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Shared Renewable Resource and International Trade: Technical Measures for Resource Management*

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Shared Renewable Resource and International Trade: Technical Measures for Resource Management

Abstract

We examine trade and strategic interaction between countries that enforce technical measures for resource management which restricts capacity of exploitation to protect an internationally shared renewable resource. The technical measures are common management tools in fisheries (e.g., restrictions on gears, vessels, areas and time). We show that under bilateral resource management, the resource exporting country gains from trade, whereas trade causes steady state utility to fall in the resource importing country because the resource exporting country implements non-cooperative management when the demand for the harvest is not so high. Under sufficiently high demand for the harvest, maximum sustainable yield (MSY) can be attained after trade by what we call cooperative management and both countries are better off. Under low demand for the harvest, trade benefits the resource importing country but may harm the resource exporting country although it implements strict resource management which leads to MSY.

Key words: International trade; Shared renewable resource; Cooperative management

1. Introduction

Renewable resources are prone to be over-exploited when they are internationally shared and traded. Considerable numbers of precious renewable resources are shared or transboundary due to biological conditions and national boundaries. Shared renewable resources refer to fishery resources, wildlife stocks, aquifers and river basin resources that are exploited by two or more countries.¹ The exploitation of shared stocks can only be managed effectively by cooperation between countries concerned. However, management of shared resource stocks is a complicated issue that can generate conflict because property rights over them are hard to define. For example, the empirical studies showed the evidence that shared fisheries stocks are indeed prone to over-exploitation.² Trade in natural resources is a topic of growing importance in international relations (see WTO [24]). For example, the world demand for fish and fishery products has been increasing dramatically in recent years.³ Renewable resources are likely to be over-exploited by international trade because a trade-induced increase in the resource price attracts entry into the resource sector and enhances country's incentive to violate international agreement on resource management. It has significance to clarify the effectiveness of international resource management under international trade.

¹ Even if renewable resources are not in fact shared or transboundary, some renewable resources have similar properties to shared renewable resources when there are biological and spatial interactions between resources. For example, productivity of agriculture and forestry may be reduced by floods, desertification and sand drifting caused by overgrazing and deforestation in adjacent countries.

² The depletion of highly migratory fish stocks such as tuna has been widely recognized in recent years. See, e.g., [1], [25] and [20].

³ According to the Food and Agriculture Organization (FAO), fish and fishery products are highly traded with more than 37% (live weight equivalent) of total production entering international trade. In 2006, world exports reached US\$85.9 billion (62.7% increase on 1996) and 194 countries, including developing countries with weak resource management, reported exports of fish and fishery products.

Typical examples of international resource management are high seas fisheries that are managed by intergovernmental entities called regional fisheries management organizations (RFMOs). In order to achieve sustainable exploitation of the resources, RFMOs are responsible for the conservation and management of various stocks and/or species, which is mandated by the United Nations Convention on the Law of the Sea.⁴ Fisheries resources are managed by various methods. There are output controls (such as the total allowable catch (TAC) and the individual fishing quota (IFQ)), input controls (or effort management) that restricts the total intensity of use of the gear, and technical measures (such as marine protected areas, restrictions on fishing gears, vessel size, engine power, time and a minimum landing size).⁵ Robust monitoring, control, and surveillance are essential for fisheries management to be effective, regardless of the methods (see, e.g., [9] and [10]).

The technical measures are important and basic management tools in fisheries, and they are historically most widely implemented management methods.⁶ There are biological and economic aspects in the technical measures. The technical measures reduce catches of juvenile fish and unintended by-catches species, and they also avoid disrupting the spawning process and conserve ecosystem. Therefore, enforcement of the

⁴ The 1995 UN Fish Stocks Agreement is aimed to facilitate the implementation of certain provisions of the Law of the Sea concerning the conservation and management of straddling fish stocks and highly migratory fish stocks.

⁵ For instance, the International Commission for the Conservation of Atlantic Tunas (ICCAT) applies restrictions against fishing quotas in member nations, minimum allowable catch sizes, time closures, restriction and controls on fishing gears, and protected areas, etc.

⁶ According to FAO [15,16], countries in the Indian Ocean and the Pacific Ocean prefer the use of gear restrictions (such as restrictions on gear type, gear size and vessel size) and the use of spatial restrictions (especially marine protected areas where fishing is prohibited) over other methods for managing marine capture fisheries. See also Chapter 5 of [5], [10] and [14].

technical measures encourages recovery of fisheries resource stocks. Economically, it costs more for fishers to catch a certain quantity of fish under the technical measures than absent such regulations because the technical measures control the catch that can be achieved from a given fishing effort. For example, a marine protected area causes additional effort for fishers to search and catch a certain quantity of fish. Although enforcement of the technical measures are environmentally friendly and economically unfriendly, the empirical studies showed that the technical measures can provide both biological and economic benefits (e.g., [12] and [21]).

The purpose of this paper is to examine international trade and strategic interaction between countries that enforce the technical measures for resource management when those countries share access to a common resource stock. We clarify gains from trade and how trade liberalization affects enforcement of resource management and the level of a shared stock. We also show and interpret the conditions under which countries can implement cooperative management. It is reasonable to assume that countries concerned implement at least the technical measures which are common in the management policy of many fisheries around the world. We can show the effectiveness of the technical measures although management by them is not the first-best policy. Although the technical measures are widely implemented in fisheries, they have not been examined in theoretical models. We assume international open access to extract the essential effects of the technical measures.

We develop a two-country model of international trade when countries enforce technical measures to maximize their steady state utility. We introduce resource management into the model developed by Takarada [22] who initially examined gains from trade under an internationally shared renewable resource. Since this study focused on gains from trade and made no analysis on resource management, we compliment their analysis. To the best of our knowledge, this paper is the first attempt to examine resource management of shared stocks in a general equilibrium model of international trade.

We obtain the following results in this paper. First, when the demand for the harvest is not so high, the resource exporting country implements non-cooperative management and mitigates enforcement level of the technical measures after trade. Although the resource importing country enforces strict management, the shared stock is reduced by trade, which leads to an increase in the price of the harvest. Thus, trade causes steady state utility to fall in the resource importing country and rise in the resource exporting country due to the terms-of-trade effects. More importantly, what we call cooperative management in this paper will be attained when the demand for the harvest is sufficiently high. Both countries implement strict technical measures and the shared stock recovers to maximum sustainable yield (MSY) after trade. Thus, both countries are better off compared with a non-cooperative management case. We find that contrary to conventional wisdom, trade liberalization can control over-exploitation.

Second, under low demand for the harvest, the resource importing country gains from trade. However, trade liberalization may harm the resource exporting country although it implements strict resource management which leads to MSY. Intuitively, strict management makes the harvest price increase excessively after trade in the resource exporting country, and it suffers welfare loss. The price of the resource good decreases after trade in the resource importing country, and it gains from trade.

The existing literature considered optimal resource management in a general equilibrium model of international trade under a common assumption that each country has a renewable resource that can be harvested by residents of that country only. The seminal article by Brander and Taylor [2] showed that a country gains from trade even without resource management when the demand for the resource good is sufficiently high. In this case, the other country with optimal resource management has comparative advantage in the resource sector and exports the harvest. The consumer country without management exports a non-resource good and its local resource stock recovers. Therefore, trade will not cause over-exploitation and higher steady state utility is

achieved in both countries after trade.⁷ The only exception is Bulte and Damania [4] who investigated whether regulatory policies are strategic substitutes or complements when countries share access to a common resource stock and impose optimal taxes on extraction effort. They have not considered gains from trade and how trade affects resource management. This paper compliments these studies.

The rest of the paper is organized as follows. Section 2 sets up the framework of the model. Section 3 is a preliminary analysis of the technical measures. Section 4 considers feasibility of cooperative resource management. Section 5 examines unilateral resource management. The concluding remarks will be provided in Section 6.

2. Basic Model

We present a two-country, two-good model with the shared renewable resource and show the autarkic and trading steady state without resource management. We refer to the countries as “domestic” and “foreign”, which share the renewable resource, and use asterisks to denote foreign variables. The two goods are H , which is the harvest of the shared stock, and M , which we refer to some other good that may be thought of as manufactures.

2.1 Autarkic steady state

The shared renewable stock is subject to competitive exploitation by two countries. We focus on the domestic country first. Production in both sectors is carried out by profit-maximizing firms operating under the condition of free entry. In addition to the shared renewable resource stock S , there is only one other factor of production, labor, L .

The harvesting of the resource is carried out according to the Schaefer harvesting function, $H_S = qSL_H$, where H_S is the supply of the harvest, L_H is the amount of

⁷ See also Chichilnsky [6,7], Emami and Johnston [13], Francis [17], Hotte, Long, and Tian [18], Jinji [19], Taylor [23], and Copeland and Taylor [11].

labor employed in the resource sector, and q reflects the harvesting technology.⁸ The relative price of the resource good, p , must equal unit cost of production, i.e., $p = w/qS$, where w is the wage rate. M is produced with constant returns to scale using labor as the only input (i.e., $M_S = L_M$) and is treated as the numeraire. Since labor is mobile between the two sectors, if M is produced, $w = 1$ must hold. The utility of the country is assumed to be the Cobb-Douglas utility function, $u = H^\beta M^{1-\beta}$, where β is a taste parameter ($0 < \beta < 1$). We assume that the two countries have identical preferences. The demand functions for H and M are $H_D = w\beta L/p$ and $M_D = w(1 - \beta)L$, respectively. Thus, we can solve the outputs of H and M in the temporary equilibrium as $H = q\beta LS$ and $M = (1 - \beta)L$, respectively.

We describe the basic structure of renewable resource growth. The net change of the resource stock S at time t is the nature growth rate $G(S)$ minus the harvest rate H , $dS/dt = G(S) - H$. We use a specific functional form for G given by $G(S) = rS(1 - S/K)$. This functional form for $G(S)$ is the logistic function which is widely used in the analysis of renewable resources. The variable K is the maximum possible size for the resource stock and represents the “carrying capacity” of the resource. The variable r is the “intrinsic” growth rate. Since access to the renewable resource is shared by two countries, the net change of the stock at time t becomes

$$dS/dt = G(S) - H_S - H_S^*. \quad (1)$$

A steady state emerges when the resource growth rate $G(S)$ equals the world harvest of the resource. Solving for the autarkic resource stock yields

$$S_A = K(1 - q\beta L/r - q^*\beta L^*/r). \quad (2)$$

The existence of the autarkic equilibrium is assured if S_A is positive. $S_A > 0$ holds if

⁸ More generally, the harvesting function can be written as $H_S = q(S)L_H$. $q(S)/S$ represents catchability and is constant under the Schaefer equation, i.e., $q(S)/S = q$. The existing literature commonly assumes the Schaefer equation. We may not obtain the following results of this paper under non-constant catchability. See, e.g., Section 8.1 of Clark [8] for discussion on the harvesting function.

and only if

$$r > q\beta L + q^*\beta L^*. \quad (3)$$

Recalling that wage rate equals 1 under diversified production, we can solve for the autarkic price at steady state in each country as follows:

$$p_A = 1/qK(1 - q\beta L/r - q^*\beta L^*/r), \quad p_A^* = 1/q^*K(1 - q\beta L/r - q^*\beta L^*/r). \quad (4)$$

We also can obtain the utility in each country at autarkic steady state:

$$u_A = L[q\beta K(1 - q\beta L/r - q^*\beta L^*/r)]^\beta (1 - \beta)^{1-\beta}, \quad (5)$$

$$u_A^* = L^*[q^*\beta K(1 - q\beta L/r - q^*\beta L^*/r)]^\beta (1 - \beta)^{1-\beta}. \quad (6)$$

2.2 Trading steady state

We consider trade between two countries that share access to a renewable resource. Without the loss of any generality, we assume that the domestic country has lower harvesting technology, which can be expressed by

$$q < q^*. \quad (7)$$

This inequality implies that the domestic country has a higher autarkic relative price of the resource good, and has a comparative disadvantage in producing it.⁹ At the trading steady state, the domestic country exports manufactures, whereas the foreign country exports the resource good. The feature of this model is that the difference in the harvesting technology between countries determines the patterns of trade, which is similar to a standard Ricardian model.¹⁰

There are three production patterns of trading steady state to be considered. First, the domestic country diversifies and the foreign country specializes in the resource good. Second, the domestic country specializes in manufactures, whereas the foreign country specializes in the resource good. Third, the domestic country specializes in

⁹ The relative prices of the two countries are the same in autarky if $q = q^*$. There is no incentive for each country to open to trade.

¹⁰ As in Brander and Taylor [3], an analog of “factor proportions” for the renewable resource determines the patterns of trade when resources are not internationally shared.

manufactures and the foreign country diversifies. Appendix A will show the specific calculations for each pattern. Intuitively, the first pattern occurs when the demand for the harvest good is high, whereas the third pattern arises under low demand for the harvest. The second pattern appears under mild demand for the harvest. In the following sections, we focus our analysis on the first pattern because both countries produce the resource good so that both countries can enforce resource management. The other two patterns will be examined in Section 5.

We explain the trading steady state of the first pattern (see Appendix A.1). Both countries produce the resource good if and only if the following inequality holds:

$$\beta L / (1 - \beta) L^* > q^* / q . \quad (8)$$

In this case, the following result is derived. The post-trade shared renewable resource stock is the same as autarky. Therefore, Eq.(3) must hold to ensure the existence of the equilibrium. Trade liberalization makes no change of steady state utility in the domestic country and causes steady state utility to rise in the foreign country.

Intuition of this result is as follows. Since both countries produce the resource good after trade, the zero-profit condition must be satisfied with interior solutions. If we assume that the resource stock is reduced by trade, the world price of the resource good must be above the domestic autarkic price, which is higher than the foreign autarkic price. However, that world price cannot clear the material balance condition. Thus, the post-trade and autarky resource stock must remain the same, so does the production of the resource good. The welfare effect of each country is quite normal.

3. Preliminary Analysis

We consider the optimal technical measures by either of the two countries although both countries harvest and can enforce resource management. The technical measures restrict capacity of exploitation. This implies that under the strict (weak) technical measures, firms exploit resources as if they are using inferior (superior) harvesting technology. In this paper, enforcement of the technical measures is modeled as

restriction on the harvesting technology. The government's problem is to maximize the steady state utility by setting the optimal harvesting technology. We assume that enforcement of the technical measures is costless for simplicity.¹¹ Moreover, it is assumed throughout this paper that Eq.(7) holds even under resource management. This assumption is necessary for determining the trade pattern. Note that $q < q^*$ has no implication that the domestic country always enforces in fact strict resource management. The difference may only express that the domestic country has inferior harvesting technology.

We focus on the case in which the foreign country implements resource management. When the domestic country enforces the technical measures, the effects of trade are the same as those without resource management. This is because that the domestic utility function remains the same even after opening trade and its government has no incentive to alter its enforcement level.

3.1 Autarkic steady state under resource management

The foreign government enforces the technical measures to maximize the autarkic utility function, Eq.(6). The foreign government's problem can be simplified as

$$\max_{q^* \geq 0} q^*(r - q\beta L - q^*\beta L^*). \quad (9)$$

Solving the maximization problem yields the optimal autarkic harvesting technology,¹²

$$q_A^* = (r - q\beta L)/2\beta L^*. \quad (10)$$

The second-order condition is satisfied.

We can easily obtain the new autarkic steady state as follows:

$$S_A' = K(1 - q\beta L/r)/2, \quad (11)$$

¹¹ The essence of the results in this paper remains valid when enforcement of the technical measures entails certain fixed costs such as fixed labor input.

¹² We can apply the results of Takarada [22] if the level of the optimal technical measures reaches the upper limit of the harvesting technology and a country will not have an incentive to change q after trade.

$$p_A' = 2/qK(1 - q\beta L/r), \quad p_A^{*'} = 4\beta L^*/rK(1 - q\beta L/r)^2, \quad (12)$$

$$u_A' = [(q\beta K/2)(1 - q\beta L/r)]^\beta (1 - \beta)^{1-\beta} L, \quad (13)$$

$$u_A^{*'} = [(rK/4)(1 - q\beta L/r)^2]^\beta \{(1 - \beta)L^*\}^{1-\beta}. \quad (14)$$

We assume $r > q\beta L$, which assures $S_A' > 0$.

3.2 Trading steady state under resource management

Now we consider free trade when the domestic country diversifies and the foreign country specializes in the steady state. To make sure that the foreign country has comparative advantage in the harvest, $q < q_A^*$ must hold. Then, we have

$$r > q\beta(L + 2L^*). \quad (15)$$

Under Eq.(15), $S_A' > 0$ holds. After opening trade, the problem of the foreign government becomes maximizing the post-trade steady state utility u_1^* (see Appendix A.1), which can be simplified as

$$\max_{q^* \geq 0} q^*(r - q\beta L - q^*\beta L^*)^\beta. \quad (16)$$

Then, we obtain the optimal post-trade harvesting technology as

$$q_1^* = (r - q\beta L)/(1 + \beta)\beta L^*. \quad (17)$$

The second-order condition is satisfied. We can derive that $q_1^* > q_A^*$. This implies that the foreign country implements weaker resource management after trade and Eq.(7) is satisfied.

Since both kinds of goods are produced in the domestic country, $w = 1$ must hold. On the other hand, the foreign country only produces the resource good and we have $w^* \geq 1$. The world price of the resource good, p_{T1} , can be written as $p_{T1} = 1/qS_{T1} = w^*/q_1^*S_{T1}$, where S_{T1} is the post-trade shared stock. Thus, we derive $w^* = q_1^*/q > 1$ which implies $r > q\beta[L + (1 + \beta)L^*]$. The demand for manufactures is $M_D = (1 - \beta)L$ in the domestic country and $M_D^* = (1 - \beta)(q_1^*/q)L^*$ in the foreign country. The world supply of manufactures can be expressed as $M_S = L - L_H$. The marker-clearing condition for manufactures is given by $L_H = \beta L - (1 - \beta)(q_1^*/$

$$q)L^* = [q\beta L(1 + \beta^2) - r(1 - \beta)]/q\beta(1 + \beta).$$

We derive the necessary and sufficient condition for this steady state. Since both goods are produced in the domestic country, we must have $0 < L_H < L$ which implies $r < q\beta L(1 + \beta^2)/(1 - \beta)$. This steady state also requires $G(S_{T1}) = qS_{T1}L_H + q_1^*S_{T1}L^*$. Then, we have $S_{T1} = \beta K(1 - q\beta L/r)/(1 + \beta)$ which is positive by Eq.(15). Summing up, we have the necessary condition as follows:

$$q\beta[L + (1 + \beta)L^*] < r < q\beta L(1 + \beta^2)/(1 - \beta). \quad (18)$$

To show sufficiency, from Eq.(18), we obtain $\beta L > (1 - \beta)L^*$. Suppose that the foreign country produces both goods, $\beta L < (1 - \beta)L^*$ must hold (See Appendix A.2). This is contradiction and the foreign country produces only the resource good if $\beta L > (1 - \beta)L^*$. The second inequality of Eq.(18) can be rewritten as $r < 2q\beta L/(1 - \beta)$ because $1 + \beta^2 < 2$. Suppose that the domestic country is also specialized and produces only manufactures, we will show in Section 5.2 that $r \geq 2q\beta L/(1 - \beta)$ must hold. This is contradiction. Hence, Eq.(18) ensures the specialized steady state for the foreign country and diversified steady state for the domestic country.

The shared stock is reduced by trade ($S_{T1} < S_A'$). Intuitively, this is because $q_1^* > q_A^*$. We have $p_{T1} = 1/qS_{T1} > p_A' = 1/qS_A'$ because $S_{T1} < S_A'$. Recall that without resource management, the foreign country gains from trade in this trading steady state. With resource management, the foreign country can choose the optimal harvesting technology. Thus, the foreign country unambiguously gains from trade. However, trade harms the domestic country because the nominal income remains the same after trade. Intuitively, from Eq.(5), we know that the domestic welfare deteriorates if the foreign harvesting technology rises ($\partial u_A/\partial q^* < 0$). This implies that the domestic country is worse off by weak resource management in the foreign country. The analysis above can be summarized in the following proposition.

Proposition 1. *Suppose that only the foreign country enforces the technical measures.*

The trading steady state is diversified for the domestic country and specialized for the foreign country, if and only if $q\beta[L + (1 + \beta)L^*] < r < q\beta L(1 + \beta^2)/(1 - \beta)$. Then, we obtain the following results:

- (i) the foreign country implements weak resource management after trade;
- (ii) the post-trade shared stock is reduced by trade;
- (iii) the foreign country with optimal resource management always gains from trade;
- (iv) the domestic country without resource management is always harmed by trade.

Since trade mitigates enforcement level of the technical measures, trade cannot bring a win-win situation. The domestic country is harmed by trade so that it has an incentive to enforce the technical measures. The case of bilateral resource management is considered in the next section. This result suggests how to modify the enforcement level after trade. We can derive $q_1^*/q_A^* = 2/(1 + \beta)$ which indicates that the foreign government can change the enforcement level optimally if it collects information of preferences. The new enforcement level never exceeds twice of the autarky level.

Now we focus on the transition pass to this trading steady state. Here we assume that the one-off adjustments in the level of the technical measures, the allocation of the labor and the wage rates are instantaneous. Right after trade opens, the foreign country eases the restriction on the technical measures, specializes in the resource good and has a wage rate which is greater than 1. Since the resource stock remains autarky, the foreign resource price becomes $w^*/q_1^*S_A' (= 1/qS_A' = p_A')$ which is higher than the autarkic foreign price ($p_A^* = 1/q_A^*S_A'$). However, the increase in the foreign wage rate not only offsets the rise in the resource price, but also allows the foreign country gains from trade. On the other hand, when trade opens, the domestic country produces both kinds of good. The total income and the resource price of the domestic country remain unchanged, so does the initial domestic utility. Until the steady state explained in Proposition 1 emerges, the resource stock diminishes, which causes the resource price to

increase further, and temporary utilities in both countries to fall.

The production pattern considered in this section will arise when the demand for the harvest is high. This may correspond to the severe overuse case in Brander and Taylor [2] who demonstrated that trade benefits a resource importing country without resource management as well as a resource exporting country with resource management. We show that the resource importing country without resource management is always harmed by trade. Our result may imply that their result is dependent on the assumption of local renewable resources.

4. Bilateral Resource Management

We consider bilateral resource management and clarify whether cooperative management can be achieved. Each country enforces the technical measures to maximize its own welfare, provided a given enforcement level of the technical measures in the other country.¹³

We examine the autarkic equilibrium. Each government solves the maximization problem such as Eq.(9). Then, the reaction functions of the domestic and foreign country are $q = (r - q^*\beta L^*)/2\beta L$ and $q^* = (r - q\beta L)/2\beta L^*$, respectively. Each country's reaction curve has a negative slope.¹⁴ We can easily show that equilibrium is unique and stable. We obtain the optimal autarkic harvesting technology in the domestic and foreign country as follows:

$$q_a = r/3\beta L, \quad q_a^* = r/3\beta L^*. \quad (19)$$

The assumption on the harvesting technology Eq.(7) becomes $q_a < q_a^*$, and it requires

$$L > L^*. \quad (20)$$

¹³ The essence of our results remains valid even if each country sequentially chooses enforcement level of the technical measures.

¹⁴ The technical measures are strategic substitutes in our model. Bulte and Damania [4] showed a similar result that taxes on extraction effort are strategic substitutes under autarky and also in the context of a two-country model.

From Eq.(19), we can obtain the autarkic steady state under bilateral resource management as follows:

$$S_a = K/3, p_a = 9\beta L/rK, p_a^* = 9\beta L^*/rK, \quad (21)$$

$$u_a = (rK/9)^\beta [(1-\beta)L]^{1-\beta}, u_a^* = (rK/9)^\beta [(1-\beta)L^*]^{1-\beta}. \quad (22)$$

These variables may be smaller or larger than those in Eqs.(11)-(14) depending on the value of q . Under bilateral resource management, the difference between u_a and u_a^* only depends on the labor endowment in each country, L and L^* . This arises from the fact that each country harvests the same quantity, $rK/9$, and only the output of manufactures differs between countries. Eq.(19) implies that both countries control over-exploitation in the same way.

4.1 Non-cooperative resource management

We consider a trading equilibrium in which each government chooses the enforcement level simultaneously in order to maximize its own welfare. Without the loss of any generality, we still assume that the domestic country exports manufactures, whereas the foreign country exports the resource good.

Each government sets the optimal harvesting technology to maximize the post-trade utility, u_1 in the domestic country and u_1^* in the foreign country (see Appendix A.1). The reaction function in the domestic and foreign country are denoted by $q = (r - q^*\beta L^*)/2\beta L$ and $q^* = (r - q\beta L)/(1 + \beta)\beta L^*$, respectively. Then, the optimal post-trade harvesting technology for each country is given by

$$q_n = r/(1 + 2\beta)L, q_n^* = r/(1 + 2\beta)\beta L^*. \quad (23)$$

This is what we call “non-cooperative resource management” case. We have $q_n/q_a = 3\beta/(1 + 2\beta) < 1$ and $q_n^*/q_a^* = 3/(1 + 2\beta) > 1$. This implies that the domestic country implements strict management, whereas the foreign country implements weak management after trade. We can also know that the domestic country implements stricter resource management and the foreign country implements weaker resource management if the demand for the harvest becomes low (i.e., a smaller β).

The post-trade resource stock is given by $S_n = \beta K / (1 + 2\beta)$ which is less than S_a . Since the zero profit condition in the resource sector, $p_n q_n S_n = 1$, holds, $p_n = (1 + 2\beta)^2 L / \beta r K$ is the world price of the harvest. Eq.(7) becomes $q_n < q_n^*$, and it requires $\beta L^* < L$ which includes Eq.(20). Diversification for the domestic country requires $0 < L_H < L$. Using a similar method as in Section 3, we can obtain $L_H = L(1 + \beta - 1/\beta)$. Thus, these conditions are rewritten as

$$L^* < L, (\sqrt{5} - 1)/2 < \beta < 1. \quad (24)$$

We assume that $r < 2q\beta L / (1 - \beta)$. Note that this assumption ensures production of the resource good in the domestic country. Under bilateral resource management, the domestic country may choose sufficiently small q which leads to no production of the resource good. We consider how we can exclude such cases. Suppose that the domestic country does not produce the resource good. Then, specialization occurs in both countries and the foreign country chooses the optimal technical measures, $q_3^* = r/2L^*$ (see Section 5.2). From Appendix A.3, we have $S_3 = K/2$, $p_3 = 4w^*L^*/rK$, and $w^* = \beta L / (1 - \beta)L^*$ under $q_3^* = r/2L^*$. If $p_3 q_3 S_3 = 2q\beta L / (1 - \beta)r > 1$, it is profitable for the domestic country to produce the resource good. Hence, the assumption $r < 2q\beta L / (1 - \beta)$ implies that the domestic country chooses a certain level of q that ensures production of the resource good.

Substituting the variables under non-cooperative resource management in u_1 and u_1^* , we obtain the post-trade utility in each country as follows:

$$u_n = [rK\beta^2 / (1 + 2\beta)^2]^\beta [(1 - \beta)L]^{1-\beta}, \quad (25)$$

$$u_n^* = \beta^{2\beta-1} [rK / (1 + 2\beta)^2]^\beta [(1 - \beta)L]^{1-\beta}. \quad (26)$$

It is easy to show that $u_n < u_a$. We know that the foreign country benefits from reduction of the harvesting technology in the domestic country. Thus, the foreign country always gains from trade. Summing up, we obtain the following lemma.

Lemma 1. *Suppose that both countries implement resource management and*

non-cooperative resource management occurs after trade. The conditions for this case are $L^ < L$ and $(\sqrt{5} - 1)/2 < \beta < 1$. Then, we obtain the following results:*

- (i) the foreign country implements weak resource management, whereas the domestic country implements strict resource management after trade;*
- (ii) the post-trade shared stock is reduced by trade;*
- (iii) the foreign country always gains from trade;*
- (iv) the domestic country always suffers utility loss after trade.*

We should note that the domestic country which imports the harvest is worse off after trade even if it implements strict resource management. Recall that trade harms the domestic country when the technical measures are only enforced by the foreign country (Proposition 1). The shared stock is still reduced by trade and the world harvest price increases after trade in the domestic country. This causes welfare loss in the domestic country because its nominal income remains the same as autarky. On the other hand, the foreign country gains from trade because of the rise in the wage rate, i.e., $w_n^* = L/\beta L^* > w_a^* = 1$. Intuitively, the foreign country benefits from setting its technical measures optimally and also from strict resource management by the domestic country.

4.2 Cooperative resource management

We examine the effects of cooperative resource management because each country can improve the other country's welfare by making a marginal decrease in its own post-trade harvesting technology that is realized in the non-cooperative equilibrium. It is not odd to assume that the foreign country has the bargaining power over international resource management because it can benefit from trade even under non-cooperative resource management. Since the domestic country is worse off under non-cooperative management, its government will reach an agreement if the domestic welfare remains at least the same as autarky. Thus, it is reasonable to consider an equilibrium in which the

foreign government maximizes its own welfare while keeping the domestic welfare as same as autarky. From Appendix A.1, the maximization problem is simplified as

$$\begin{aligned} & \max_{q \geq 0, q^* \geq 0} \ln q^* - (1 - \beta) \ln q + \beta \ln(r - q\beta L - q^*\beta L^*) \\ & \text{s. t. } q(r - q\beta L - q^*\beta L^*) \geq Y, \end{aligned} \quad (27)$$

where $Y \equiv q_a(r - q_a\beta L - q_a^*\beta L^*) = r^2/9\beta L$. Solving an interior solution for each country, we obtain

$$q_c = 2r/9\beta L, \quad q_c^* = 5r/18\beta L^*. \quad (28)$$

This is what we call ‘‘cooperative resource management’’ case. We have $q_c/q_a = 2/3$ and $q_c^*/q_a^* = 5/6$, which implies that changes in enforcement level is independent of the parameters.

We derive the conditions for cooperative resource management. The domestic labor employed in the resource sector is denoted by $L_H = (9\beta - 5)L/4$. Note that Eq.(7), $q_c < q_c^*$, is satisfied under Eq.(20). Diversification for the domestic country requires $0 < L_H < L$. These conditions are rewritten as

$$L^* < L, \quad 5/9 < \beta < 1. \quad (29)$$

As in Section 4.1, we assume that $r < 2q\beta L/(1 - \beta)$.

The post-trade resource stock is given by $S_c = K/2$ which is MSY. The world price of the harvest is $p_c = p_a = 9\beta L/rK$ and the foreign demand for the harvest is denoted by $H_D^* = 5rK/36$. Since the domestic nominal income remains the same as autarky, its welfare also remains unchanged. The foreign post-trade utility under cooperative management is denoted by $u_c^* = (5/4)(rK/9)^\beta [(1 - \beta)L]^{1-\beta}$. We can easily show that $u_c^* > u_a^*$. The foreign country gains from trade because of the usual reason. Summing up, we obtain the following lemma (the proof is straightforward).

Lemma 2. *Suppose that both countries implement resource management and cooperative resource management occurs after trade. The conditions for this case are $L^* < L$ and $5/9 < \beta < 1$. Then, we obtain the following results:*

(i) *both countries implement strict resource management after trade;*

- (ii) the post-trade shared stock recovers to MSY after trade;
- (iii) the foreign country always gains from trade;
- (iv) the utility level of the domestic country remains the same as autarky.

Comparing variables under cooperative resource management with those under other cases, we can show that $q_c < q_n < q_a$, $q_c^* < q_a^* < q_n^*$, and $S_n < S_a < S_c$. Under cooperative resource management, both countries implement most strict resource management so that MSY is achieved. Therefore, the world supply of the harvest is the maximum level. This result suggests that contrary to conventional wisdom, trade liberalization can mitigate over-exploitation through cooperative resource management.

4.3 Cooperation or non-cooperation

Now we consider feasibility of cooperative resource management. Comparing the conditions of non-cooperative and cooperative resource management, there exists an overlapped range, i.e.,¹⁵

$$(\sqrt{5} - 1)/2 < \beta < 1. \quad (30)$$

While the domestic country always prefers cooperative management, it is ambiguous whether the foreign country which has the bargaining power prefers cooperative management. From the analysis above, we have

$$u_n^*/u_c^* = (4/5\beta)[3\beta/(1 + 2\beta)]^{2\beta}. \quad (31)$$

We can show that Eq.(31) is strictly decreasing when $(\sqrt{5} - 1)/2 < \beta < 1$. We also find that $\lim_{\beta \rightarrow (\sqrt{5}-1)/2} (u_n^*/u_c^*) > 1$ and $\lim_{\beta \rightarrow 1} (u_n^*/u_c^*) < 1$. Thus, there exists $\tilde{\beta}$ that satisfies $u_n^*/u_c^* = 1$, i.e., $\tilde{\beta} \approx 0.64310$. The foreign country will choose

¹⁵ When $5/9 < \beta < (\sqrt{5} - 1)/2$, there only exists the cooperative equilibrium. In this case, the price of the harvest is too low so that it is beneficial for the foreign country to sustain MSY.

non-cooperative resource management under $(\sqrt{5} - 1)/2 < \beta \leq \tilde{\beta}$ because $u_n^* \geq u_c^*$, whereas the foreign country will cooperate with the domestic country under $\tilde{\beta} < \beta < 1$ because $u_n^* < u_c^*$. Note that the decision by the foreign government only depends on the taste parameter, β .

Then, we obtain the following proposition.

Proposition 2. *Suppose that both countries implement resource management and the conditions $(\sqrt{5} - 1)/2 < \beta < 1$ and $L^* < L$ hold. Then, the foreign country chooses non-cooperative resource management if $(\sqrt{5} - 1)/2 < \beta \leq \tilde{\beta}$. Otherwise, the foreign country implements cooperative resource management.*

When the demand for the resource good is high ($\beta > \tilde{\beta}$), its relative price is also high so that a country can benefit from producing a large amount of the resource good. The terms-of-trade effects are in favor of the resource exporting country and therefore it has an incentive to control over-exploitation and attain MSY. We can show that the quantity of the harvest in the foreign country under cooperation, $H_{Sc}^* = 5rK/36\beta$, is larger than that under non-cooperation, $H_{Sn}^* = rK/(1 + 2\beta)^2$. Therefore, the foreign country benefits much from cooperation. However, when the demand for the harvest is not so high, the harvest price is not high enough for the foreign country to cooperate. The foreign country can be better off by non-cooperative resource management because the foreign country discontinues keeping the welfare level of the domestic country and the domestic country implements strict resource management even under non-cooperation.

Let us consider what happens when trade opens. Under non-cooperative management, the transition pass to the new trading steady state is almost the same as we discussed in Section 3.2. The only difference is that right after trade opens, the initial domestic resource price is higher than autarky ($1/q_n S_a > 1/q_a S_a = p_a$), which causes

the initial domestic non-cooperative utility to fall. As the resource stock diminishes, the non-cooperative resource price rises, and the welfare in the domestic country just gets worse and worse.

Under cooperative management, the initial foreign resource price becomes $w_c^*/q_c^*S_a (= 1/q_c^*S_a)$ which is higher than the autarkic foreign price ($p_a^* = 1/q_a^*S_a$) and also higher than the initial non-cooperative foreign price of the harvest ($w_n^*/q_n^*S_a = 1/q_n^*S_a$). The increase in the foreign wage rate offsets the welfare loss caused by the rise of the resource price, so that the initial foreign cooperative utility rises, but not as high as the non-cooperative situation. The resource stock recovers to MSY as time goes by, which leads to the decline of the resource price and the further increase of the foreign cooperative utility. On the other hand, the initial domestic resource price is also higher than autarky ($1/q_c^*S_a > 1/q_a^*S_a = p_a$), which causes the initial domestic cooperative utility to fall. As the resource stock recovers, the welfare in the domestic country rises to the autarkic level.

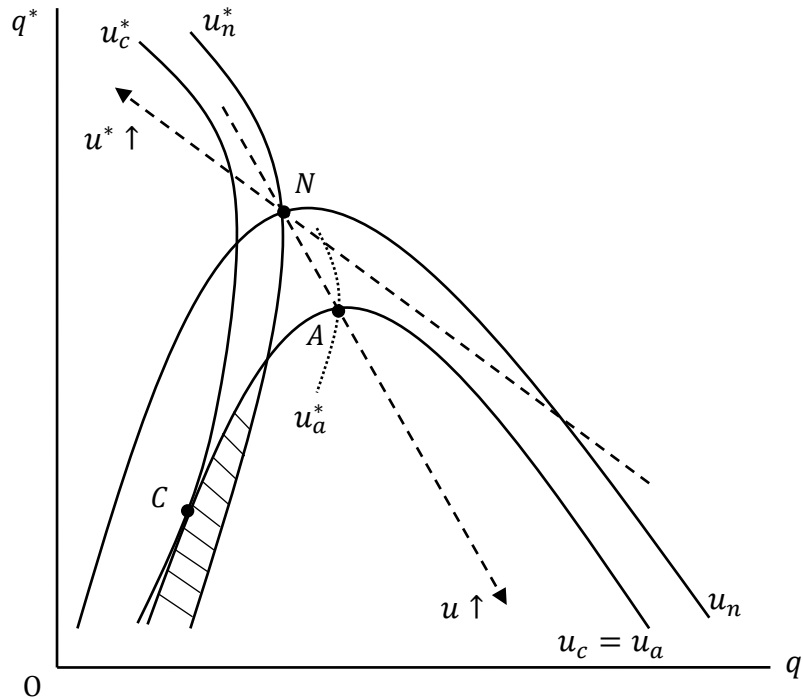


Figure 1 Cooperative resource management

We can depict the iso-utility curves of both countries in the same figure (see Appendix B). Figure 1 shows that the equilibrium will be achieved by implementing cooperative resource management. When bilateral resource management is enforced, the autarkic point is A. When free trade opens, the non-cooperative management point is N where the foreign country gains but the domestic country suffers loss. As a matter of fact, there exists a win-win area (both countries gain from trade) which is marked as a shadow part, if the two countries cooperate with each other. The equilibrium under cooperative resource management case is denoted by point C. Figure 2 shows the equilibrium achieved by implementing non-cooperative resource management. The domestic country can mitigate the welfare loss by trade and the foreign country can benefit more if the two countries work out together (a shadow part). However, the cooperative equilibrium we discussed here (the domestic country does not suffer from trade), point C, will never happen.

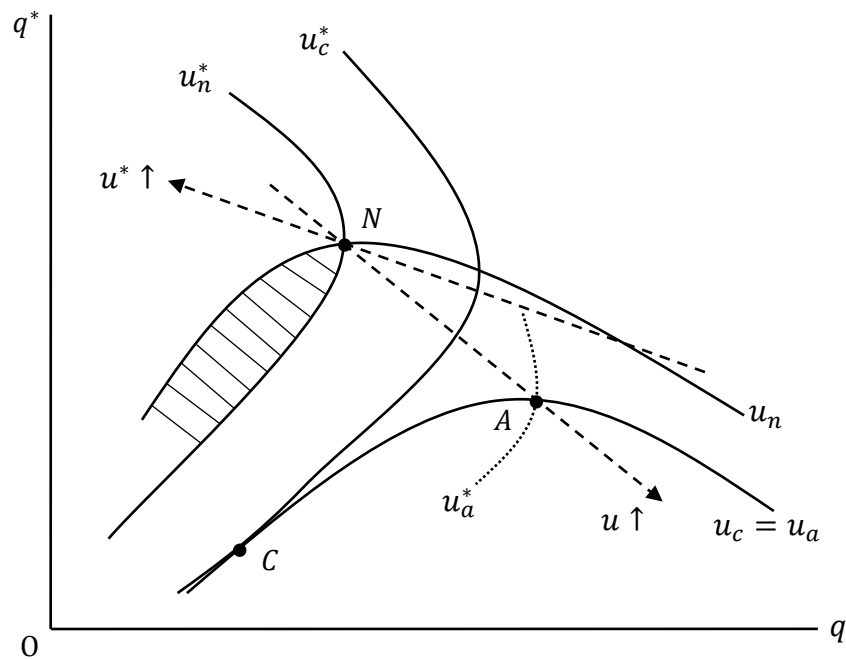


Figure 2 Non-cooperative resource management

5. Unilateral Resource Management

There still left other two trading steady states to be discussed. Since the domestic

country specializes in manufactures at both of these steady states, only the foreign country can enforce the technical measures after trade. We examine the effects of trade when only the foreign country implements resource management in autarky. We may also consider the case of bilateral resource management in autarky as in Section 4 but the effects of trade are ambiguous. Thus, we focus on the autarkic equilibrium which is examined in Section 3.1.

5.1 Specialization only in the domestic country

Without resource management, the pattern of production is specialized for the domestic country and diversified for the foreign country, if and only if $\beta L / (1 - \beta)L^* < 1$ (see Appendix A.2). Intuitively, this production pattern occurs when the demand for the harvest is low. In this case, the shared resource stock is reduced by trade. We assume $r > q^*\beta(L + L^*)$ to make sure the post-trade resource stock to be positive. Free trade may cause the domestic steady state utility, u_2 , fall or rise. On the other hand, the foreign steady state utility is always reduced by trade ($u_2^* < u_A^*$).

Now we consider resource management by the foreign country. The foreign government's problem is to maximize the post-trade steady state utility, u_2^* . This can be simplified as $\max_{q^* \geq 0} q^*[r - q^*\beta(L + L^*)]$. Then, we obtain the optimal post-trade harvesting technology as

$$q_2^* = r / 2\beta(L + L^*). \quad (32)$$

Eq.(7) implies that $r > 2q\beta(L + L^*)$. The necessary and sufficient condition for this steady state is

$$\beta L < (1 - \beta)L^*. \quad (33)$$

Comparing Eq.(10) with Eq.(32), we have $q_2^* < q_A^*$ because $r > 2q\beta(L + L^*)$. Under q_2^* , the shared stock recovers up to MSY. Then, we obtain the following proposition.

Proposition 3. *Suppose that only the foreign country implements resource management, and the domestic country specializes in manufactures and the foreign country diversifies*

after trade. The necessary and sufficient condition for this case is $\beta L < (1 - \beta)L^*$.

Then, we obtain the following results:

- (i) the foreign country implements strict resource management after trade;
- (ii) the shared resource stock recovers to MSY after trade;
- (iii) the domestic country always gains from trade;
- (iv) the foreign country with resource management always suffers utility loss.

Proof: See Appendix C.1.

The foreign country produces both goods and has a wage rate equals to 1 at every point on the transition pass. Right after trade opens, since the resource stock remains autarky and strict resource management is implemented, the resource price rises and the initial utility falls in the foreign country. The resource stock recovers to MSY as time proceeds, which leads to the decreasing of the resource price and the increasing of the temporary utility. However, the steady-state resource price is still higher than foreign autarkic resource price. Thus, the welfare of the foreign country can never reach to its autarky level. Meanwhile, the domestic country specializes in manufactures immediately when trade opens. Since the resource price is lower than autarky, the domestic country gains from trade. As the resource stock recovers, the world price of the resource good falls. Therefore, the domestic welfare gets better and better.

The welfare effects of this trading steady state are striking. Although the level of the shared stock is MSY, the foreign country has to allocate more labor into the resource sector to accomplish the world demand for the resource good due to strict resource management. This leads to the utility loss in the foreign country. On the contrary, Brander and Taylor [2] demonstrated that a country with resource management always gains from trade although MSY is not attained. The shared resource in this case appears to be a local resource because the foreign country is the only country to exploit the shared resource. However, our result is inconsistent with the result under a local resource, which suggests that effectiveness of resource management depends on the

nature of the renewable resource (shared or local resources).

5.2 Specialization in both countries

Without resource management, the pattern of production is specialized for both the domestic and foreign country, if and only if $1 \leq \beta L / (1 - \beta)L^* \leq q^*/q$ (see Appendix A.3). This pattern of production arises under the mild demand for the harvest. In this case, the shared stock is reduced by trade. We assume $r > q^*L^*$ to make sure the post-trade resource stock to be positive. The domestic and foreign steady state utility level may fall or rise after trade.

Under unilateral resource management, the foreign government's problem is to maximize the post-trade steady state utility, u_3^* , which can be simplified as $\max_{q^* \geq 0} q^*(r - q^*L^*)$. The optimal post-trade harvesting technology is given by $q_3^* = r/2L^*$. Eq.(7) implies that $r > 2qL^*$. Then, we obtain the following proposition.

Proposition 4. *Suppose that only the foreign country implements resource management and both countries specialize after trade. The necessary and sufficient condition for this case is $\beta L \geq (1 - \beta)L^*$ and $r \geq 2q\beta L / (1 - \beta)$. Then, we obtain the following results:*

- (i) *the foreign country implements strict resource management after trade;*
- (ii) *the shared resource stock recovers to MSY after trade;*
- (iii) *the domestic country always gains from trade;*
- (iv) *trade may benefit or harm the foreign country with resource management.*

Proof: See Appendix C.2.

This result implies that a win-win situation may occur when the steady state is specialized for both countries, which is similar to the case without resource management. The domestic country experiences gains from trade because of the same reason as in Proposition 3. The foreign country benefits from trade if the increase of the

wage rate covers the welfare loss caused by the rise of the resource price after trade.

6. Concluding Remarks

This paper examines the effects of trade between countries that enforce the technical measures for resource management when those countries share access to a common resource stock. The technical measures restrict over-capacity of exploitation to protect renewable resources. Enforcement of the technical measures is common in fisheries and its concept may be applied to other renewable resources such as aquifers and river basin resources. We make no claim that the present model explains all aspects of the technical measures. The basic insights of our analysis will have relevance as long as the technical measures increase costs to harvest a certain quantity of the resource good.

The main contribution of this paper is to consider resource management of shared renewable stocks in a general equilibrium model of international trade. Analyses of the existing literature are commonly based on partial equilibrium models where prices are given and where there is no factor movement between sectors, and neither explicitly investigate the role of international trade. With consideration of the price effect and factor movement, we obtain striking results.

We show that cooperative resource management will be achieved when the demand for the harvest is sufficiently high without assuming sanctions and side payments. Although enforcement of the technical measures is not the first-best policy, international trade succeeds in conservation of highly valued shared resources. However, under mild demand for the harvest, unfortunately, non-cooperative resource management is realized and trade exacerbates the level of the shared resource stock. We should note that over-exploitation occurs although countries are not myopic and implement robust monitoring, control and surveillance. This result suggests that relatively valuable shared resources are most in jeopardy and countries concerned should establish a close international relationship to protect such shared stocks.

We also demonstrate that under low demand for the harvest, trade liberalization may

harm the resource exporting country with strict resource management which leads to MSY. It appears that the resource exporting country can optimally control over-exploitation because only that country produces the resource good in this case. The result implies that the technical measures fail to fully internalize the negative externalities caused by the shared stock. Since the shared resource is open access, there is no positive profit in the resource sector. This may be the reason why the resource exporting country even with strict technical measures is unlikely to benefit from trade.

A general equilibrium analysis provides important insights and a better understanding of shared resources that cannot be derived in partial equilibrium models. It is important to consider other types of resource management such as output controls in a general equilibrium model when countries or regions share renewable resources. We expect that qualitative features of our results remain valid even under other management tools.

Appendix A: Trade without resource management

In this appendix, we explain the results under three patterns of trading steady state without resource management, which is shown by Takarada [22].

A.1 Harvest in both countries

When the domestic country produces both goods and the foreign country only produces H , we have $w = 1$ and $w^* \geq 1$. The world price of H can be written as $p_1 = 1/(qS_1) = w^*/(q^*S_1)$, where S_1 is the post-trade resource stock. Then, we have $w^* = q^*/q > 1$, $M_D = (1 - \beta)L$, and $M_D^* = (1 - \beta)w^*L^*$.

Since M is only produced in the domestic country, the world supply of M is $M_S = L - L_H$. Therefore, the market-clearing condition for M yields $L_H = \beta L - (1 - \beta)(q^*/q)L^*$. Since H is also produced in the domestic country, we must have $0 < L_H < L$, which leads to $\beta L/(1 - \beta)L^* > q^*/q$. This steady state requires $G(S_1) = qS_1L_H + q^*S_1L^*$. Then, we obtain $S_1 = K(1 - q\beta L/r - q^*\beta L^*/r) = S_A$.

The domestic utility remains the same as autarky,

$$u_1 = L[q\beta K(1 - q\beta L/r - q^*\beta L^*/r)]^\beta (1 - \beta)^{1-\beta} = u_A. \quad (\text{A1})$$

The foreign utility rises after trade and is denoted by

$$u_1^* = L^*(q^*/q)\{\beta qK(1 - q\beta L/r - q^*\beta L^*/r)\}^\beta (1 - \beta)^{1-\beta} = u_A^*(q^*/q). \quad (\text{A2})$$

A.2 Production of manufactures in both countries

When the domestic country only produces M and the foreign country produces both goods, we have $w = w^* = 1$. Then, $M_D = (1 - \beta)L$ and $M_D^* = (1 - \beta)L^*$. The supply of M in each country is given by $M_S = L$ and $M_S^* = L^* - L_H^*$. The material balance condition for M implies that $L_H^* = \beta(L + L^*)$. Since M is also produced in the foreign country, we must have $0 < L_H^* < L^*$, which leads to

$$\beta L / (1 - \beta)L^* < 1. \quad (\text{A3})$$

To show sufficiency, we rewrite Eq.(A3) as $(1 - \beta)(L + L^*) > L$. Wage rates w and w^* cannot be less than 1. Therefore, we have $(1 - \beta)(wL + w^*L^*) > L$. The left hand side, $(1 - \beta)(wL + w^*L^*)$, is the world demand of M , whereas the right hand side, L , is the maximum amount of M that can be produced in the domestic country. This implies that the foreign country also produces a certain amount of M . Hence, Eq.(A3) ensures a diversified steady state for the foreign country.

A steady state requires $G(S_2) = q^*S_2L_H^*$, where S_2 is the post-trade stock. We obtain

$$S_2 = K(1 - q^*\beta L/r - q^*\beta L^*/r). \quad (\text{A4})$$

$S_2 > 0$ holds if and only if $r > q^*\beta(L + L^*)$. $S_2 < S_A$ because $q < q^*$.

The domestic utility after trade can be expressed as

$$u_2 = L[q^*\beta K(1 - q^*\beta L/r - q^*\beta L^*/r)]^\beta (1 - \beta)^{1-\beta}. \quad (\text{A5})$$

We can show that $u_2 > u_A$ if $r > (q + q^*)\beta L + q^*\beta L^*$. The foreign utility falls after trade and is denoted by

$$u_2^* = L^*[q^*\beta K(1 - q^*\beta L/r - q^*\beta L^*/r)]^\beta (1 - \beta)^{1-\beta}. \quad (\text{A6})$$

A.3 Specialization in both countries

When the domestic country specializes in M and the foreign country specializes in H , this steady state requires $G(S_3) = q^*S_3L^*$, where S_3 is the post-trade resource stock. Then, we obtain

$$S_3 = K(1 - q^*L^*/r). \quad (A7)$$

$S_3 > 0$ holds under $r > q^*L^*$.

The wage rate in the foreign country must satisfy $w^* \geq 1$. The world price of H can be written as $p_3 = w^*/q^*S_3$ which cannot exceed the domestic production cost of the resource good $1/qS_3$. Thus, the condition for this steady state is $1 \leq w^* \leq q^*/q$. We obtain $M_D = (1 - \beta)L$ and $M_D^* = (1 - \beta)w^*L^*$. The world supply of M is $M_S = L$. The market-clearing condition implies $w^* = \beta L / (1 - \beta)L^*$. Then, the necessary and sufficient condition becomes $1 \leq \beta L / (1 - \beta)L^* \leq q^*/q$. The domestic and foreign steady state utility may both fall or rise after trade and they are given by

$$u_3 = (1 - \beta)L^{1-\beta} [q^*KL^*(1 - q^*L^*/r)]^\beta, \quad (A8)$$

$$u_3^* = \beta L^{1-\beta} [q^*KL^*(1 - q^*L^*/r)]^\beta. \quad (A9)$$

Appendix B: Iso-utility curves

The domestic post-trade utility, Eq.(A1), can be simplified as

$$v \equiv q(r - q\beta L - q^*\beta L^*), \quad (B1)$$

where v is the domestic utility level. We obtain the iso-utility curve of the domestic country when $v = v_0$ as follows:

$$q^* = (r - q\beta L - v_0/q)/\beta L^*. \quad (B2)$$

Then, we have $dq^*/dq = (v_0q^{-2} - \beta L)/\beta L^*$, and $dq^*/dq = 0$ when $q = \sqrt{v_0/\beta L}$. $d^2q^*/dq^2 < 0$ holds as long as $v_0 > 0$. Thus, the domestic iso-utility curve is concave and has one vertex at $(q, q^*) = (\sqrt{v_0/\beta L}, (r - 2\sqrt{v_0\beta L})/\beta L^*)$ which will always be on the domestic reaction function,

$$q^* = (r - 2q\beta L)/\beta L^*. \quad (B3)$$

Moreover, we can easily know that when q increases, v also increases. Hence, the iso-utility curve will shift down when the domestic welfare is improved.

As for the foreign country, we can simplify the post-trade utility, Eq.(A2), as

$$v^* \equiv \ln q^* - (1 - \beta) \ln q + \beta \ln(r - q\beta L - q^*\beta L^*), \quad (\text{B4})$$

where v^* is the foreign utility level. According to Eq.(B4), we assume that there exists a function $q = f(q^*; v_0^*)$ when $v^* = v_0^*$. Totally differentiating Eq.(B4), we obtain

$$dq/dq^* = (q/q^*)(r - q\beta L - q^*\beta L^* - q^*\beta^2 L^*)[(1 - \beta)(r - q\beta L - q^*\beta L^*) + q\beta^2 L]^{-1}. \quad (\text{B5})$$

$dq/dq^* = 0$ if and only if

$$q^* = (r - q\beta L)/[\beta(1 + \beta)L^*]. \quad (\text{B6})$$

Eq.(B6) is the foreign reaction function. Note that the slope of Eq.(B3) is smaller than that of Eq.(B6). $dq/dq^* > 0$ when $q^* < (r - q\beta L)/[\beta(1 + \beta)L^*]$, and $dq/dq^* < 0$ when $q^* > (r - q\beta L)/[\beta(1 + \beta)L^*]$. Thus, the foreign iso-utility curve is quasi-concave. $v^* = (1 + \beta)[\ln(r - q\beta L) - \ln(1 + \beta)] - (1 - \beta)(\ln q + \ln \beta) - \ln L^*$ holds by replacing q^* , Eq.(B6), in Eq.(B4). The foreign iso-utility curve will shift leftward when its welfare is improved because

$$dv^*/dq = [-r(1 - \beta) - 2q\beta^2 L]/q(r - q\beta L) < 0. \quad (\text{B7})$$

Appendix C: Proofs of propositions

C.1 Proof of Proposition 3

The assumption that foreign country exports H requires $q < q_2^*$ which implies $r > 2q\beta(L + L^*)$. In this production pattern, Eq.(A3) must hold, which is shown in Appendix A.2.

Substituting q_2^* for q^* in Eq.(A4), the post-trade resource stock becomes $S_{T2} = K/2 > S_A'$. The world price of H is $p_{T2} = 1/q_2^* S_{T2} = 4\beta(L + L^*)/rK$. From Eqs.(12) and (B1), we can easily show that $p_A' > p_{T2}$. From Eq.(B1), we have $r/q\beta > 2(L + L^*)$ which implies

$$1 - q\beta L/r > 1 - L/2(L + L^*) = (L + 2L^*)/2(L + L^*). \quad (\text{C1})$$

Then, from Eq.(12), we obtain

$$\begin{aligned} p_{T2}/p_A^* &= [(L + L^*)/L^*](1 - q\beta L/r)^2 \\ &> [(L + L^*)/L^*][(L + 2L^*)/2(L + L^*)]^2 > 1. \end{aligned} \quad (C2)$$

Since the nominal income remains the same as autarky in both countries, trade benefits the domestic country but harms the foreign country.

C.2 Proof of Proposition 4

Substituting q_3^* for q^* in Eq.(A7), the post-trade resource stock becomes $S_{T3} = K/2 > S_A'$. From Appendix A.3, the market clearing condition implies that $w^* = \beta L/(1 - \beta)L^*$. Since the foreign country specializes in H , $w^* \geq 1$ must hold. Then, we have

$$\beta L/(1 - \beta)L^* \geq 1. \quad (C3)$$

The world price of H is $p_{T3} = w^*/q_3^* S_{T3} = 4\beta L/rK(1 - \beta)$. This price cannot exceed the domestic production cost of H , $1/(qS_{T3})$, because the domestic country does not produce H in this trading steady state. Then, we obtain

$$r \geq 2q\beta L/(1 - \beta). \quad (C4)$$

Now we show sufficiency. Eq.(C3) contradicts the condition of diversified steady state for the foreign country, Eq.(A3). Moreover, under $q_3^* = r/2L^*$, Eq.(C4) contradicts the condition of diversified steady state for the domestic country, $\beta L/(1 - \beta)L^* > q^*/q$, which is shown in Appendix A.1. Hence, Eqs.(C3) and (C4) ensure specialized steady state for both countries.

We have $q_A^* - q_3^* = [r(1 - \beta) - q\beta L]/2\beta L^* > 0$ because $r(1 - \beta) - q\beta L > 0$ by Eq.(C4). We can easily derive $p_A' > p_{T3}$ by substituting Eq.(C4) into p_{T3} . Since the domestic nominal income remains the same as autarky, the domestic country always gains from trade. The foreign steady state utility is denoted by $u_{T3}^* = \beta L^{1-\beta} (rK/4)^\beta$. The effect of trade on u_{T3}^* is ambiguous. We can obtain that $u_{T3}^* > u_A'$ if $\beta [L/(1 - \beta)L^*]^{1-\beta} > (1 - q\beta L/r)^{2\beta}$.

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