note that the medium overuse case was not seen in Brander and Taylor (1997b).

Different trade patterns arise in these three cases, as shown in the following proposition:

Proposition 1 *Assume that $2r > r^*$. In the free trade steady state, (i) in the mild overuse case, the country in the open-access regime has a comparative advantage in the resource good and hence exports the resource good, regardless of the relative resource abundance; (ii) in the medium overuse case, the foreign country (i.e., the relatively resource abundant country) always has a comparative advantage in the resource good and hence exports the resource good, regardless of the resource management regime; and (iii) in the severe overuse case, the country in the conservationist regime has a comparative*

advantage in the resource good and hence exports the resource good, regardless of the relative resource abundance.

The proposition implies that when the relative demand is low or high, the trade pattern is determined by the difference in the resource management regime. When the relative demand is medium, on the other hand, the relative resource abundance determines the trade pattern. The former shows that the results in Brander and Taylor (1997b) generally hold in the cases of mild and severe overuses as long as the difference in the resource abundance is small. The latter shows that introducing asymmetry in the resource abundance yields a possibility which was not examined by Brander and Taylor (1997b).

Since the results in the mild and severe overuse cases are basically the same as those in Brander and Taylor (1997b), I only provide an intuitive explanation on the medium overuse case. The medium overuse case is depicted in Figure 5. If the home country is in the conservationist regime and the foreign country is in the open-access regime, the autarky prices of the resource good in the home and foreign countries are given by p^1 and p^{*1}, respectively. Since $p^1 > p^{*1}$, it is obvious that the foreign country which is relatively resource abundant and in the open-access regime has a comparative advantage in the resource good. After trade is liberalized, the world equilibrium price must lie somewhere between the two autarky prices. Since the world equilibrium price under free trade is higher than p^{*1} and lower than p^1, the home country imports the resource good from the foreign country and exports manufactures to the foreign country. If the home country is in the open-access regime and the foreign country is in the conservationist regime, on the other hand, the autarky prices of the resource good in the home and foreign

countries are given by p^2 and p^{*2}, respectively. Since $p^2 > p^{*2}$, again the foreign country has a comparative advantage in the resource good. The world equilibrium price under free trade is higher than p^{*2} and lower than p^2 and hence the home country imports the resource good from the foreign country and exports manufactures to the foreign country.

3.1.2 Large differences

I now turn to the large difference case. With a large difference, there are only two possible cases: medium overuse and severe overuse cases, as shown in Figure 4. The relative demand curve denoted as RD_2 corresponds to the medium overuse case and that denoted as RD_3 corresponds to the severe overuse case. Trade patterns in the medium and severe overuse cases with a large difference are the same as those in the medium and severe overuse cases with a small difference, respectively, and hence are determined by (ii) and (iii) in Proposition 1, respectively. The following proposition is thus obtained:

Proposition 2 *Assume that* $2r < r^*$. *In the free trade steady state, if the foreign country (i.e., the relatively resource abundant country) is in the conservationist regime, it always has a comparative advantage in the resource good and hence exports the resource good, regardless of the level of the world relative demand.*

The proposition implies that if the difference in the relative resource abundance between the two countries is sufficiently large and if the resource abundant country optimally manages its renewable resource, the resource scarce country never has a comparative advantage in the resource good even if it is in the open-access regime. This result sharply contrasts with those with symmetric resource abundance in Brander and Taylor

(1997b) and with a small difference in the above case. When the resource abundance is symmetric, the country in the open-access regime always has a chance to obtain a comparative advantage in the resource good. While this result generally holds for the small difference case, it cannot be extended to the large difference case.

Despite the large difference in the relative resource abundance, however, the home country (i.e., the relatively resource scarce country) still has a chance to become the exporter of the resource good in the severe overuse case if it is in the conservationist regime and the foreign country is in the open-access regime. This implies that the large difference in the relative resource abundance does not fully rule out the possibility that the difference in the resource management regime determines trade patterns.

3.2 Welfare effects of trade liberalization

I now analyze the welfare effects of liberalizing trade. I first consider the small difference case. As Brander and Taylor (1997b) have shown, in the mild overuse case, the country in the conservationist regime gains from trade, while the country in the open-access regime suffers from lower steady-state welfare. In the severe overuse case, the country in the conservationist regime gains from trade and the country in the open-access regime also enjoys higher steady-state welfare. These results generally hold in my case.

The medium overuse case, on the other hand, was not examined by Brander and Taylor (1997b) and hence needs some investigation. As seen in Figure 5, the home country faces the world price for the resource good which is lower than its autarky price and imports the resource good, regardless of the resource management regime. The resource stock in the home country is raised over time, which shifts its production

possibility frontier outward, leading to gains from trade. The welfare implications of trade in the foreign country, by contrast, depend on its resource management regime. If it is in the conservationist regime, a possible externality arising from the open-access resource is absent and hence it gains from trade for the standard reasons. If it is in the open-access regime, then trade reduces its resource stock over time, which shifts its production possibility frontier inward. Consequently, the steady-state consumption of the two goods in the foreign country is reduced by trade and hence the foreign country has lower steady state utility.

The following proposition summarizes the results on the welfare effects of trade in the small difference case.

Proposition 3 *Assume that* $2r > r^*$. *After trade is liberalized, (i) in the mild overuse case, either country has lower steady-state utility if it is in the open-access regime and gains from trade if it is in the conservationist regime; (ii) in the medium overuse case, the home country (i.e., the relatively resource scarce country) always has higher steady-state utility and the foreign country (i.e., the relatively resource abundant country) also gains from trade if it is in the conservationist regime but has lower steady-state utility if it is in the open-access regime; and (iii) in the severe overuse case, both countries gain from trade.*

I next consider the large difference case. As shown in the previous subsection, with a large difference there are only medium overuse and severe overuse cases. Welfare effects in each case are generally the same as those with a small difference.

An interesting result in the large difference case is that the home country that is

relatively resource scarce never loses from trade. If it is in the conservationist regime, it gains from trade for the standard reasons. Even if the home country is in the open-access regime, it enjoys higher steady-state utility because there is no possibility for the home country with the open-access regime to have a comparative advantage in the resource good. This result sharply contrast with those shown by Brander and Taylor (1997a, b), where any country has a possibility to lose from trade if it is in the open-access regime.

The foreign country, on the other hand, may suffer from lower steady-state utility if it is in the open-access regime. The reason is the same as that discussed in the small difference case.

The following proposition summarizes the argument.

Proposition 4 *Assume that* $2r < r^*$. *The home country (i.e., the relative resource scarce country) never loses from trade. The foreign country (i.e., the relative resource abundant country), on the other hand, may suffer from lower steady-state utility if it is in the open-access regime.*

4 Conclusions

In this paper, I have examined the implications of the interaction between relative resource abundance and resource management regime on trade patterns and welfare effects of trade liberalization. I have used an extended version of the model developed by Brander and Taylor (1997b) in which two countries with different regimes of renewable resource management engage in trade with each other. The Brander and Taylor's model has been extended by allowing the relative resource abundance to differ between the two

trading countries.

I have found that when the difference in the resource abundance is relatively small, trade patterns are determined by the relative resource abundance if the relative demand for the resource good is at a medium level. If the relative demand for the resource good is high or low, on the other hand, trade patterns are determined by the difference in the resource management regime rather than the relative resource abundance. Moreover, when the resource abundance is sufficiently different between the two countries, trade patterns are determined by the relative resource abundance unless the relative demand is sufficiently high. If the relative demand is sufficiently high, the resource scarce country sill has a chance to export the resource good if it is in the conservationist regime and the partner country is in the open-access regime.

As for the welfare effects of trade liberalization, the only possibility that the resource scarce country loses from trade is under the situation that the relative resource abundance is not so different, the relative demand is low, and the country is in the open-access regime. The resource abundant country, on the other hand, may lose from trade if it is in the open-access regime. When the relative demand is sufficiently high, however, the resource abundant country under the open-access regime gains from trade, because it does not have a comparative advantage in the resource good in that case.

The above results imply that when countries differ in the relative resource abundance as well as in the resource management regime, which of the two factors determines trade patterns and welfare effects of trade liberalization depends on the conditions with respect to the relative resource abundance and the relative demand.

In this paper, I have not dealt explicitly with discounting of future utility. It should be emphasized that this approach provides a useful benchmark and analytical simplification. However, it is also important to note that, as Brander and Taylor (1997b) have argued, this approach can be defensible from several points of view, including inter-temporal equity considerations. The readers would be advised to read Brander and Taylor (1997b, pp.290-291) for more detailed discussion on this issue.

A Appendix: Proofs of Lemmas and Propositions

A.1 Proof of Lemma 1

The steady state stock levels in the open-access and conservationist regimes are given by (13) and (14), respectively. If $1/\alpha p \leq K/2$, the result is obvious. If $1/\alpha p > K/2$, since $1/\alpha p < K$ it holds that $1/2\alpha p > 1/\alpha p - K/2$, or $K/2 + 1/2\alpha p > 1/\alpha p$, or $S^c > S^o$. Since S^c and S^o both depend only on the factors that are common between the two countries and are independent of r, the result holds for both countries. □

A.2 Proof of Lemma 2

Since the steady state stock level is independent of r in both management regimes, the effect of an increase in r on the steady state relative supply in each regime can be examined by differentiating (9) with respect to r, which yields

$$\frac{\partial RS_{ss}}{\partial r} = \frac{LS(1 - S/K)}{(L - (r/\alpha)(1 - S/K))^2} > 0,$$

which implies that an increase in r raises the relative supply. Since the steady state stock level in each regime is the same in the two countries, the foreign country that has a higher value of r must have a larger relative supply in each regime. □

A.3 Proof of Lemma 3

For the first and second parts, since $RS^{o\prime}(1/\alpha K) = r\alpha K^2/L$ and $RS^{*c\prime}(1/\alpha K) = r^*\alpha K^2/2L$, it holds that $RS^{o\prime}(1/\alpha K) > RS^{*c\prime}(1/\alpha K)$ if $2r > r^*$ and that $RS^{o\prime}(1/\alpha K) < RS^{*c\prime}(1/\alpha K)$ if $2r < r^*$. As Brander and Taylor (1997b) have shown, $RS^{*c\prime}(p) > 0$ for all $p > 1/\alpha K$, while $RS^{o\prime}(p) > 0$ for $1/\alpha K < p < p^C$ and $RS^{o\prime}(p) < 0$ for $p > p^C$, where

$p^C = (1+(\alpha L)^{1/2}/(\alpha L - r)^{1/2})/\alpha K$. Thus, if $2r > r^*$, $RS^o(p)$ and $RS^{*c}(p)$ must intersect only once at the backward-bending part of $RS^o(p)$ and hence p^{x1} is uniquely determined. If $2r < r^*$, $RS^o(p)$ and $RS^{*c}(p)$ do not intersect each other because $RS^o(p) < RS^{*c}(p)$ holds for any $p > 1/\alpha K$.

For the third part, since $RS^{*o\prime}(1/\alpha K) = r^*\alpha K^2/L > RS^{c\prime}(1/\alpha K) = r\alpha K^2/2L$, I have $RS^{*o} > RS^c$ for p that is slightly higher than $1/\alpha K$. Similarly to the proof for the first two parts, $RS^{c\prime}(p) > 0$ for all $p > 1/\alpha K$, while $RS^{*o\prime}(p) > 0$ for $1/\alpha K < p < p^{*C}$ and $RS^{*o\prime}(p) < 0$ for $p > p^{*C}$, where $p^{*C} = (1 + (\alpha L)^{1/2}/(\alpha L - r^*)^{1/2})/\alpha K$. Thus, $RS^c(p)$ and $RS^{*o}(p)$ must intersect only once at the backward-bending part of RS^{*o} and hence p^{x2} is uniquely determined. The fourth part is proved by direct construction using Figure 1. Starting from the intersection of $RS^o(p)$ and $RS^{*c}(p)$, since $RS^{*o}(p)$ lies outside of $RS^o(p)$ and $RS^c(p)$ lies inside of $RS^{*c}(p)$ and since the curves intersect at the backward-bending part of $RS^o(p)$ and $RS^{*o}(p)$, then $RS^{*o}(p)$ and $RS^c(p)$ must intersect at a higher price. □

A.4 Proof of Proposition 1

(i) In the mild overuse case, when $2r > r^*$ holds, Brander and Taylor's (1997b, Proposition 4) proof is valid for both the case in which the home country is in the open-access regime and the case in which the foreign country is in the open-access regime.

(ii) I prove the result in the medium overuse case using Figure 5. Consider first the case in which the foreign country is in the open-access regime. In this case, since the relative demand curve intersects with RS^c and RS^{*o} at the price lower than p^{x2}, the autarky price of the foreign country p^{*1} is lower than that of the home country p^1. The

world price must lie between the two prices. It follows from the shape of the relative supply curves that the foreign country necessarily exports the resource good and the home country necessarily import it. Consider next the case in which the home country is in the open-access regime. In this case, since the relative demand curve intersects with RS^o and RS^{*c} at the price higher than p^{x1}, the autarky price of the foreign country p^{*2} is lower than that of the home country p^2. The world price must lie between the two prices. Thus, similarly to the previous case, it follows that the foreign country necessarily exports the resource good and the home country necessarily import it.

(iii) In the severe overuse case, Brander and Taylor's (1997b, Proposition 5) proof is valid for both the case in which the home country is in the open-access regime and the case in which the foreign country is in the open-access regime. □

A.5 Proof of Proposition 2

When $2r < r^*$, $RS^o(p) < RS^{*c}(p)$ holds for any $p > 1/\alpha K$ from Lemma 3. Thus, as long as the foreign country is in the conservationist regime, the autarky price of the foreign country is always lower than that of the home country for any level of the relative demand. Since the world price must lie between the two autarky prices, it follows that the foreign country necessarily exports the resource good and the home country necessarily import it in the free trade steady-state for any level of the world relative demand. □

A.6 Proof of Proposition 3

(i) In the mild overuse case, when $2r > r^*$ holds, Brander and Taylor's (1997b, Proposition 4) proof is valid for both the case in which the home country is in the open-access

regime and the case in which the foreign country is in the open-access regime.

(ii) In the medium overuse case, as shown in Proposition 1, the home country always imports the resource good, irrespective of the resource management regime. If the home country is in the conservationist regime, there is no externality associated with the renewable resource and hence the home country gains from trade for the standard reasons. Even if the home country is in the open-access regime and there exists an externality with respect to managing the renewable resource, the nominal income in the home country does not change before and after trade is liberalized and the price of the resource good falls after trade is liberalized. Thus, it follows that welfare rises in the home country. With regard to the foreign country, on the other hand, welfare is raised by trade liberalization if it is in the conservationist regime for the standard reasons. If the foreign country is in the open-access regime, it exports the resource good, as shown in Proposition 1. The nominal income in the foreign country does not change before and after trade is liberalized and the price of the resource good rises after trade is liberalized. Thus, it follows that welfare falls in the foreign country if it is in the open-access regime.[4]

(iii) In the severe overuse case, Brander and Taylor's (1997b, Proposition 5) proof is valid for both the case in which the home country is in the open-access regime and the case in which the foreign country is in the open-access regime. □

[4]Brander and Taylor (1997a) provide mode detailed proof for welfare loss from trade in the exporting country of the resource good with the open-access regime.

A.7 Proof of Proposition 4

Any country that is in the conservationist regime gains from tade for the standard reasons because there is no externality associated with the renewable resource in that country. Even if the home country is in the open-access regime, as shown in Proposition 2, it faces a lower price of the resource good and imports the resource good after trade is liberalized. The nominal income in the home country does not change before and after trade is liberalized. Consequently, the home country does not lose from trade even if it is in the open-access regime. On the other hand, if the foreign country is in the open-access regime and if the medium overuse case prevails, it has lower steady-state utility, as shown in Proposition 3 (ii). □

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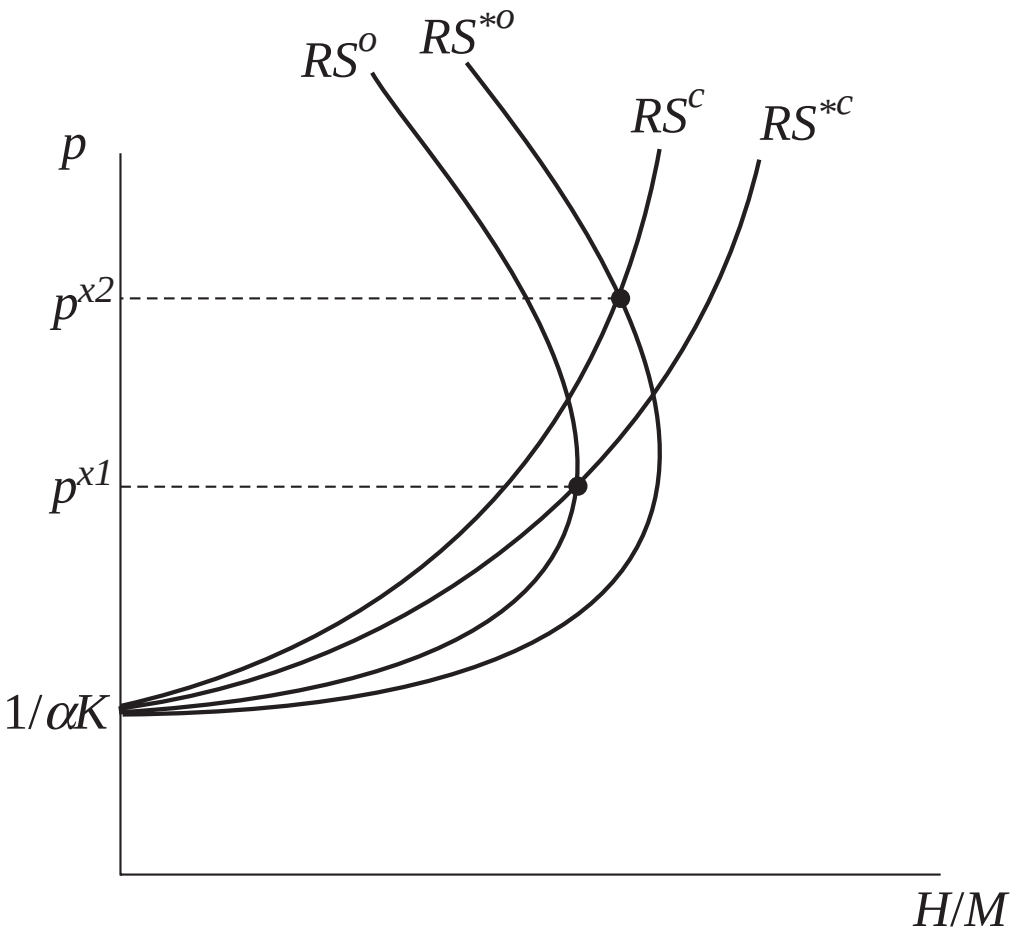

Figure 1: Relative supply curves: small difference

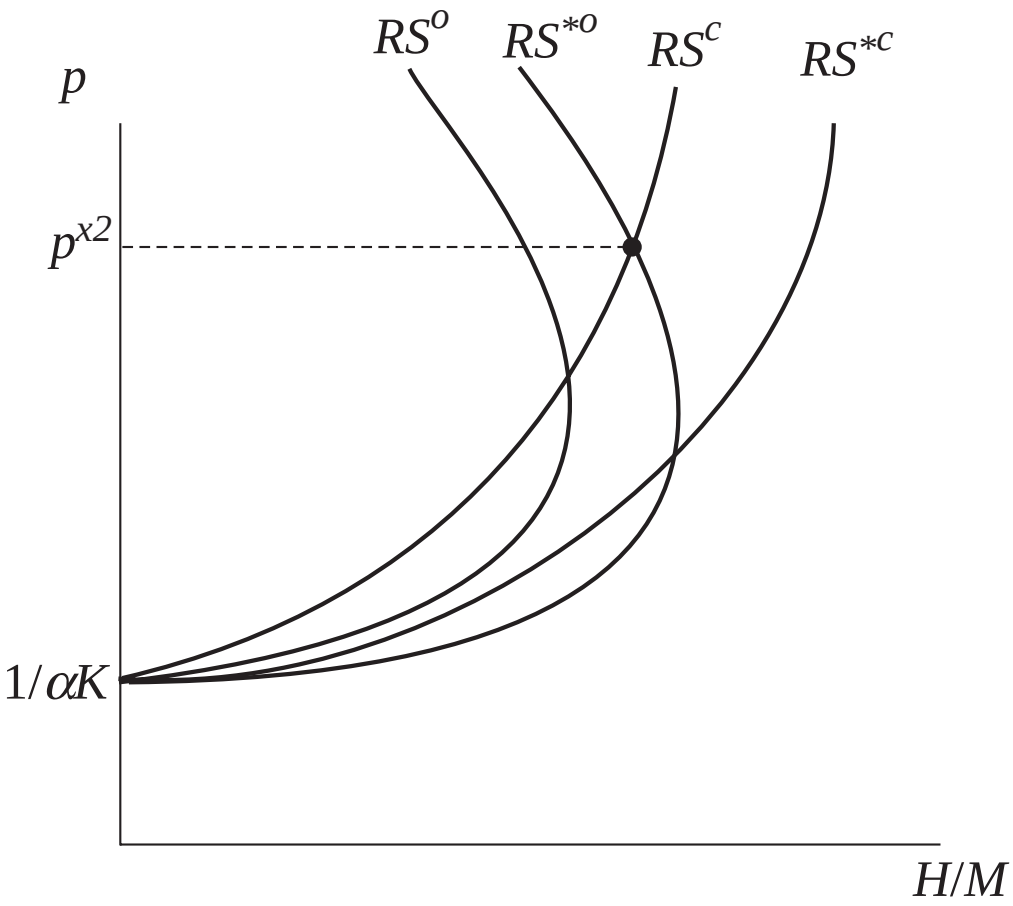

Figure 2: Relative supply curves: large difference

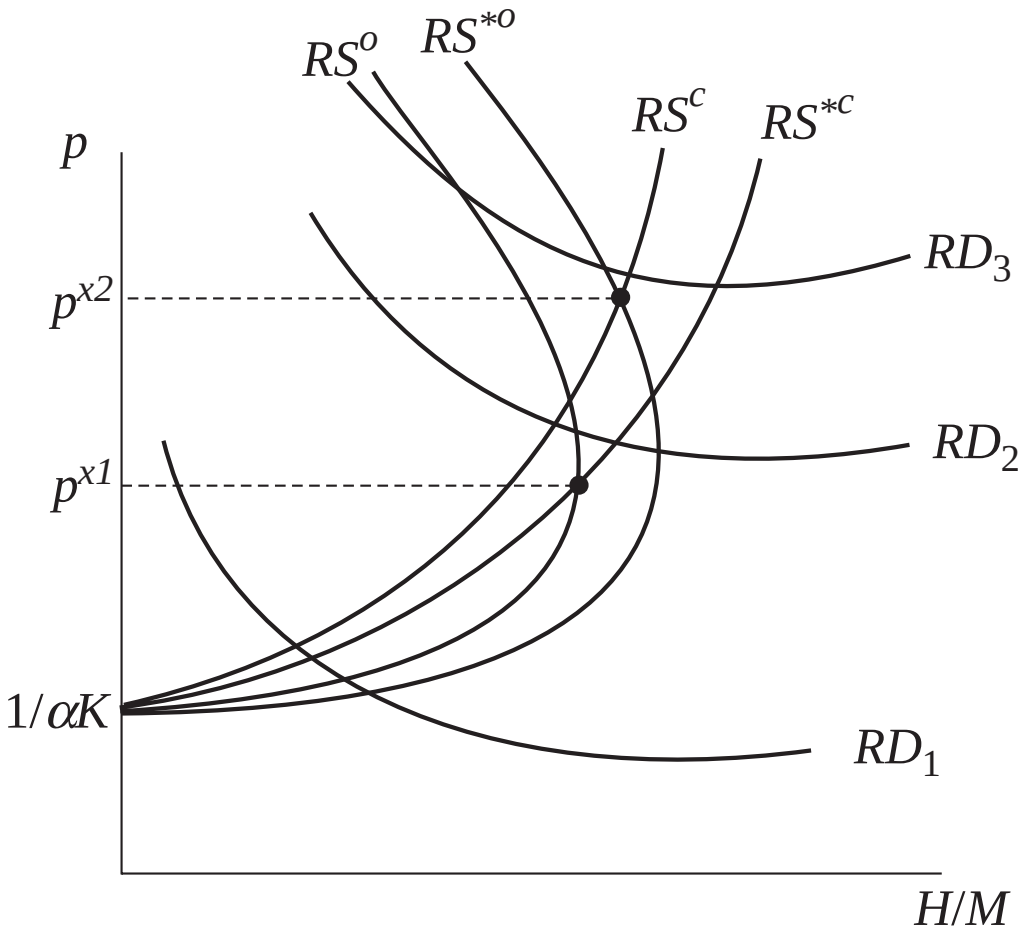

Figure 3: Three possible cases with a small difference: mild, medium, and severe overuses

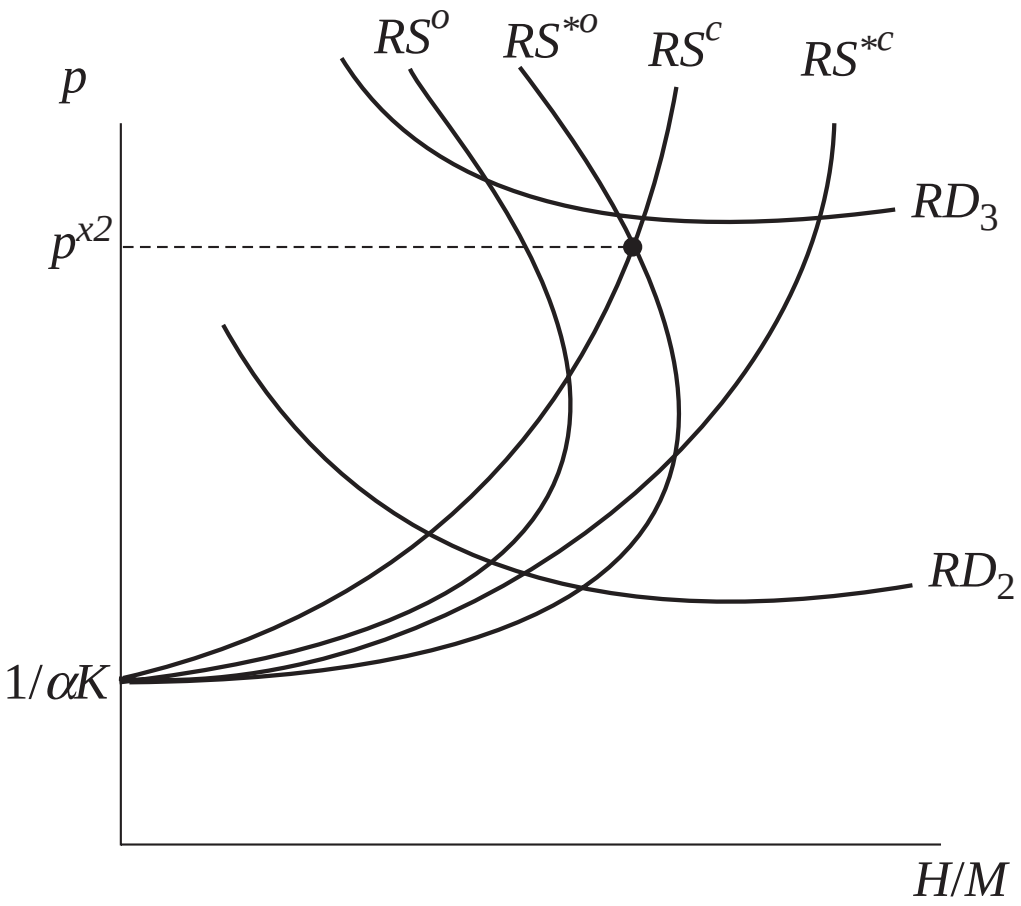

Figure 4: Two cases with a large difference: medium and severe overuses

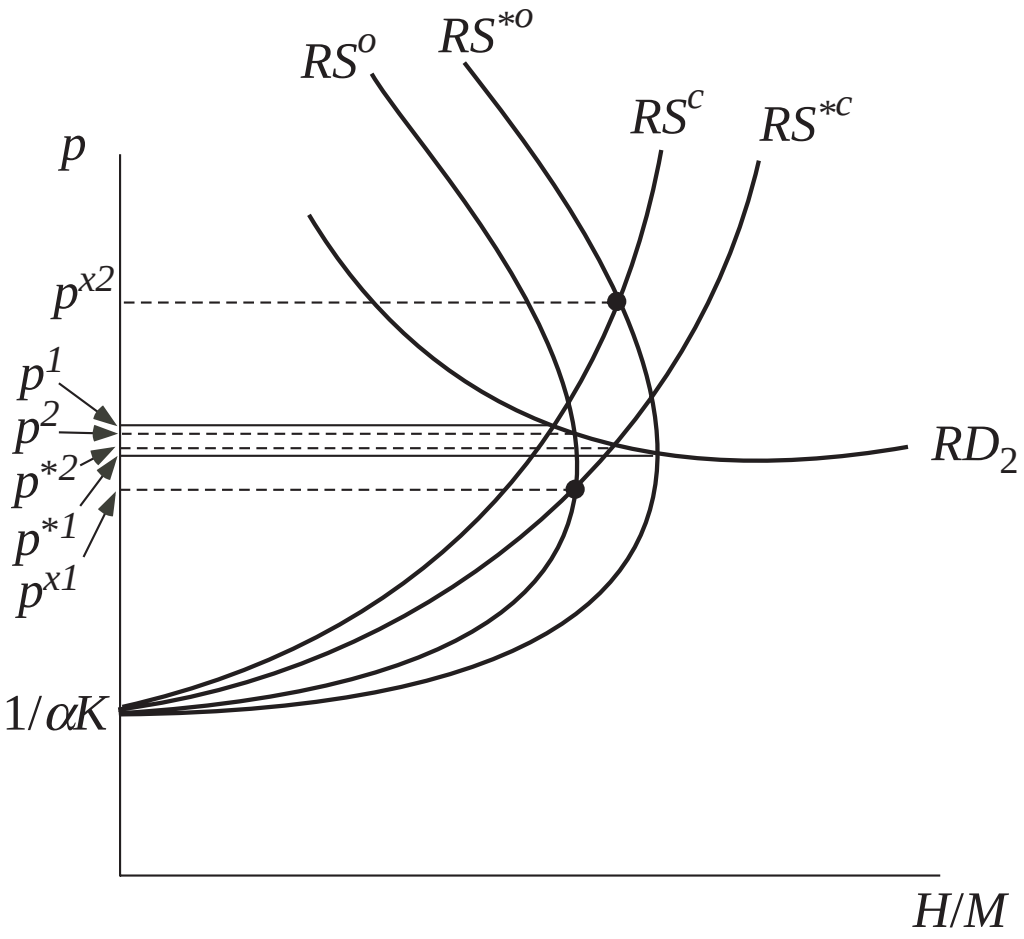

Figure 5: Trade liberalization in the medium overuse case