RIETI Discussion Paper Series 10-E-035

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The Research Institute of Economy, Trade and Industry
http://www.rieti.go.jp/en/

RIETI Discussion Paper Series 10-E-035

June 2010

Shared Renewable Resource and International Trade: Technical measures for fisheries management*

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Abstract

We examine trade and strategic interaction between countries that enforce technical measures for fisheries management (e.g., restrictions on fishing gears, vessels, areas and time) when countries share access to a common resource stock. Although technical measures are important as basic management tools, compliance with such measures makes it more costly for the fishermen to catch a certain quantity of fish. We show that under bilateral management, the resource exporting country gains from trade, whereas trade causes the steady state utility to fall in the resource importing country because the resource exporting country implements non-cooperative resource management when demand for a harvest is not so high. Under sufficiently high demand for a harvest, maximum sustainable yield can be attained after trade by what we call cooperative management; a situation in which both countries are better off. Under low demand for a harvest, trade benefits the resource importing country but may harm the resource exporting country regardless of whether it implements strict resource management or not.

Key words: International trade; Shared fisheries resources; cooperative management

JEL classification: F11; F18; Q22; Q27; Q28

* I gratefully acknowledge constructive comments and suggestions from Masahisa Fujita, Keisaku Higashida, Masayuki Morikawa, Nobuyuki Yagi, Kazuhito Yamashita, and seminar participants at the Research Institute of Economy, Trade and Industry (RIETI). Any remaining errors are my own.

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1. Introduction

Since the rise of the extended fisheries jurisdiction during the 1970s, one of the most pervasive of the fisheries management problems has been the international management of shared fisheries resources. Shared fisheries stocks occur within two or more Exclusive Economic Zones (EEZs) or the maritime boundary of a national jurisdiction and the adjacent high seas.[1] The exploitation of shared stocks can only be managed effectively by cooperation between countries concerned. Typical examples 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. 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. However, shared fisheries resources are more likely to be over-exploited because their management is a complicated issue that can generate conflict. The empirical studies showed the evidence that shared fisheries stocks are indeed prone to over-exploitation (e.g., Armstrong and Sumaila (2001) and McWhinnie (2009)).[2] Cooperative management based on collaboration in research and joint management can bring about positive outcomes.[3] Thus, it is important to consider how international management can be cooperative and effective for conservation of shared stocks.

Recently, the world demand for fish and fishery products has been increasing dramatically. Fisheries 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. According to the Food and

[1] Fisheries resource stocks are internationally shared depending on their relationship to national boundaries as well as their biological conditions. The Food and Agriculture Organization (FAO) uses the term “shared” generically to refer to transboundary, straddling, and highly migratory fish stocks (see, e.g., FAO (2004)).

[2] The depletion of highly migratory fish stocks such as tuna has been widely recognized in recent years. See, for example, WWF (2006).

[3] An example of cooperative management is joint management of resources in the Barents Sea by Norway and Russia. See, for example, Aranda, Murillas, and Motos (2006) and WWF (2008).

Agriculture Organization (FAO)'s the State of World Fisheries and Aquaculture 2008, fish and fishery products are highly traded with more than 37% (live weight equivalent) of total production entering international trade as various food and feed products. 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. It is commonly argued that along with the lack of effective and cooperative management, the depletion of fisheries resource stocks have been expedited by a substantial increase in international trade.[4] Hence, it has significance to clarify the effects of trade on shared stocks and enforcement of international resource management.

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 restrictions on fishing gears, vessel size, engine power, fishing area, time and a minimum landing size). While management of catch directly controls fisheries resources, fishing effort management and technical measures are indirect controls. Robust monitoring, control, and surveillance are essential for fisheries management to be effective, regardless of the methods (see, e.g., Clark (2006) and Cochrane and Garcia (2009)).

The purpose of this paper is to examine international trade and strategic interaction between countries that enforce the technical measures for fisheries 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.

The technical measures are important and basic fisheries management, and they are

[4] For example, bluefin tuna is one of the highly traded fishery resources. Proposals to ban the trade in eastern Atlantic and Mediterranean bluefin tuna have been rejected at the fifteenth meeting of the parties to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in Doha, Qatar, in March 2010, despite evidence that stocks of the fish have fallen below 20% of their historical levels.

historically most widely implemented management tools.[5] There are biological and economic aspects in the technical measures. The technical measures reduce catches of small juvenile fish and unintended by-catches species, and they also avoid disrupting the spawning process and conserve ecosystem. Therefore, enforcement of the technical measures encourages recovery of fisheries resource stocks. Economically, it costs more 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.[6] Although enforcement of the technical measures are basically environmentally friendly but economically unfriendly, the empirical studies showed that the technical measures can provide both biological and economic benefits (e.g., Pawson, Pickett, and Smith (2005) and Diekert, Hjermann, Nævdal, Stenseth (2010)).

We develop a two-country, two-good model in which countries enforce optimal technical measures to maximize their steady state utility. We introduce resource management into the model developed by Takarada (2009) and Takarada, Dong, and Ogawa (2009) who initially examined gains from trade under an internationally shared renewable resource in a general equilibrium model. Since these studies 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, under bilateral resource management, while the resource exporting country gains from trade, trade liberalization may cause steady state utility to fall in the resource importing country. 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

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[5] According to FAO (2007, 2009), 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 Charles (2001), Cochrane and Garcia (2009) and FAO (2002).

[6] For example, restriction on fishing areas (e.g., a marine protected area) cause additional effort for fishers to catch a certain quantity of fish.

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.

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. We should note that MSY is achieved under international trade. Without resource management, Takarada (2009) showed that trade never increases the level of the shared stock. We find that contrary to conventional wisdom, trade liberalization can control over-exploitation. Thus, both countries are better off compared with a non-cooperative management case. This result suggests that the negative externalities caused by shared stocks can be internalized by cooperation when the harvest good becomes valuable.

Second, under low demand for the harvest, the resource importing country gains from trade. We demonstrate a striking result that trade liberalization may harm the resource exporting country although it implements strict resource management which leads to MSY. Intuitively, although the stock recovers to MSY, strict management makes the harvest price increase after trade in the resource exporting country, and it suffers welfare loss. On the other hand, the price of the resource good decreases after trade in the resource importing country, and it gains from trade liberalization.

In this paper, we focus on the technical measures for fisheries management among others because of the following reason. First, the technical measures represent an important and basic toolbox in the management policy of many fisheries around the world. It is reasonable to assume that countries concerned implement at least the technical measures. Second, we can show the effectiveness of the technical measures although management by them is not the first-best policy. It is shown in this paper that the technical measures can control over-exploitation and attain MSY. More importantly, under acceptable conditions, countries implement cooperative management and both countries are better off. The technical measures require not only robust monitoring, control, and surveillance but a clear and precise definition of regulations because a given effort should correspond to a constant ability to harvest fish. We can bear enforcement costs if the technical measures bring welfare improvement. This paper is intended to show the possibility that the technical measures manage shared stocks effectively and achieve Pareto improvement.

The existing literature considered optimal resource management in a general equilibrium model 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 (1997) examined the effects of trade liberalization in a Ricardian type of general equilibrium model when only one country regulates resource harvesting to maximize its steady state utility.[7] Their main result is 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. The authors also showed that a country with resource management always gains from trade regardless of the value of the demand parameter for the harvest. This paper compliments their analysis by considering the case of shared stocks.

The only exception is Bulte and Damania (2005) who developed a general equilibrium model when countries share access to a common resource stock. They investigated whether regulatory policies are strategic substitutes or complements when countries impose taxes on extraction effort in order to maximize their own welfare. The authors have not considered gains from trade and how trade affects resource management because their focus was on strategic interaction between countries.

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.

[7] See also Chichilnsky (1993, 1994), Emami and Johnston (2000), Francis (2005), Hotte et al. (2000), Jinji (2007), Taylor (2009), and Copeland and Taylor (2009).

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. The basic model is based on Takarada (2009). 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 present model is a Ricardian type of general equilibrium model. We focus on the domestic country first. The internationally shared renewable stock is an open-access resource. 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 production function, $H_S = qSL_H$, where H_S is the supply of the harvest. L_H is the amount of labor employed in the resource sector and q reflects the harvesting technology. 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. Good M is produced with constant returns to scale using labor as the only input, i.e., $M_S = L_M$. Good M is treated as the numeraire. Since labor is mobile between the two sectors, if manufactures are 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 good 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 good 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.

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

We use a specific functional form for G given by

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

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. The per-capita growth rate $G(S)/S$ would be approximately equal to r if the current stock is relatively small enough compared with the carrying capacity. The growth rate declines linearly as S increases.

Since access to the renewable resource is shared by two countries, the net change of the stock at time t becomes

$$dS/dt = G(S) - H_S - H_S^*. \tag{3}$$

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

$$S_A = K(1 - q\beta L/r - q^*\beta L^*/r). \tag{4}$$

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

$$r > q\beta L + q^*\beta L^*. \tag{5}$$

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

$$p_A = 1/qK(1 - q\beta L/r - q^*\beta L^*/r),\ p_A^* = 1/qK(1 - q\beta L/r - q^*\beta L^*/r). \tag{6}$$

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

$$u_A = L[q\beta K(1 - q\beta L/r - q^*\beta L^*/r)]^{\beta}(1-\beta)^{1-\beta}, \tag{7}$$

$$u_A^* = L^*[q^*\beta K(1 - q\beta L/r - q^*\beta L^*/r)]^{\beta}(1-\beta)^{1-\beta}. \tag{8}$$

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

$$q < q^*. \tag{9}$$

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.[8] At the trading steady state, the domestic country exports manufactures and imports the resource good, whereas the foreign country exports the resource good and imports manufactures. The feature of a model with the shared resource is that the difference in the harvesting technology between countries determines the patterns of trade, which is similar to a standard Ricardian model.[9]

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 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:

$$\beta L/(1-\beta)L^* > q^*/q\ . \tag{10}$$

In this case, the following result is derived. The post-trade shared renewable resource stock is the same as autarky. Therefore, condition (5) must hold to ensure the existence of the

[8] 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.
[9] As in Brander and Taylor (1998), an analog of "factor proportions" for the renewable resource determines the patterns of trade when resources are not internationally shared.

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. We assume that the government's problem is to maximize the steady state utility by setting the optimal harvesting technology. The technical measures control the catch that can be achieved from a given fishing effort. This implies that under the strict (weak) technical measures, fishers catch fish 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. We assume that enforcement of the technical measures is costless for simplicity. Moreover, it is assumed throughout this paper that Eq.(9) 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 enforces in fact strict resource management. The difference may just arise from the fact that the domestic country has inferior harvesting technology in terms of the technological sense.

We focus on the case in which the foreign country, which exports the harvest, implements resource management. When the domestic country, which exports manufactures, 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 harvesting technology. Therefore, even after trade, the domestic country enforces the optimal technical measures in autarky.

3.1 Autarkic steady state under resource management

The foreign government enforces the technical measures to maximize the autarkic utility function, Eq.(8). The foreign government's problem can be simplified as

$$\max_{q^*\geq 0} q^*(r - q\beta L - q^*\beta L^*). \tag{11}$$

Solving the maximization problem yields the optimal autarkic harvesting technology,

$$q_A^* = (r - q\beta L)/2\beta L^*. \tag{12}$$

The second-order condition is satisfied.

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

$$S_A{}' = K(1 - q\beta L/r)/2, \tag{13}$$

$$p_A{}' = 2/qK(1 - q\beta L/r),\ p_A^{*\prime} = 4\beta L^*/rK(1 - q\beta L/r)^2, \tag{14}$$

$$u_A{}' = [(q\beta K/2)(1 - q\beta L/r)]^\beta (1-\beta)^{1-\beta} L, \tag{15}$$

$$u_A^{*\prime} = [(rK/4)(1 - q\beta L/r)^2]^\beta \{(1-\beta)L^*\}^{1-\beta}\ . \tag{16}$$

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

$$r > q\beta(L + 2L^*). \tag{17}$$

Under Eq.(17), $S_A{}' > 0$ 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

$$\max_{q^*\geq 0} q^*(r - q\beta L - q^*\beta L^*)^\beta. \tag{18}$$

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

$$q_1^* = (r - q\beta L)/(1+\beta)\beta L^*. \tag{19}$$

We can easily show that 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.

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, 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 $MD=1-\beta L$ 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.(17). Summing up, we have the necessary condition as follows:

$$q\beta[L + (1+\beta)L^*] < r < q\beta L(1+\beta^2)/(1-\beta). \tag{20}$$

To show sufficiency, we rewrite Eq.(20) as $q\beta[L + (1+\beta)L^*] < q\beta L(1+\beta^2)/(1-\beta)$, which results in $\beta L > (1-\beta)L^*$. 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 $\beta L > (1-\beta)L^*$. On the other hand, the second inequality of Eq.(20), $r < q\beta L(1+\beta^2)/(1-\beta)$, 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, $r \geq 2q\beta L/(1-\beta)$ must hold (see Appendix B.2). This is contradiction. Hence, Eq.(20) ensures the specialized steady state for the foreign country and diversified steady state for the domestic country.

We can show that the shared stock decreases after 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 even without resource management, the foreign country gains from trade in this trading steady state (see Appendix A.1). 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.(7), 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 the foreign country specializes in the resource good, 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 always suffers utility loss after trade.

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

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 (1997) who examined resource management when each country has a renewable resource that can be harvested by residents of that country only. The authors demonstrated that trade benefits not only a country with resource management, which exports the resource good, but a country without resource management, which imports the resource good, although they considered only the case of diversification in both countries. However, 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. We assume that a country enforces the technical measures to maximize its own welfare, provided a given enforcement level of the technical measures in the other country.

Let us examine the autarkic equilibrium. Each government solves the maximization problem such as Eq.(11). 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. 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:

$$q_a = r/3\beta L,\ q_a^* = r/3\beta L^*. \tag{21}$$

From Eq.(21), we can obtain the autarkic steady state under bilateral resource management as follows:

$$S_a = K/3,\ p_a = 9\beta L/rK,\ p_a^* = 9\beta L^*/rK, \tag{22}$$

$$u_a = (rK/9)^\beta[(1-\beta)L]^{1-\beta},\ u_a^* = (rK/9)^\beta[(1-\beta)L^*]^{1-\beta}. \tag{23}$$

These variables may be smaller or larger than those in Eqs.(13)-(16) 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.(21) implies that both countries control over-exploitation in the same way.

The technical measures are strategic substitutes in our model. Bulte and Damania (2005) showed a similar result that taxes on extraction effort are strategic substitutes under autarky and also in the context of a two-country model, although two countries are diversified in production in their model.

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

$$q_n = r/(1+2\beta)L,\ \ q_n^* = r/(1+2\beta)\beta L^*. \tag{24}$$

This is what we call "non-cooperative resource management" case. We can easily show that $q_n/q_a = 3\beta/(1+2\beta) < 1$ and $q_n^*/q_a^* = 3/(1+2\beta) > 1$. This implies that the domestic country implements strict resource management, whereas the foreign country implements weak resource 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).

We obtain the post-trade resource stock as $S_n = \beta K/(1+2\beta)$ 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. Assumption Eq.(9) becomes $q_n < q_n^*$ and diversification for the domestic country requires $0 < L_H < L$. Using a similar method as in Section 3, we can obtain that $L_H = L(1+\beta-1/\beta)$. Thus, these conditions are rewritten as

$$\beta L^* < L,\ \left(\sqrt{5}-1\right)/2 < \beta < 1. \tag{25}$$

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 $q_3^* = r/2L^*$ (see Appendix B.2). If $p_3 q S_3 > 1$ holds, it is profitable for the domestic country to produce the resource good. Then, we obtain $p_3 q S_3 = 2q\beta L/(1-\beta)r > 1$. 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:

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

$$u_n^* = \beta^{2\beta-1}[rK/(1+2\beta)^2]^\beta[(1-\beta)L]^{1-\beta}. \tag{27}$$

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 $\beta L^* < L$ and $\left(\sqrt{5}-1\right)/2 < \beta < 1$. 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. The result suggests that the negative externalities caused by the shared stock is not fully internalized under non-cooperative resource management.

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 resource management, the domestic government will reach an agreement if its 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

$$\max_{q \geq 0, q^* \geq 0} \ln q^* - (1-\beta)\ln q + \beta \ln(r - q\beta L - q^*\beta L^*)$$
$$\text{s.t. } q(r - q\beta L - q^*\beta L^*) \geq Y, \tag{28}$$

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, the following first-order conditions must be satisfied:

$$-(1-\beta)/q-\beta^2L/(r-q\beta L-q^*\beta L^*)+\nu(r-2q\beta L-q^*\beta L^*)=0, \tag{29}$$

$$1/q^*-\beta^2L^*/(r-q\beta L-q^*\beta L^*)-\nu q\beta L^*=0, \tag{30}$$

$$q(r-q\beta L-q^*\beta L^*)=Y, \tag{31}$$

where ν is a Lagrange multiplier. Then, we obtain

$$q_c=2r/9\beta L,\ q_c^*=5r/18\beta L^*. \tag{32}$$

This is what we call "cooperative resource management" case. We obtain that $q_c/q_a=2/3$ 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 $L_H=(9\beta-5)L/4$. Assumption Eq.(9) becomes $q_c<q_c^*$ and diversification for the domestic country requires $0<L_H<L$. These conditions are rewritten as

$$4L^*<5L,\ 5/9<\beta<1. \tag{33}$$

As in Section 4.1, we assume that $r<2q\beta L/(1-\beta)$. This assumption ensures that the domestic country has a certain harvesting technology and produces the resource good.

We can derive the post-trade resource stock as $S_c=K/2$ 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. We can obtain the post-trade utility under cooperative resource management in the foreign country as

$$u_c^*=(5/4)(rK/9)^\beta[(1-\beta)L]^{1-\beta}. \tag{34}$$

We can easily show $u_c^*>u_a^*$. The foreign country gains from trade because of the usual reason. Summing up, we obtain the following lemma. The proof of Lemma 2 is straightforward.

Lemma 2. *Suppose that both countries implement resource management and cooperative resource management occurs after trade. The conditions for this case are* $4L^*<5L$ *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. Although derivation of MSY may depend on the specific functional forms of the model, the 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.,

$$\left(\sqrt{5}-1\right)/2 < \beta < 1,\ L^*/L < \min\{5/4,\ 1/\beta\}. \tag{35}$$

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

$$u_n^*/u_c^* = (4/5\beta)[3\beta/(1+2\beta)]^{2\beta} \tag{36}$$

We can show that the right hand side of Eq.(36) is strictly decreasing when $\left(\sqrt{5}-1\right)/2 < \beta < 1$. We can also find that $\lim_{\beta\to(\sqrt{5}-1)/2}(u_n^*/u_c^*) > 1$ and $\lim_{\beta\to1}(u_n^*/u_c^*) < 1$. Thus, there exists $\tilde{\beta}$ that satisfies $u_n^*/u_c^* = 1$, i.e., $\tilde{\beta} \approx 0.64310$. The foreign country will choose non-cooperative resource management under $\left(\sqrt{5}-1\right)/2 < \beta \le \tilde{\beta}$ because $u_n^* \ge u_c^*$, 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 $L^*/L < min\{5/4,\ 1/\beta\}$ 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.*

Intuition of this result is as follows. When the demand for the resource good is high ($\beta > \tilde{\beta}$), its relative price is also high so that we can benefit from producing the resource good more. 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 form 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.

We should note that cooperative resource management is feasible without sanctions or side payments by countries concerned. The point is the price effect which plays an important role in a general equilibrium model. The resource exporting country prefers a large quantity of the harvest if the harvest price becomes sufficiently high. This feature also depends on the setting such that the resource exporting country is not myopic and maximizes its steady state utility.

Taking the demand parameter, β, as the horizontal axis and the ratio of labor endowments between countries, L^*/L, as the vertical axis, we can depict the non-cooperative and cooperative resource management areas (see Figure 1). The shadow part is the cooperation area and the shading part is the non-cooperation area. When $5/9 < \beta < (\sqrt{5}-1)/2$, there only exists the cooperative equilibrium. In this case, the price of the harvest is low so that it is beneficial for the foreign country to sustain MSY. There only exists the non-cooperative equilibrium when $L^*/L > 5/4$.

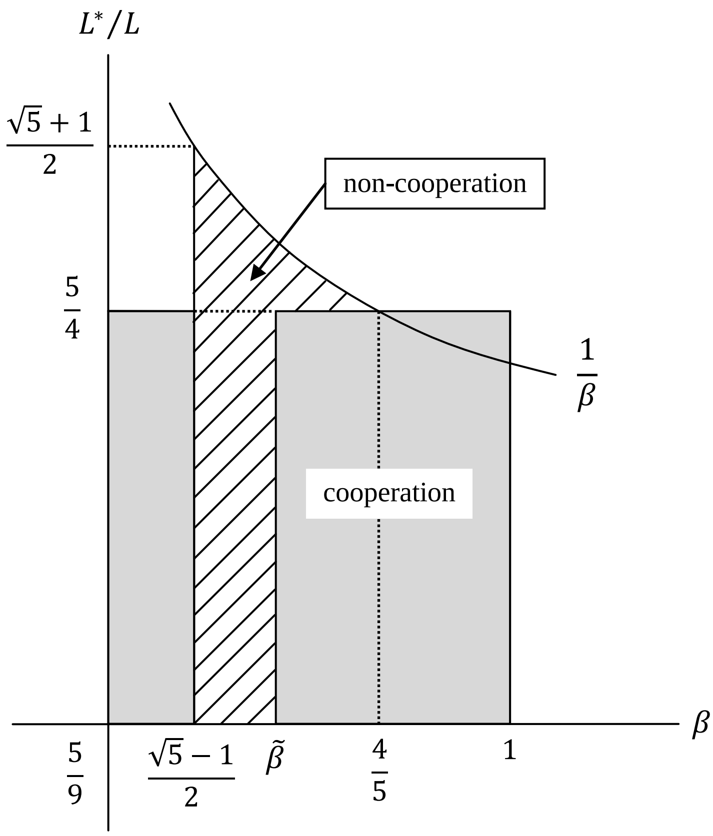

Figure 1 Cooperative and non-cooperative resource management

5. Unilateral Resource Management

There still left other two trading steady states to be discussed. Since the domestic country specializes in producing 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 the technical measures, 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. Resource management is meaningless in the domestic country because it specializes in manufactures. 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

$$q_2^{*} = r/2\beta(L+L^{*}). \tag{37}$$

Assumption Eq.(9) implies that $r > 2q\beta(L+L^{*})$. The necessary and sufficient condition for this steady state is

$$\beta L < (1-\beta)L^{*}. \tag{38}$$

Comparing Eq.(12) with Eq.(37), we have $q_2^{*} < q_A^{*}$ because $r > 2q\beta(L+L^{*})$. This indicates that the foreign country implements strict resource management after trade. 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 B.1.

Intuition of this result is as follows. Although the resource stock recovers to MSY by strict resource management, the harvest price still increases after trade in the foreign country. Since the foreign country produces both kinds of goods, its nominal income remains the same even after trade. Thus, the foreign country suffers utility loss. On the other hand, the harvest price falls after trade in the domestic country. The domestic country experiences gains from trade because of strict resource management by the foreign country.

The welfare effects of this trading steady state are striking. The foreign country, which implements the technical measures, never benefits from trade. Although 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 because of strict resource management. This leads to the utility loss in the foreign country. On the contrary, Brander and Taylor (1997) demonstrated that a country with resource management always gains from trade even if it exports the resource good. Our result suggests that effectiveness of resource management depends on the nature of the renewable resource, i.e., shared or local resources. Takarada (2009) showed that without resource management, trade may cause steady state utility to fall in the resource importing country. However, we show that the resource importing country benefits from trade under resource management by the resource exporting country.

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 welfare effects of free trade are ambiguous for both countries. 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 $\max_{q^* \geq 0} q^*(r - q^* L^*)$. Then, we derive the optimal post-trade harvesting technology as

$$q_3^* = r/2L^*. \tag{39}$$

Assumption Eq.(9) implies that $r > 2qL^*$. From the condition $1 \leq \beta L/(1-\beta)L^* \leq q^*/q$, we obtain

$$\beta L \geq (1-\beta)L^*,\ r \geq 2q\beta L/(1-\beta). \tag{40}$$

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 B.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 experience 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 international trade between countries that enforce the technical measures for fisheries management when those countries share access to a common resource stock. We clarify the possibility of cooperative resource management of the shared stock. The technical measures are basic fisheries management and most widely implemented management tools. Therefore, it is reasonable to consider the technical measures as a method for international management of shared fisheries stocks. In this paper, enforcement of the technical measures is modeled as restriction on the harvesting technology because the technical measures control the catch that can be achieved from a given fishing effort. 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 catch a certain quantity of the harvest.

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 under bilateral resource management, what we call cooperative management will be achieved when the demand for the harvest is sufficiently high. In this high demand case, the price of the harvest is high so that the shared stock is most in jeopardy. However, both countries enforce strict technical measures and the shared stock recovers to MSY after trade. Although enforcement of the technical measures is not the first-best policy, they can internalize the negative externalities caused by over-exploitation of the shared resource stock. This result implies that international trade succeeds in conservation of the shared resource.

Cooperative resource management is realized because the government is not myopic and maximizes its steady state utility, and implements robust monitoring, control and surveillance. Under a high price of the harvest, the resource exporting country prefers keeping a large resource stock to harvest the resource efficiently and to export a large amount of the harvest. On the other hand, the resource importing country wishes to avoid over-exploitation in order to import the harvest with a lower price than absent cooperative resource management. Thus, both countries are better off compared with the non-cooperative management case. 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 suggest that countries concerned should conserve highly valued shared resources in the world market.

We also demonstrate that contrary to conventional wisdom, under low demand for the harvest, trade liberalization may harm the resource exporting country with strict resource management which leads to MSY. Since the shared resource is open access in this paper, there is no positive profit in the resource sector. This may be the reason why a country with strict technical measures is unlikely to experience gains from trade.

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. A general equilibrium analysis provides important insights and a better understanding of shared resources that cannot be derived in partial equilibrium models.

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 (2009).

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 can be expressed as $L_H = \beta L - (1-\beta)(q^*/q)L^*$. 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 must have $w = w^* = 1$. Then, we have $M_D = (1-\beta)L$ 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 $r > q^*\beta(L + L^*)$. We can easily obtain $S_2 < S_A$ 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 $G(S_3) = q^* S_3 L^*$, where S_3 is the post-trade resource stock. Then, we obtain

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

$S_3 > 0$ 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

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

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

Appendix B: Proofs of propositions

B.1 Proof of Proposition 3

The assumption that foreign country exports H requires $q < q_2^*$, which implies

$$r > 2q\beta(L + L^*). \quad \text{(B1)}$$

In this production pattern, Eq.(A.3) 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.(14) and (B1), we can easily show that $p_A' > p_{T2}$. From Eq.(B1), we have $r/q\beta > 2(L + L^*)$, which implies that $1 - q\beta L/r > 1 - L/2(L + L^*) = (L + 2L^*)/2(L + L^*)$. Then, from Eq.(14), we obtain

$$p_{T2}/p_A^{*\prime} = [(L + L^*)/L^*](1 - q\beta L/r)^2$$
$$> [(L + L^*)/L^*][(L + 2L^*)/2(L + L^*)]^2 > 1. \quad \text{(B2)}$$

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

B.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

$$\beta L/(1 - \beta)L^* \geq 1. \quad \text{(B3)}$$

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

$$r \geq 2q\beta L/(1 - \beta). \quad \text{(B4)}$$

Now we show sufficiency. Eq.(B3) contradicts the condition of diversified steady state for the foreign country, Eq.(A3). Moreover, Eq.(B4) 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.(B3) and (B4) ensure specialized steady state for both countries.

Taking the difference between q_A^* and q_3^* yields $q_A^* - q_3^* = [r(1 - \beta) - q\beta L]/2\beta L^*$. From Eq.(B4), we know that $r(1 - \beta) - q\beta L > 0$. Thus, $q_A^* > q_3^*$. We can easily derive $p_A' > p_{T3}$ because of Eq.(B4). Since the domestic nominal income remains the same as autarky, the domestic country always gains from trade. The steady state utility of the foreign country 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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