Title	RENEWABLE RESOURCE EXPLOITATION: INTERNATIONAL TRADE AND OPTIMAL STRATEGIC POLICY FOR THE LONG-TERM
Sub Title	
Author	GOTO, Kumiko
Publisher	Keio Economic Society, Keio University
Publication year	2002
Jtitle	Keio economic studies Vol.39, No.2 (2002.) ,p.65- 85
JaLC DOI	
Abstract	Short and long-term strategic policies of two countries' governments are examined, by adopting a two-country model where each country is endowed with respective renewable resource stock and which is a two-stage game involving two gov ernments and their respective firms that produce a homogenous product derived from a renewable resource. This paper shows that the foreign country of a resource exporter has a trade-off between the expansion of foreign market share and the conservation of its own renewable resource stock, while the domestic country of a resource importer does not have such a trade-off.
Notes	
Genre	Journal Article
URL	https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara_id=AA00260492-20020002-0065

KEIO ECONOMIC STUDIES **39**(2), 65–85 (2002)

RENEWABLE RESOURCE EXPLOITATION: INTERNATIONAL TRADE AND OPTIMAL STRATEGIC POLICY FOR THE LONG-TERM

Kumiko GOTO

The Faculty of Real Estate Science, Meikai University, Chiba Japan

First version received January 2002; final version accepted January 2003

Abstract: Short and long-term strategic policies of two countries' governments are examined, by adopting a two-country model where each country is endowed with respective renewable resource stock and which is a two-stage game involving two governments and their respective firms that produce a homogenous product derived from a renewable resource. This paper shows that the foreign country of a resource exporter has a trade-off between the expansion of foreign market share and the conservation of its own renewable resource stock, while the domestic country of a resource importer does not have such a trade-off.

1. INTRODUCTION

There is a close connection between international trade and the exploitation of renewable resources. Since the 1970's, there has been a twofold increase in the export of the world's total forest products, while in the same period international trade of pulp and paper products has increased threefold. This increase shows that nations endowed with natural resources have striven to increase their production and trade using those resources. Therefore, it is necessary to consider international trade and trade policies in order to analyze renewable resource management fully. However, there has been relatively little formal economic analysis addressing the relationship between international trade policy and renewable resource management.[1] Focusing on only a single country exporting a resource, Barbier and Rauscher (1994) and Schulz (1996) examine the effects of reduction in the terms of trade for tropical timber or living resource on steady

Acknowledgement. I would like to thank Professor Yasunori Ishii and an anonymous refree of this journal for very helpful and constructive comments. I am responsible for any remaining errors.
e-mail: kgoto@meikai.ac.jp

[1] For example, Barbier et al. (1995) examine the links between the trade in tropical timber products and deforestation in Indonesia and Haener and Luckert (1998) review forest certification.

state renewable resource stock. By contrast, Brander and Taylor (1998b) present a two-good, two-country model with respectively open access renewable resources, which they use to examine trade flows, gains and losses from trade, and effects of import or an export taxes on steady state resource stocks of both countries.[2] The analysis in a two-country model is important as it allows us to examine the interaction of exploitation between imported or exported resources and domestic consumed resources. However, Brander and Taylor do not take into account whether these policies determined by governments are optimal or not, because the trade policies in their model are fixed.

This paper establishes a two-country model, in which each country is endowed with its own renewable resource stock and each country's firm produces a homogenous product derived from a renewable resource. Using this model, the optimal policies for the expansion of domestic market share and the conservation of renewable resource stock are examined. If the traded product is a natural one, derived from a renewable resource, it is necessary to ascertain whether the government's policies are appropriate in the long term from an environmental standpoint. Therefore, not only the short-term effects of the trade policies from an economic standpoint but also their long-term effects from an environmental standpoint on amounts of traded resource, products, and/or renewable resource stocks are examined. Thus, differences in the short and long-term optimal policies determined by governments are demonstrated explicitly. A matter of a trade-off between market share's expansion and resource conservation is more serious for rather a tropical country than an industrial country. Some tropical countries restrict log exports for reasons of industry development, employment, and environmental well being by imposing export taxes.[3] It is important to examine whether the imposition of such taxes is optimal and effective.

The model clips the resource trade in forest or paper products between a tropical country and an industrial country from various types of real natural resource trades because this type of resource trade is pointed out as the issue of environmental destruction. And it is assumed that a tropical country, which is an exporter of natural resources because of lower resource extraction cost, is a small country and has no product market of its own, while an industrial country is an importer of foreign natural resources and has a domestic product market. In the market, domestic and foreign firms produce a homogenous product competitively. The renewable resource of each country has a dy-

[2] Brander and Taylor (1997b) and Chichilnisky (1991, 1993, 1994) consider trade between a country with an open access renewable resource and a country with well defined property rights to renewable resource, and examine trade pattern, gains and losses from trade, but do not consider policy interventions. Okuguchi (1998) has modeled international duopoly in commercial fishing, where two countries harvest fish in an open-access sea, and clarified how changes in the values of biological, demand and technical parameters will affect the non-extinction condition for the fish stock, but he does not take policy interventions into consideration. For other examples of renewable resource analysis, see Brander and Taylor (1997a, 1998a).

[3] For discussion of this issue, see van Kooten et al. (1999). Barbier et al. (1995) discuss the case of Indonesia. Brander and Taylor (1998b) examine such an export tax in two-country model though they do not consider whether such a tax is optimal or not.

namic structure of the classic Schaefer (1957) type.[4] Although there are several policies, this paper focuses on output subsidies and export resource tax that are mentioned above.

The basic model employed is a two-stage game involving two governments and their respective firms that extract their resources and produce natural products. In the first stage, both countries' governments determine independently their optimal strategic policies and then announce them to both countries' firms, where it is assumed that the policies are credible for the firms. In the second stage, given the policies that were determined in the first stage, both countries' firms choose independently their traded resources and outputs. Both countries' competitive firms are price-takers. Finally, both countries' firms supply their outputs to a product market.

The paper is organized as follows. Section 2 presents a basic model. Section 3 investigates the effects, and optimal levels, of domestic and foreign policies in short-term. Section 4 investigates the effects and optimal levels of the domestic and foreign policies in long-term, where renewable resource stocks are endogenously determined in the model. Concluding remarks are made in Section 5.

2. THE BASIC MODEL

The analysis of this paper uses not comparative dynamics but comparative statics though renewable resource has dynamic characteristics. For an inspection about characteristics of equilibrium is considered to be the most meaningful but not paths to equilibrium. Figure 1 illustrates the model setting for this paper. Let there be two countries, a domestic country and a foreign country with its own renewable resource stock respectively. In each country there are identical and infinitesimal competitive firms and hence their behavior is just given by that of a representative firm. Therefore, it is assumed that there exists each representative firm in each country. The markets of a product and traded resource are assumed to be in perfect competition. A domestic representative firm is engaged in producing a product by using both domestic and foreign renewable resources and supplying the product in a domestic product market. On the other hand, a foreign representative firm is engaged in exporting some part of his extracted renewable resource, in producing a product from the remainder of the extracted resource, and in selling the product in a domestic market.

In the first stage, the domestic and foreign governments determine their policies independently. That is, the domestic government determines a per-unit subsidy on production s, which is given to the domestic firm. The foreign government determines a per-unit subsidy on production s^*, which is given to the foreign firm and an export resource tax t^*, which is imposed on the foreign export resource (the domestic import resource). Then, in the second stage, a domestic market is opened for a product supplied by domestic and foreign representative firms, and a traded resource market is also opened for a renewable resource supplied by a foreign representative firm. In this stage a domestic representative firm and a foreign representative firm, whose products

[4] Clark (1990) provides the comprehensive overviews of renewable resource economics.

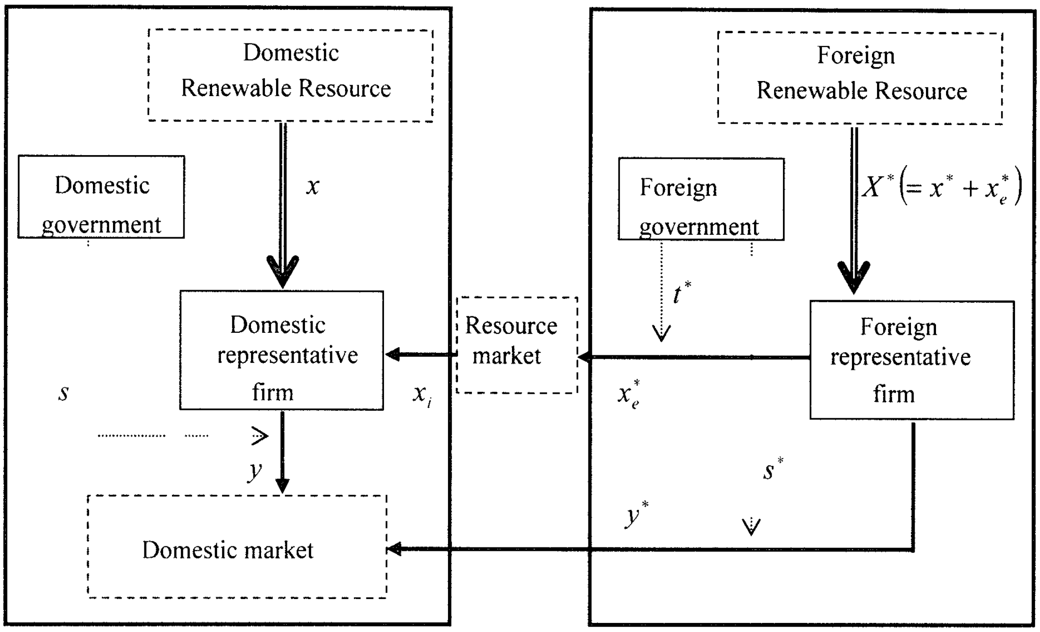

Figure 1. For the basic model the following variables are defined, where notation is simplified by omitting the argument of time-dependent variables:
$N(N^*)$, renewable resource stock of domestic (foreign) country;
x, renewable resource extracted by a representative firm of domestic country;
$X^*(=x^*+x_e^*)$, renewable resource extracted by a representative firm of foreign country;
x^*, renewable resource input of a representative firm of foreign country for a foreign product;
x_i, renewable resource imported by a representative firm of domestic country;
x_e^*, renewable resource exported by a representative firm of foreign country;
$y(y^*)$, total output of a representative firm of domestic (foreign) country;
s, a per-unit domestic subsidy on production; s^*, a per-unit foreign subsidy on production;
t^*, a per-unit foreign export resource tax.

are homogeneous, decide their traded levels of resources and output respectively, given government policies and their rival's choices. This paper applies backward induction by analyzing the firms' optimal choices in the second stage, and then it examines the effects of policies on the firms' choices in the first stage.

Before proceeding to details of market structure, it is necessary to describe the basic structure of renewable resource growth. Each country has a renewable resource stock. The changes in the stocks at time t of domestic and foreign countries are the natural growth rates $G(N)$ and $G^*(N^*)$, minus the harvest rate x and X^*, that is, respectively,

$$dN/dt = G(N) - x\,, \tag{1}$$

$$dN^*/dt = G^*(N^*) - X^*\,. \tag{2}$$

where X^* is the sum of renewable resource using for a foreign product x^* and renewable resource exported by a foreign representative firm x_e^*, that is, $X^* = x^* + x_e^*$. The biological growth laws of domestic and foreign countries are respectively given by

$$G(N) = rN(1 - N/K), \tag{3}$$

$$G^*(N^*) = r^*N^*(1 - N^*/K^*). \tag{4}$$

This functional form for $G(N)$ or $G^*(N^*)$ is the logistic function, which is widely used in the analysis of renewable resources and is, perhaps, the simplest empirically plausible functional form for biological growth in a constrained environment. The variable K or K^*, referred to as the "carrying capacity", is the maximum possible size for the resource stock of domestic or foreign country. If $N = K$ or ($N^* = K^*$), further growth cannot occur. The variable r or r^* is the "intrinsic" or "uncongested" growth rate. Proportional growth rate $G(N)/N$ ($G^*(N^*)/N^*$) would be approximately equal to $r(r^*)$ if congestion were negligible in the sense that carrying capacity was large relative to the current stock of the domestic (foreign) country.

There exists a product market only in the domestic country. The inverse demand function of the domestic market is specified by

$$p = a - bY \quad \text{and} \quad a, b > 0, \tag{5}$$

where p is the domestic product price, a and b are positive constants, and Y is the sum of sales by a domestic representative firm y and exports of a foreign representative firm y^*. Then, $Y(= y + y^*)$ is the total amount of product supplied (consumed) in the domestic country.

A product is produced with a linear homogeneous production function using only a renewable resource. Even though domestic and foreign representative firms produce a homogeneous product, their marginal productivity is different in each country due to technological differences in the two countries. Therefore, a domestic and foreign firm's production functions are respectively given by

$$y = k(x + x_i), \tag{6}$$

$$y^* = k^*x^*, \tag{7}$$

where $y(y^*)$ is a domestic (foreign) firm's output, $x + x_i(x^*)$ is renewable resource input of a domestic (foreign) firm. The domestic resource input $x + x_i$ is the sum of resource extracted from the domestic renewable resource x and resource imported from the foreign country x_i. And $k(k^*)$ is a domestic (foreign) yield rate, where k and k^* are positive constants that satisfy $k > k^*$.

The production-cost function of extracting a resource follows Okuguchi (1998). If the renewable resource stock $N(N^*)$ of the domestic (foreign) country is given, the unit cost of extracting a resource will increase proportionally as the extracting rate $x(X^*)$ of a domestic (foreign) firm increases. In this case, the total extracting cost will be proportional to the square of the harvest rate. If, on the other hand, the extraction rate is given, extracting will be easier and less costly as the resource stock increases. Therefore, given the extraction rate, the extracting cost is inversely proportional to the resource stock. A domestic and foreign representative firm's production-cost functions are given respectively by

$$c(x, N) = \alpha x^2/N \quad \text{and} \quad \alpha > 0\,, \tag{8}$$

$$c^*(N^*, N^*) = \alpha^* X^{*2}/N^* \quad \text{and} \quad \alpha^* > 0\,, \quad X^* = x^* + x_e^* \tag{9}$$

where $\alpha(\alpha^*)$ is a positive constant of a domestic (foreign) firm.

Under the assumptions and features explained above, profit π of the domestic firm in the second stage is defined as

$$\pi = pk(x + x_i) - \frac{\alpha x^2}{N} - (q^* + t^*)x_i + sk(x + x_i)\,. \tag{10}$$

In (10), the first term is sale revenue from the domestic market, the second is extracting costs of the domestic resources, the third is import costs, and the last is subsidy receipts. The domestic firm, given domestic and foreign governments' policies, a price of a product p and a price of a traded resource $q^* + t^*$ where a per-unit foreign export resource tax t^* is charged by the foreign government, decides extracting resources x to maximize his profit defined in (10). But profit of the domestic firm is linear in import resources x_i. The domestic representative firm with a linear homogeneous production function given by (6) faces the prices of a product and an imported resource that satisfy $k \leq (q^* + t^*)/(p + s)$.[5] But if $k < (q^* + t^*)/(p + s)$, then it is expected that the domestic firm discontinues production by using imported resources and hence a resource is not traded, that is, $x_i = 0$ because the domestic firm's profit from the production by imported resources is minus. This non-trading case of $k < (q^* + t^*)/(p + s)$ is here eliminated in order to focus on the trading case of $k = (q^* + t^*)/(p + s)$, which is the main issue of this paper. Therefore, it is here assumed that in resource market equilibrium q^* should be adjusted in order that $k = (q^* + t^*)/(p + s)$ is satisfied. Thus, the first-order conditions for profit maximization of the domestic firm are given by

$$pk - \frac{2\alpha}{N}x + sk = 0\,, \tag{11a}$$

$$pk - (q^* + t^*) + sk = 0\,, \tag{11b}$$

and the second-order conditions are satisfied.

On the other hand, profit π^* of the foreign firm in the second stage is given by

$$\pi^* = pk^*x^* - \frac{\alpha^*(x^* + x_e^*)^2}{N^*} + q^*x_e^* + s^*k^*x^*\,, \tag{12}$$

where the first term is sale revenue from the domestic product market, the second is extracting costs of the foreign resources, the third is sale revenue of export, and the last is subsidy receipts. The foreign firm, given a price of a product p and a price of a traded resource q^*, decides extracting resources x^* and export resources x_e^* to maximize his

[5] The case $k > (q^* + t^*)/(p + s)$ is excluded. For it denotes that the more the firm produces, the more his profit can be, but that is impossible in the real world on the grounds of the impossibility of infinite resource input, the incompatibility with the assumption of firms' price taker, and the possibility of entry of other firms.

profit defined in (12). Therefore, the first-order conditions for profit maximization of the foreign firm are given by

$$pk^* - \frac{2\alpha^*(x^* + x_e^*)}{N^*} + s^*k^* = 0\,, \tag{13a}$$

$$-\frac{2\alpha^*(x^* + x_e^*)}{N^*} + q^* = 0\,, \tag{13b}$$

and the second-order condition is satisfied. In the resource market denoted by the inverse demand and supply functions (11b) and (13b), the condition certifying the existence and uniqueness of the market equilibrium is clarified in Appendix 1, and moreover, it is showed that equilibrium in the second stage which is derived in next paragraph satisfies the condition on a certain assumption.

Taking account of $p = a - b(kx + kx_e^* + k^*x^*)$ in equilibrium and substituting (13b) into (11b) on the grounds that q^* of the inverse demand function (11b) equals that of the inverse supply function (13b) in equilibrium, (11a), (11b), (13a), and (13b) are reduced as follow:

$$-\left(bk^2 + \frac{2\alpha}{N}\right)x - bk^2x_e^* - bkk^*x^* + ak + ks = 0\,, \tag{14a}$$

$$-bk^2x - \left(bk^2 + \frac{2\alpha^*}{N^*}\right)x_e^* - \left(bkk^* + \frac{2\alpha^*}{N^*}\right)x^* + ak + ks - t^* = 0\,, \tag{14b}$$

$$-bkk^*x - \left(bkk^* + \frac{2\alpha^*}{N^*}\right)x_e^* - \left(bk^{*2} + \frac{2\alpha^*}{N^*}\right)x^* + ak^* + k^*s^* = 0\,. \tag{14c}$$

Equilibrium in the second stage is given by x, x_e^*, and x^* which satisfy the simultaneous equation system (14a), (14b), and (14c). Thus, comparative static solution of the simultaneous equation system (14a), (14b), and (14c) can be represented by

$$\begin{bmatrix} D_{11} & D_{12} & D_{13} \\ D_{21} & D_{22} & D_{23} \\ D_{31} & D_{32} & D_{33} \end{bmatrix} \begin{bmatrix} x \\ x_e^* \\ x^* \end{bmatrix} = \begin{bmatrix} -ak - ks \\ -ak - ks + t^* \\ -ak^* - k^*s^* \end{bmatrix}, \tag{15}$$

where

$$D_{11} = -bk^2 - 2\alpha/N\,, \quad D_{12} = -bk^2\,, \quad D_{13} = -bkk^*\,,$$
$$D_{21} = -bk^2\,, \quad D_{22} = -bk^2 - 2\alpha^*/N^*\,, \quad D_{23} = -bkk^* - 2\alpha^*/N^*\,,$$
$$D_{31} = -bkk^*\,, \quad D_{32} = -bkk^* - 2\alpha^*/N^*\,, \quad D_{33} = -bk^{*2} - 2\alpha^*/N^*\,.$$

The determinant D of the Hessian matrix of this system is given by

$$D = -4b(k - k^*)^2 \frac{\alpha\alpha^*}{NN^*}\,,$$

and thus $D < 0$. Equilibrium in the second stage is unique and stable because the Fuller's criterion (1968) is satisfied.[6]

3. THE EFFECTS AND OPTIMAL LEVELS OF POLICIES IN SHORT-TERM

This section analyzes first the effects of the domestic and foreign output subsidies and the foreign export resource tax, and next the optimal levels of the policies determined by the domestic and foreign governments in short-term equilibrium.

The short-term effects of a change in the policies on the extracted resource of the domestic firm x, the export (import) resource of the foreign (domestic) firm x_e^*, and the resource using for a product of the foreign firm x^*, are given by differentiating (14a), (14b), and (14c) completely with respect to s, s^*, and t^*, given renewable resource stocks of the domestic and foreign countries N and N^*. Thus, one obtains:

$$\frac{\partial x}{\partial s} < 0, \quad \frac{\partial x_e^*}{\partial s} > 0, \quad \frac{\partial x^*}{\partial s} < 0, \quad \frac{\partial X^*}{\partial s} < 0, \quad \frac{\partial y}{\partial s} > 0, \quad \frac{\partial y^*}{\partial s} < 0, \tag{16a}$$

$$\frac{\partial x}{\partial s^*} > 0, \quad \frac{\partial x_e^*}{\partial s^*} < 0, \quad \frac{\partial x^*}{\partial s^*} > 0, \quad \frac{\partial X^*}{\partial s^*} > 0, \quad \frac{\partial y}{\partial s^*} < 0, \quad \frac{\partial y^*}{\partial s^*} > 0, \tag{16b}$$

$$\frac{\partial x}{\partial t^*} > 0, \quad \frac{\partial x_e^*}{\partial t^*} < 0, \quad \frac{\partial x^*}{\partial t^*} > 0, \quad \frac{\partial X^*}{\partial t^*} > 0, \quad \frac{\partial y}{\partial t^*} < 0, \quad \frac{\partial y^*}{\partial t^*} > 0, \tag{16c}$$

(See Appendix 2 for derivation of these results.)

Taking (16a), (16b), and (16c) into consideration, one can present:

PROPOSITION 1. (i) *Although an increase in the domestic subsidy on production s reduces the domestic extracted resource x, yet it raises the domestic output y through an increase in the traded resource x_e^*. And it reduces the foreign output y^* and extracted resources X^*.*

(ii) *An increase in the foreign subsidy on production s^* or the foreign export resource tax t^* has the same effects. Each increase raises the foreign output y^* and extracted resources X^*. And it reduces the domestic output y through a decrease in the traded resource x_e^* despite an increase in the domestic extracted resource x.*

Proposition 1(i) presents very striking result, that is, an increase in the domestic subsidy on production s reduces the domestic extracted resource x. The intuitive reason for this result is that for the domestic firm producing both a renewable resource and an output, a per-unit domestic subsidy on production makes a relative price of an output rise, and therefore producing not a renewable resource but an output is more favorable. The production of an output, of which relative price becomes higher, increases, on the other hand, that of a renewable resource, of which relative price becomes lower, decreases subject to the production possibility set of the domestic country. And thus a subsidy

[6] That is, the trace and determinant of the Hessian matrix of this system are both negative and the following condition is satisfied: $\begin{vmatrix} D_{22}+D_{11} & D_{23} & -D_{13} \\ D_{32} & D_{33}+D_{11} & D_{12} \\ -D_{31} & D_{21} & D_{33}+D_{22} \end{vmatrix} < 0.$

on production reduces the domestic extracted resource x and increases the imported resource x_e^* for the reduction of the domestic renewable resource. Furthermore, by this Proposition it is found that a domestic (foreign) subsidy on production is justified in order to raise the domestic (foreign) market share. However, an increase in the domestic subsidy on production reduces both domestic and foreign extracted resources, x and X^*, while an increase in the foreign subsidy on production or export resource tax raises them. The reason for this difference is that while the effects of decreases in the domestic extracted resource x and resource using for the foreign output x^* are larger than that of a increase in the foreign export resource x_e^* by a domestic subsidy on production, the effects of increases in the farmer are larger than that of a decrease in the latter by a foreign subsidy on production or export resource tax.

Let us now turn to the derivation of optimal levels of the subsidy determined by the domestic government and the subsidy and export resource tax determined by the foreign government. For simplicity, it is assumed that the domestic and foreign governments know all the reactions of domestic and foreign firms to changes in policies without uncertainty. The domestic net welfare is defined as

$$W = \int_0^{y+y^*} (a - b\tau)d\tau - \{a - b(y + y^*)\}(y + y^*) + \pi - sy\,, \tag{17}$$

where the first and second terms constitute the domestic consumer's surplus, the second is profits of the domestic firm given by (10), and the last is total payment of the domestic subsidy. It is now assumed that the domestic government decides s so as to maximize the domestic net welfare given as (17). Using the conditions for maximizing firm's profits, (11a) and (11b), the first-order condition for maximizing the domestic net welfare with respect to s is given by

$$b(y + y^*)\frac{\partial(y + y^*)}{\partial s} + \frac{\partial \pi}{\partial x^*}\frac{\partial x^*}{\partial s} - s\frac{\partial y}{\partial s} = 0\,, \tag{18}$$

where it is assumed that the second-order condition is satisfied. Rearranging (18) and using (16a) and (A-4) yield

$$s = \frac{b(y + y^*)\{\partial(y + y^*)/\partial s\} + (\partial\pi/\partial x^*)(\partial x^*/\partial s)}{\partial y/\partial s} > 0\,, \tag{19}$$

where $\partial\pi/\partial x^* = -bkk^*(x+x_e^*) < 0$. That is, the optimal level of the domestic subsidy on production is positive.

The foreign net welfare is defined as

$$W^* = \pi^* - s^*y^* + t^*x_e^*\,. \tag{20}$$

The first term is profits of the foreign firm given by (12), the second is the total payment of the foreign subsidy and the last is the total revenue of the foreign export resource tax. It is also assumed that the foreign government decides s^* and t^* so as to maximize the foreign net welfare given by (20). Using the conditions for maximizing firm's profits, (13a) and (13b), the first-order conditions for maximizing the foreign net welfare with respect to s^* and t^* are respectively given by

$$\frac{\partial \pi^*}{\partial x}\frac{\partial x}{\partial s^*} - s^*\frac{\partial y^*}{\partial s^*} + t^*\frac{\partial x_e^*}{\partial s^*} = 0\,, \tag{21}$$

and

$$\frac{\partial \pi^*}{\partial x}\frac{\partial x}{\partial t^*} + t^*\frac{\partial x_e^*}{\partial t^*} + x_e^* - s^*\frac{\partial y^*}{\partial t^*} = 0\,, \tag{22}$$

where it is assumed that the second-order conditions are satisfied. Solving the simultaneous equation system (21) and (22) yield

$$s^* = \frac{x_e^*(\partial x_e^*/\partial s^*) + (\partial \pi^*/\partial x)(\partial x/\partial t^*)\{(\partial x_e^*/\partial s^*) - k^*(\partial x_e^*/\partial t^*)\}}{(\partial y^*/\partial t^*)(\partial x_e^*/\partial s^*) - (\partial y^*/\partial s^*)(\partial x_e^*/\partial t^*)}\,, \tag{23}$$

and

$$t^* = \frac{x_e^* k^*(\partial x^*/\partial s^*) + (\partial \pi^*/\partial x)(\partial x/\partial t^*)k^*\{(\partial x^*/\partial s^*) - k^*(\partial x^*/\partial t^*)\}}{(\partial y^*/\partial t^*)(\partial x_e^*/\partial s^*) - (\partial y^*/\partial s^*)(\partial x_e^*/\partial t^*)}\,, \tag{24}$$

where $\partial \pi^*/\partial x < 0$. Considering that the denominator of (23) is positive, the sign of s^* is positive, if the numerator of (23) is positive, that is, $x_e^*/x^* < A$, however, if that of (23) is negative, that is, $x_e^*/x^* > A$, the sign of s^* is negative, where $A = b^2k^2k^{*2}/\{2bkk^*(\alpha/N) + 2bk^2(\alpha^*/N^*) + 4(\alpha\alpha^*/NN^*)\} > 0$. On the other hand, if the numerator of (24) is positive, that is, $x_e^*/x^* > B$, the sign of t^* is positive, however, if that of (24) is negative, that is, $x_e^*/x^* < B$, the sign of t^* is negative, where $B = b^2k^3k^*/\{2bk^2(\alpha/N) + 2bk^2(\alpha^*/N^*) + 4(\alpha\alpha^*/NN^*)\} > 0$. Thus, considering that $A < B$, it is found that the optimal policies of the foreign government are divided into three cases: (i) $x_e^*/x^* > A$, (ii) $B < x_e^*/x^* < A$, and (iii) $x_e^*/x^* < B$.

In (i), when the export resource rate x_e^*/x^* is high (or the foreign output rate is low), then, the optimal level of the foreign subsidy on production is negative and that of the foreign export tax is positive. In (ii), when the export resource rate x_e^*/x^* is middle, then, both optimal levels of the foreign subsidy on production and the export resource tax are negative. And in (iii), when the export resource rate x_e^*/x^* is low (or the foreign output rate is high), then, the optimal level of the foreign subsidy on production is positive and that of the foreign export resource tax is negative.

Now, taking (19), (23), and (24) into consideration, one can present:

PROPOSITION 2. *The optimal short-term policy of the domestic government is to subsidize output. By contrast, the optimal short-term policies of the foreign government are to impose both of tax on production and export resource tax if the export resource rate is high (or the foreign output rate is low), however, if the foreign output rate is high (or the foreign resource rate is low), the foreign optimal policies are to subsidize both of production and export resource, and moreover, if the export resource rate (or the foreign output rate) is middle, the optimal policies of the foreign government are to impose an output tax and to subsidize an export resource.*

Combining this proposition with Proposition 1, it is found that the domestic optimal short-term policy, that is, a subsidy on production operates to raise the domestic market share. By contrast, it is found that the foreign optimal short-term policies operate to cancel each other's effects on the foreign market share. That is, if the export resource rate is high, while an export resource tax operates to raise the foreign market share, a tax on production operates to reduce its share. On the other hand, if the output rate is high, while a subsidy on production operates to raise the foreign market share, an export resource subsidy operates to reduce its share. Thus, the short-term optimal policies of the foreign government do not necessarily operate in favor of the expansion of foreign market share, while that of the domestic government does in favor of that of domestic market share. In this short-term case, an export resource tax of a tropical country is justified only if the export resource rate is high, but the optimal policy mix of an export resource tax and an output tax does not necessarily encourage the industry development of a foreign policy object.

4. THE EFFECTS AND OPTIMAL LEVELS OF POLICIES IN LONG-TERM

This section considers the long-term steady state equilibrium, where there is no growth in the domestic and foreign renewable resources and the domestic and foreign renewable resource stocks N and N^* are taken endogenously. The way in which the policies controlled by the domestic and foreign governments will affect steady state renewable resource stocks of the domestic and foreign countries is examined. First, this section provides the steady state material balance requirements of the domestic and foreign countries. Next, the effects of the domestic and foreign output subsidies and the foreign export resource tax are analyzed, and third, the optimal levels of the policies determined by the domestic and foreign governments in long-term equilibrium are derived.

The steady state material balance requirements of the domestic and foreign countries are based on setting (1) and (2) to 0 respectively. By considering that $X^* = x_e^* + x^*$, and using (3) and (4), one can obtain

$$x - rN + \frac{rN^2}{K} = 0\,, \tag{25}$$

$$x_e^* + x^* - r^*N^* + \frac{r^*N^{*2}}{K^*} = 0\,. \tag{26}$$

Long-term equilibrium in the second stage is given by x, x_e^*, x^*, N, and N^* which satisfy the simultaneous equation system (14a), (14b), (14c), (25), and (26). Thus, comparative static solution of the simultaneous equation system (14a), (14b), (14c), (25), and (26) can be represented by

$$\begin{bmatrix} D^L_{11} & D^L_{12} & D^L_{13} & D^L_{14} & 0 \\ D^L_{21} & D^L_{22} & D^L_{23} & 0 & D^L_{25} \\ D^L_{31} & D^L_{32} & D^L_{33} & 0 & D^L_{35} \\ 1 & 0 & 0 & D^L_{44} & 0 \\ 0 & 1 & 1 & 0 & D^L_{55} \end{bmatrix} \begin{bmatrix} x \\ x_e^* \\ x^* \\ N \\ N^* \end{bmatrix} = \begin{bmatrix} -ak - ks \\ -ak - ks + t^* \\ -ak^* - k^*s^* \\ 0 \\ 0 \end{bmatrix}, \tag{27}$$

where

$$D^L_{11} = D_{11},\ D^L_{12} = D_{12},\ D^L_{13} = D_{13},\ D^L_{14} = 2\alpha x/N^2,$$
$$D^L_{21} = D_{21},\ D^L_{22} = D_{22},\ D^L_{23} = D_{23},\ D^L_{25} = (2\alpha^*/N^{*2})(x_e^* + x^*),$$
$$D^L_{31} = D_{31},\ D^L_{32} = D_{32},\ D^L_{33} = D_{33},\ D^L_{35} = (2\alpha^*/N^{*2})(x_e^* + x^*),$$
$$D^L_{44} = -r + (2rN/K),\ D^L_{55} = -r^* + (2r^*N^*/K^*).$$

The determinant D^L of the Hessian matrix of this system is given by

$$D^L = -4b(k - k^*)^2 \frac{\alpha\alpha^* r r^*}{KK^*},$$

and thus $D^L < 0$. It is not evident that long-term equilibrium in the second stage is unique and stable, however, in order to make the following analyses meaningful it is here assumed that long-term equilibrium in the second stage is unique and stable.

The long-term effects of a change in the policies on the extracted resource of the domestic firm x, the export (import) resource of the foreign (domestic) firm x_e^*, the resource using for a product of foreign firms x^*, the domestic renewable resource stock N, and the foreign renewable resource stock N^* are given by differentiating (14a), (14b), (14c), (25), and (26) completely with respect to s, s^*, and t^*. Thus, one obtains:

$$\frac{\partial x}{\partial s} < 0,\ \frac{\partial x_e^*}{\partial s} > 0,\ \frac{\partial x^*}{\partial s} < 0,\ \frac{\partial X^*}{\partial s} < 0,\ \frac{\partial y}{\partial s} > 0,\ \frac{\partial y^*}{\partial s} < 0,\ \frac{\partial N}{\partial s} > 0,\ \frac{\partial N^*}{\partial s} > 0, \tag{28a}$$

$$\frac{\partial x}{\partial s^*} > 0,\ \frac{\partial x_e^*}{\partial s^*} < 0,\ \frac{\partial x^*}{\partial s^*} > 0,\ \frac{\partial X^*}{\partial s^*} > 0,\ \frac{\partial y}{\partial s^*} < 0,\ \frac{\partial y^*}{\partial s^*} > 0,\ \frac{\partial N}{\partial s^*} > 0,\ \frac{\partial N^*}{\partial s^*} < 0, \tag{28b}$$

$$\frac{\partial x}{\partial t^*} > 0,\ \frac{\partial x_e^*}{\partial t^*} < 0,\ \frac{\partial x^*}{\partial t^*} > 0,\ \frac{\partial X^*}{\partial t^*} > 0,\ \frac{\partial y}{\partial t^*} < 0,\ \frac{\partial y^*}{\partial t^*} > 0,\ \frac{\partial N}{\partial t^*} < 0,\ \frac{\partial N^*}{\partial t^*} > 0. \tag{28c}$$

(See Appendix 3 for derivation of these results.)

Taking (28a), (28b), and (28c) into consideration, one can present:

PROPOSITION 3. (i) *A rise in the domestic subsidy on production s causes rises in both the domestic and foreign renewable resource stocks N and N^*. The long-term effects of the domestic subsidy on other variables x, x_e^*, x^*, X^*, y, y^* are the same as the short-term effects.*

(ii) *A rise in the foreign subsidy on production s^* causes a decline in the foreign renewable resource stock N^* and, however, a rise in the domestic renewable resource stock N. By contrast, a rise in the foreign export resource tax t^* causes a rise in the former and a decline in the latter. The long-term effects of the foreign subsidy on production or export resource tax on other variables x, x_e^*, x^*, X^*, y, y^* are the same as the short-term effects respectively.*

Proposition 3 (i) implies that the domestic country does not have a trade-off between the expansion of domestic market share and the conservation of world's resource stocks.

By contrast, Proposition 3 (ii) implies that the foreign country has a trade-off between the expansion of foreign market share and the conservation of the foreign resource stock in an subsidy on production, however, does not have such a trade-off in an export resource tax. Thus, a domestic (foreign) subsidy on production is justified in order to raise the domestic (foreign) market share, however, an subsidy on production of an resource exporter causes a depletion of its own country's resource stock.

Now, I analyze the optimal levels of the policies determined by the domestic and foreign governments in long-term steady state equilibrium. Taking the domestic and foreign resource stocks N and N^* endogenously, and differentiating (17) with respect to s, the first-order condition for maximizing the domestic net welfare in the long-term is given by

$$b(y+y^*)\frac{\partial(y+y^*)}{\partial s}+\frac{\partial\pi}{\partial x^*}\frac{\partial x^*}{\partial s}+\frac{\partial\pi}{\partial N}\frac{\partial N}{\partial s}-s\frac{\partial y}{\partial s}=0, \tag{29}$$

where it is assumed that the second-order condition is satisfied. Rearranging (29) and using (28a) and (A13)–(A15) yield

$$s=\frac{b(y+y^*)\{\partial(y+y^*)/\partial s\}+(\partial\pi/\partial x^*)(\partial x^*/\partial s)+(\partial\pi/\partial N)(\partial N/\partial s)}{\partial y/\partial s}>0, \tag{30}$$

where $\partial\pi/\partial x^* < 0$ and $\partial\pi/\partial N > 0$. Therefore, the long-term optimal level of the domestic subsidy on production is as positive as that of the short-term subsidy on production.

By contrast, taking the domestic and foreign resource stocks N and N^* endogenously, and differentiating (20) with respect to s^* and t^* respectively, the first-order conditions for maximizing the domestic net welfare in the long-term are given by

$$\frac{\partial\pi^*}{\partial x}\frac{\partial x}{\partial s^*}+\frac{\partial\pi^*}{\partial N^*}\frac{\partial N^*}{\partial s^*}-s^*\frac{\partial y^*}{\partial s^*}+t^*\frac{\partial x_e^*}{\partial s^*}=0, \tag{31}$$

and

$$\frac{\partial\pi^*}{\partial x}\frac{\partial x}{\partial t^*}+\frac{\partial\pi^*}{\partial N^*}\frac{\partial N^*}{\partial t^*}+t^*\frac{\partial x_e^*}{\partial t^*}+x_e^*-s^*\frac{\partial y^*}{\partial t^*}=0, \tag{32}$$

where it is assumed that the second-order conditions is satisfied respectively. Solving the simultaneous equation system (31) and (32) yeilds

$$s^*=\frac{\begin{array}{c}(\partial\pi^*/\partial x)(\partial x/\partial t^*)\{k^*(\partial x_e^*/\partial t^*)-(\partial x_e^*/\partial s^*)\}\\ -(\partial\pi^*/\partial N^*)(\partial N^*/\partial t^*)\{(\partial x_e^*/\partial t^*)+(\partial x_e^*/\partial s^*)\}-x_e^*(\partial x_e^*/\partial s^*)\end{array}}{(\partial y^*/\partial s^*)(\partial x_e^*/\partial t^*)-(\partial y^*/\partial t^*)(\partial x_e^*/\partial s^*)}, \tag{33}$$

and

$$t^*=\frac{\begin{array}{c}(\partial\pi^*/\partial x)(\partial x/\partial t^*)\{k^*(\partial y^*/\partial t^*)-(\partial y^*/\partial s^*)\}\\ -(\partial\pi^*/\partial N^*)(\partial N^*/\partial t^*)\{(\partial y^*/\partial t^*)+(\partial y^*/\partial s^*)\}-x_e^*(\partial y^*/\partial s^*)\end{array}}{(\partial y^*/\partial s^*)(\partial x_e^*/\partial t^*)-(\partial y^*/\partial t^*)(\partial x_e^*/\partial s^*)}, \tag{34}$$

where $\partial\pi^*/\partial N^* > 0$. Considering that the denominator of (33) is negative, the sign of s^* is positive, if the numerator of (33) is negative, that is, $x^* > E$, however, if that of (33) is positive, that is, $x^* < E$, the sign of s^* is negative, where

$$E = \frac{\begin{array}{c}-(\partial x_e^*/\partial s^*)\{r^*N^* - (r^*N^{*2}/K^*)\} + (1/D^L)2bkk^*(k-k^*)(\alpha\alpha^*r/K)\\ \{r^* - (r^*N^*/K^*)\}^2\{(\partial x_e^*/\partial t^*) + (\partial x_e^*/\partial s^*)\}\end{array}}{-(1/D^L)b^2k^2k^{*3}\{r-(2rN/K)\}\{r^*-(2r^*N^*/K^*)\} - (\partial x_e^*/\partial s^*)} > 0\,.$$

On the other hand, if the numerator of (34) is negative, that is, $x^* < F$, the sign of t^* is positive, however, if that of (34) is positive, that is, $x^* > F$, the sign of t^* is negative, where

$$F = \frac{\begin{array}{c}(\partial x^*/\partial s^*)\{r^*N^* - (r^*N^{*2}/K^*)\} - (1/D^L)2bkk^*(k-k^*)(\alpha\alpha^*r/K)\\ \{r^* - (r^*N^*/K^*)\}^2\{(\partial x^*/\partial t^*) + (\partial x^*/\partial s^*)\}\end{array}}{-(1/D^L)b^2k^3k^{*2}\{r-(2rN/K)\}\{r^*-(2r^*N^*/K^*)\} + (\partial x^*/\partial s^*)} > 0\,.$$

Thus, considering that E and F seem to be approximately equal, the optimal policies of the foreign government are divided roughly into two cases: (i) $x^* > E$ and $x^* > F$, and (ii) $x^* < E$ and $x^* < F$.

In (i), when the resource using for a foreign product x^* is high, that is, by the constraint of (26) that case denotes that the export resource x_e^* is low, then, the optimal level of the foreign subsidy on production is positive and that of the foreign export resource tax is negative. And in (ii), when the resource using for a foreign product x^* is low, or the export resource x_e^* is high, then, the optimal level of the foreign subsidy on production is negative and that of the foreign export tax is positive.

Now, taking (30), (33), and (34) into consideration, one can present:

PROPOSITION 4. *The optimal long-term policy of the domestic government is to subsidize on production. By contrast, the optimal long-term policies of the foreign government are to impose taxes both on production and export resource if the export resource is high (or the resource using for a foreign product is low), however, if the export resource is low (or the resource using for a foreign product is high), the foreign optimal long-term policies are to subsidize both on production and export resource.*

The long-term optimal policies of the domestic and foreign governments are the almost same as those of short-term, which is shown by Proposition 2. In this long-term case, an export resource tax of a tropical country is also justified only if the export resource rate is high, as the same in the short-term case. Although the optimal policy mix of an export resource tax and an output tax does not necessarily encourage the industry development of a foreign policy object, however, those policies have the effects to conserve its own renewable resource stock.

Now, Proposition 3 and 4 combine to present:

COROLLARY: (i) *The long-term optimal policy of the domestic government, which is a subsidy on production, increases domestic market share and conserves world's renewable resource stocks.*

(ii) *If the foreign export resource rate is high, the long-term optimal polices of the foreign government, that are taxes on production and export resource, conserves the foreign resource stock but depletes the domestic resource stock. On the other hand, if the foreign output rate is high, the long-term polices, that are subsidies on production and export resource, depletes the foreign stock but conserves the domestic stock. In both cases, the optimal policy mix of the foreign government does not necessarily operate in favor of the expansion of foreign market share.*

Corollary (i) implies that the domestic country of a resource importer has no trade-off between its market share expansion and the resource conservation. The reason for this result is mainly that since an increase in the domestic subsidy on production reduces the domestic extracted resource, however, increases the domestic output through an increase of imported resource, as is shown by Proposition 1 (i). By contrast, the foreign country of a resource exporter faces a serious trade-off. Especially if the foreign output rate is high, the foreign optimal policy mix may lead its own resource stock to exhaustion. Thus, these asymmetric results derived in this paper may implicate that a policy coordination of both countries of resource importer and exporter is needed so as to conserve renewable resource stocks of the world and to develop the resource exporter's industry in this type of resource trade.

5. CONCLUDING REMARKS

If a traded product is derived from a renewable resource, such as a forest or paper product, it is important to verify whether the government's policies are adequate not only to increase domestic market share but also to preserve environmental well being in the long-term. This paper establishes a two-country model where both of domestic and foreign countries are endowed with respective renewable resource stocks. The model sets up a two-stage game involving two governments and their respective representative firms that produce a homogenous product derived from a renewable resource. Using this model, the short and long-term effects of domestic and foreign output subsidies, and foreign export resource tax on the amount of traded resource, outputs, and/or renewable resource stocks are investigated, and moreover, the optimal policies of the domestic and foreign governments are examined. The derived results are summarized as follows.

First of all, the striking result is presented, that is, an increase in the domestic subsidy on production reduces the domestic extracted resource. The reason for this result is that a per-unit domestic subsidy on production makes producing not a renewable resource but an output more favorable for the domestic representative firm. However, the subsidy results in an increase of the domestic output through an increase in the imported renewable resource. Thus, in both of short-term case given the domestic and foreign renewable resource stocks and long-term case taken both stocks endogenously, a domestic (foreign) subsidy on production is justified in order to raise the domestic (foreign) market share. On the other hand, while a rise in the domestic subsidy on production causes rises in both domestic and foreign resource stocks, a rise in the foreign subsidy on production causes a decline in the foreign resource stock and a rise in the domestic resource stock. Thus, while the domestic country does not have a trade-off between the expansion of domestic market share and the conservation of world's renewable resource stocks, the foreign country has a trade-off between the expansion of foreign market share and the conservation of the foreign resource stock in a subsidy on production. But a rise in the foreign export resource tax causes a rise in the foreign stock and a decline in the domestic stock, therefore, the foreign country does not have such a trade-off in an export resource tax.

Next, the long-term optimal policy of the domestic government, which is a subsidy on production, increases the domestic market share and conserves world's renewable resource stocks. By contrast, if the foreign export resource rate is high, the long-term optimal polices of the foreign government, that are taxes on production and an export resource, conserves the foreign resource stock but depletes the domestic resource stock. On the other hand, if the foreign output rate is high, the long-term polices, that are subsidies on production and an export resource, depletes the foreign stock but conserves the domestic stock. In both cases, the optimal policy mix of the foreign government does not necessarily operate in favor of the expansion of the foreign market share. Therefore, the foreign country of a resource exporter faces a serious trade-off. Especially if the foreign output rate is high, the foreign optimal policy mix may lead its own renewable resource stock to exhaustion.

Thirdly, in short and long-term cases, an export resource tax of a tropical country is justified only if the export resource rate is high. Although the optimal policy mix of taxes on production and an export resource does not necessarily encourage the industry development which is the policy object, however, the policy mix have the effects to conserve its own renewable resource stock.

Thus, these asymmetric results derived in this paper may implicate that a policy coordination of both countries of a resource importer and a resource exporter is needed so as to conserve the renewable resource stocks of the world and to develop the resource exporter's industry in this type of resource trade.

APPENDIX

1. Existence and uniqueness of resource market equilibrium

The inverse demand function (11b) is displaced $q_d^* = q_d^*(p)$, and the inverse supply function (13b) is displaced $q_s^* = q_s^*(x_e^*, x^*)$ in the short-term or $q_s^* = q_s^*(x_e^*, x^*, N^*)$ in the long-term. The resource market for $\exists x^*$, p in the short-term or for $\exists x^*$, N^*, p in the long-term is illustrated in Figure A1. If $q_s^*(0, x^*) \geq q_d^*(p)$ for $\exists x^*$, p in the short-term (or $q_s^*(0, x^*, N^*) \geq q_d^*(p)$ for $\exists x^*$, N^*, p in the long-term), which case denotes that the foreign firm's marginal cost when the exported resource is zero is higher than the domestic firm's demand price of the imported resource, then the market equilibrium does not exist. On the other hand, if $q_s^*(0, x^*) < q_d^*(p)$ for $\exists x^*$, p in the short-term (or $q_s^*(0, x^*, N^*) < q_d^*(p)$ for $\exists x^*, N^* p$ in the long-term), which case denotes that the former is lower than the latter, then the equilibrium exists uniquely.

Now, we have to examine whether the condition $q_s^*(0, \hat{x}^*) < q_d^*(\hat{p})$ in the short-term (or $q_s^*(0, \hat{x}^*, \hat{N}^*) < q_d^*(\hat{p})$ in the long-term) is satisfied at $\hat{p}, \hat{x}^*$, and/or $\hat{N}^*$ of equilibrium in the second stage. Considering that $\hat{p} = a - b(k\hat{x} + k\hat{x}_e^* + k^*\hat{x}^*)$ and (14b) are satisfied on equilibrium in the second stage, since $q_s^*(0, \hat{x}^*) = (2\alpha^*/N^*)\hat{x}^*$ in the short-term (or $q_s^*(0, \hat{x}^*, \hat{N}^*) = (2\alpha^*/\hat{N}^*)\hat{x}^*$ in the long-term) and $q_d^*(\hat{p}) = -bk^2\hat{x} - bkk^*\hat{x}^* + ak + sk - t^*$ are derived, it is found that $q_d^*(\hat{p}) - q_s^*(0, \hat{x}^*) = (bk^2 + 2\alpha^*/N^*)\hat{x}_e^*$ in the short-term (or $q_d^*(\hat{p}) - q_s^*(0, \hat{x}^*, \hat{N}^*) = (bk^2 + 2\alpha^*/\hat{N}^*)\hat{x}_e^*$ in the long-term). Thus, it is found that the equilibrium of the resource market exists uniquely if and only if $\hat{x}_e^* > 0$, that is, x_e^* of equilibrium in the second stage is positive.

The follow is necessary conditions for $\hat{x}_e^* > 0$ in short- or long-term. In the short-term, considering the sufficient conditions $k^*s^* - k^*s + t^* > 0$ for $\hat{x} > 0$ and $ks^* - ks + t^* > 0$ for $\hat{x}^* + \hat{x}_e^* > 0$, it is found that the condition $ks - k^*s^* - t^* + ak - ak^* > 0$ is necessary for $\hat{x}_e^* > 0$, where

$$\hat{x} = \frac{k(k^*s^* - k^*s + t^*)N}{2\alpha(k - k^*)}, \quad \hat{x}^* + \hat{x}_e^* = \frac{k^{2*}(ks^* - ks + t^*)N^*}{2\alpha^*(k - k^{**})}, \quad \text{and}$$

$$\hat{x}_e^* = \frac{\begin{array}{c} 2bk^2(k^*s^* - k^*s + t^*)(\alpha^*/N^*) + 2bk^{*2}(ks^* - ks + t^*)(\alpha/N) \\ -4\{ks - k^*s^* - t^* + ak - ak^*\}\{(\alpha\alpha^*/NN^*) \end{array}}{-4b(k - k^*)^2(\alpha\alpha^*/NN^*)}.$$

In the long-term, the condition $ks - k^*s^* - t^* + ak - ak^* > 0$ is necessary for $\hat{x}_e^* > 0$, because if $ks - k^*s^* - t^* + ak - ak^* < 0$, that is, $ak^* + k^*s^* > ak + ks - t^* > 0$, then $\hat{x}_e^* < 0$, where

$$\hat{x}_e^* = \frac{\begin{array}{c} (ak + ks - t^*)[(2r\alpha/K)\{bk^{*2}(r^* - 2r^*N^*/K^*) - 2r^*\alpha^*/K^*\}] \\ +(ak + ks)2bkk^*(r^*\alpha^*/K^*)(r - 2rN/K) \\ -t^*2bk^2(r^*\alpha^*/K^*)(r - 2rN/K) \\ -(ak^* + k^*s^*)[(2r\alpha/K)\{bkk^*(r^* - 2r^*N^*/K^*) \\ -2r^*\alpha^*/K^*\} + 2bk^2(r^*\alpha^*/K^*)(r - 2rN/K)] \end{array}}{-4b(k - k^*)^2(\alpha\alpha^*rr^*/KK^*)}.$$

Thus, it is found that the necessary condition for $\hat{x}_e^* > 0$ is $ks - k^*s^* - t^* + ak - ak^* > 0$ in both short- and long-terms.

2. *Derivation of* (16a), (16b), *and* (16c)

The effects of a change in the domestic subsidy s on the extracted resource of the domestic firm x, the export (import) resource of the foreign (domestic) firm x_e^*, and the resource using for a product of foreign firms x^* are given by totally differentiating (15a), (15b), and (15c) with respect to s:

$$\begin{bmatrix} D_{11} & D_{12} & D_{13} \\ D_{21} & D_{22} & D_{23} \\ D_{31} & D_{32} & D_{33} \end{bmatrix} \begin{bmatrix} \partial x/\partial s \\ \partial x_e^*/\partial s \\ \partial x^*/\partial s \end{bmatrix} = \begin{bmatrix} -k \\ -k \\ 0 \end{bmatrix}. \quad \text{(A-1)}$$

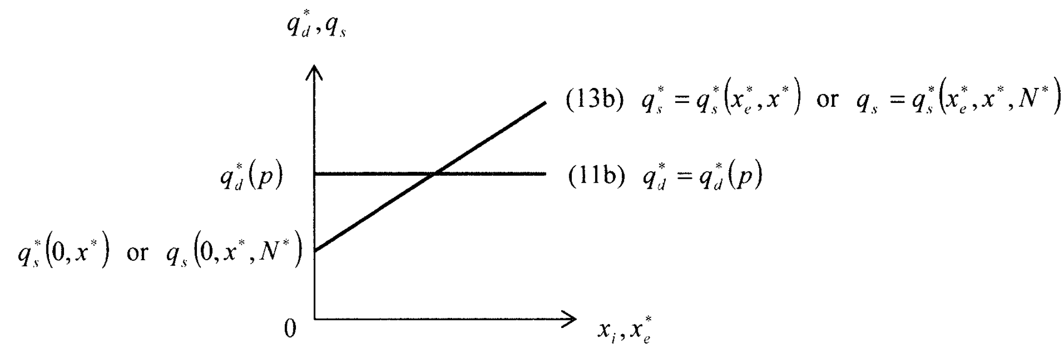

FIGURE A1. The resource market for $\exists x^*$, p or $\exists x^*$, N^*, p.

Solving (A-1) through the application of Cramer's rule, one obtains

$$\frac{\partial x}{\partial s} = \left\{2bkk^*(k - k^*)\frac{\alpha^*}{N^*}\right\}\bigg/ D < 0, \tag{A-2}$$

$$\frac{\partial x_e^*}{\partial s} = \left(- 2bkk^{*2}\frac{\alpha}{N} - 2bk^2k^*\frac{\alpha^*}{N^*} - 4k\frac{\alpha\alpha^*}{NN^*}\right)\bigg/ D > 0, \tag{A-3}$$

$$\frac{\partial x^*}{\partial s} = \left(2bk^2k^*\frac{\alpha}{N} + 2bk^2k^*\frac{\alpha^*}{N^*} + 4k\frac{\alpha\alpha^*}{NN^*}\right)\bigg/ D < 0. \tag{A-4}$$

Using (A-2)–(A-4) and considering that $\partial X^*/\partial s = \partial(x^*+x_e^*)/\partial s$, $\partial y/\partial s = k(\partial x/\partial s)+ k(\partial x_e^*/\partial s)$, and $\partial y^*/\partial s = k^*(\partial x^*/\partial s)$, one can derive (16a).

Similarly, totally differentiating (15a), (15b) and (15c) with respect to s^* and t^* respectively, one can derive

$$\begin{bmatrix} D_{11} & D_{12} & D_{13} \\ D_{21} & D_{22} & D_{23} \\ D_{31} & D_{32} & D_{33} \end{bmatrix} \begin{bmatrix} \partial x/\partial s^* \\ \partial x_e^*/\partial s^* \\ \partial x^*/\partial s^* \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ -k^* \end{bmatrix}, \tag{A-5}$$

and

$$\begin{bmatrix} D_{11} & D_{12} & D_{13} \\ D_{21} & D_{22} & D_{23} \\ D_{31} & D_{32} & D_{33} \end{bmatrix} \begin{bmatrix} \partial x/\partial t^* \\ \partial x_e^*/\partial t^* \\ \partial x^*/\partial t^* \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}. \tag{A-6}$$

Then, solving (A-5) and (A-6) respectively, the following effects of a change in the foreign subsidy s^* and a change in the foreign export tax t^* can be derived:

$$\frac{\partial x}{\partial s^*} = \left\{ - 2bkk^*(k - k^*)\frac{\alpha^*}{N^*}\right\}\bigg/ D > 0, \tag{A-7}$$

$$\frac{\partial x_e^*}{\partial s^*} = \left(2bkk^{*2}\frac{\alpha}{N} + 2bk^2k^*\frac{\alpha^*}{N^*} + 4k^*\frac{\alpha\alpha^*}{NN^*}\right)\bigg/ D < 0, \tag{A-8}$$

$$\frac{\partial x^*}{\partial s^*} = \left(-2bk^2k^*\frac{\alpha}{N} - 2bk^2k^*\frac{\alpha^*}{N^*} - 4k^*\frac{\alpha\alpha^*}{NN^*}\right) \bigg/ D > 0\,, \tag{A-9}$$

and

$$\frac{\partial x}{\partial t^*} = \left\{ -2bk(k-k^*)\frac{\alpha^*}{N^*}\right\} \bigg/ D > 0\,, \tag{A-10}$$

$$\frac{\partial x_e^*}{\partial t^*} = \left(2bk^{*2}\frac{\alpha}{N} + 2bk^2\frac{\alpha^*}{N^*} + 4\frac{\alpha\alpha^*}{NN^*}\right) \bigg/ D < 0\,, \tag{A-11}$$

$$\frac{\partial x^*}{\partial t^*} = \left(-2bkk^*\frac{\alpha}{N} - 2bk^2\frac{\alpha^*}{N^*} - 4\frac{\alpha\alpha^*}{NN^*}\right) \bigg/ D > 0\,. \tag{A-12}$$

Using (A-7)-(A-12), one can derive (16b) and (16c).

3. Derivation of (28a), (28b), *and* (28c)

As in Appendix 2, the effects of a change in the domestic subsidy s, the foreign subsidy s^*, and the foreign export tax t^* on the extracted resource of the domestic firm x, the export (import) resource of the foreign (domestic) firm x_e^*, the resource using for a product of foreign firms x^*, the domestic renewable resource stock N, and the foreign renewable resource stock N^* can be derived:

$$\frac{\partial x}{\partial s} = \left\{ -2bkk^*(k-k^*)\frac{\alpha^* r r^*}{K^*}\left(1 - \frac{2N}{K}\right)\right\} \bigg/ D^L < 0\,, \tag{A-13}$$

$$\frac{\partial x_e^*}{\partial s} = \left\{ 2bk^2k^*\frac{\alpha^* r r^*}{K^*}\left(1 - \frac{2N}{K}\right) + 2bkk^{*2}\frac{\alpha r r^*}{K}\left(1 - \frac{2N^*}{K^*}\right) - 4k\frac{\alpha\alpha^* r r^*}{KK^*}\right\} \bigg/ D^L > 0\,, \tag{A-14}$$

$$\frac{\partial x^*}{\partial s} = \left\{ -2bk^2k^*\frac{\alpha^* r r^*}{K^*}\left(1 - \frac{2N}{K}\right) - 2bk^2k^*\frac{\alpha r r^*}{K}\left(1 - \frac{2N^*}{K^*}\right) + 4k\frac{\alpha\alpha^* r r^*}{KK^*}\right\} \bigg/ D^L < 0\,, \tag{A-15}$$

$$\frac{\partial N}{\partial s} = \left\{ -2bkk^*(k-k^*)\frac{\alpha^* r^*}{K^*}\right\} \bigg/ D^L > 0\,, \tag{A-16}$$

$$\frac{\partial N^*}{\partial s} = \left\{ -2bkk^*(k-k^*)\frac{\alpha r}{K}\right\} \bigg/ D^L > 0\,, \tag{A-17}$$

$$\frac{\partial x}{\partial s^*} = \left\{ 2bkk^*(k-k^*)\frac{\alpha^* r r^*}{K^*}\left(1 - \frac{2N}{K}\right)\right\} \bigg/ D^L > 0\,, \tag{A-18}$$

$$\frac{\partial x_e^*}{\partial s^*} = \Bigg\{ -2bk^2k^*\frac{\alpha^* r r^*}{K^*}\left(1-\frac{2N}{K}\right)$$
$$-2bkk^{*2}\frac{\alpha r r^*}{K}\left(1-\frac{2N^*}{K^*}\right)+4k^*\frac{\alpha\alpha^* r r^*}{KK^*}\Bigg\}\Big/ D^L < 0\,, \qquad \text{(A-19)}$$

$$\frac{\partial x^*}{\partial s^*} = \Bigg\{ 2bk^2k^*\frac{\alpha^* r r^*}{K^*}\left(1-\frac{2N}{K}\right)$$
$$+2bk^2k^*\frac{\alpha r r^*}{K}\left(1-\frac{2N^*}{K^*}\right)-4k^*\frac{\alpha\alpha^* r r^*}{KK^*}\Bigg\}\Big/ D^L > 0\,, \qquad \text{(A-20)}$$

$$\frac{\partial N}{\partial s^*} = \left\{ -2bkk^*(k-k^*)\frac{\alpha^* r^*}{K^*}\right\}\Big/ D^L > 0\,, \qquad \text{(A-21)}$$

$$\frac{\partial N^*}{\partial s^*} = \left\{ 2bkk^*(k-k^*)\frac{\alpha r}{K}\right\}\Big/ D^L < 0\,, \qquad \text{(A-22)}$$

$$\frac{\partial x}{\partial t^*} = \left\{ 2bk(k-k^*)\frac{\alpha^* r r^*}{K^*}\left(1-\frac{2N}{K}\right)\right\}\Big/ D^L > 0\,, \qquad \text{(A-23)}$$

$$\frac{\partial x_e^*}{\partial t^*} = \Bigg\{ -2bk^2\frac{\alpha^* r r^*}{K^*}\left(1-\frac{2N}{K}\right)$$
$$-2bk^{*2}\frac{\alpha r r^*}{K}\left(1-\frac{2N^*}{K^*}\right)+4\frac{\alpha\alpha^* r r^*}{KK^*}\Bigg\}\Big/ D^L < 0\,, \qquad \text{(A-24)}$$

$$\frac{\partial x^*}{\partial t^*} = \Bigg\{ 2bk^2\frac{\alpha^* r r^*}{K^*}\left(1-\frac{2N}{K}\right)$$
$$+2bkk^*\frac{\alpha r r^*}{K}\left(1-\frac{2N^*}{K^*}\right)-4\frac{\alpha\alpha^* r r^*}{KK^*}\Bigg\}\Big/ D^L > 0\,, \qquad \text{(A-25)}$$

$$\frac{\partial N}{\partial t^*} = \left\{ 2bk(k-k^*)\frac{\alpha^* r^*}{K^*}\right\}\Big/ D^L < 0\,, \qquad \text{(A-26)}$$

$$\frac{\partial N^*}{\partial t^*} = \left\{ -2bkk^*(k-k^*)\frac{\alpha r}{K}\right\}\Big/ D^L > 0\,, \qquad \text{(A-27)}$$

where $1 - 2N/K < 0$ and $1 - 2N^*/K^* < 0$, for it is assumed that both countries' renewable resources are under private property rights and hence over-exploitations of renewable resources as in open access equilibrium do not occur. Using (A-13)–(A-27), one can derive (28a), (28b), and (28c).

REFERENCES

Barbier, E. B. and M. Rauscher (1994), "Trade, tropical deforestation and policy interventions", *Environmental and Resource Economics*, **4**, 75–90.

————, N. Bockstael, J. C. Burgess and I. Strand (1995), "The linkages between the timber trade and tropical deforestation - Indonesia", *World Economy*, **18**(3), 411–442.

Brander, J. A. and M. S. Taylor (1997a), "International trade and open-access renewable resources: the small open economy case", *Canadian Journal of Economics*, **30**(3), 526–552.

——— and ——— (1997b), "International trade between consumer and conservationist countries", *Resource and Energy Economics*, **19**, 267–297.

——— and ——— (1998a), "The simple economics of Easter Island: a Ricardo-Malthus model of renewable resource use", *American Economic Review*, **88**(1), 119–138.

——— and ——— (1998b), "Open access renewable resources: Trade and trade policy in a two-country model", *Journal of International Economics*, **44**, 181–209.

Chichilnisky, G. (1991), "Global environment and North-South trade," *Asian Journal of Economics and Social Studies*, **10**, 185–201.

——— (1993), "North-South trade and the dynamics of renewable resources", *Structural Change and Economic Dynamics*, **4**(2), 219–248.

——— (1994), "North-South trade and the global environment", *American Economic Review*, **84**, 851–874.

Clark, C. W. (1990), *Mathematical bioeconomics: The optimal management of renewable resources*, 2nd ed., New York: Wiley.

Fuller, A. T. (1968), "Conditions for a matrix to have only characteristic roots with negative real parts", *Journal of Mathematical Analysis Applications*, **23**, 71–98.

Haener, M. K. and M. K. Luckert (1998), "Forest certification: economic issues and welfare implications", *Canadian Public Policy*, **24**, S83–S94.

Okuguchi, K. (1998), "Long-run fish stock and imperfectly competitive international commercial fishing", *Keio Economic Studies*, **35**(1), 9–17.

Schaefer, M. B. (1957), "Some considerations of population dynamics and economics in relation to the management of marine fisheries", *Journal of the Fisheries Research Board of Canada*, **14**, 635–647.

Schulz, C-E. (1996), "Trade policy and ecology", *Environmental and Resource Economics*, **8**, 15–38.

van Kooten G. C., R. A. Sedjo and E. H. Bulte (1999), " Tropical deforestation: issues and policies", in F. Henk and T. Tietenberg (eds.), *The international yearbook of environmental and resource economics 1999/2000: a survey of current issues*, UK: E. Elgar, 198–249.