Discussion Paper No.145 SEP 2024

Trade in environmental permits and technological transfer in a structuralist North-South model

Taro Abe

名古屋学院大学総合研究所
University Research Institute
Nagoya Gakuin University
Nagoya, Aichi, Japan

Trade in environmental permits and technological transfer in a structuralist North–South model

Taro Abe*

Abstract

This paper introduces the Razmi (2016) model, including technology transfers from the postindustrial Global North regarding environmental technologies to the comparatively underdeveloped Global South. We examine the varying impact of regulations and technology transfer policies for greenhouse gas emissions and pollution exports with and without an international permit trading market.

The main conclusions are as follows. With a sufficient international permit trading market, policies that promote technology transfer to the South or reduce pollution exports increase the North–South gap. Such policies reduce the North–South gap without an international emissions trading market. In sum, specific environmental policies and North–South interests differ depending on the presence or absence of an international permit trading market.

Key words: North–South economy, Environmental Macroeconomics, Greenhouse Gases, Emissions, Technology Transfer

JEL Classifications: Q50, F18, O44

1 Introduction

Global warming due to carbon dioxide emissions and other greenhouse gases has become increasingly severe, and environmental macroeconomics, which focuses on macroeconomic sustainability, has flourished. The environment is fundamentally supply-constrained, and few studies initially emerged from the postKeynesian perspective, which emphasizes effective demand. Nonetheless, research has increased recently, and the field of environmental macroeconomics has taken a firm position. Ando (2021) stated that this increase occurred because emphasizing irreversible historical time has highlighted the importance of the postKeynesian approach. Furthermore, sizable effective demand shortfalls are expected as greenhouse gas emissions are curbed, and unrealistic "weak sustainability" expectations of resource and artificial capital substitutability are also anticipated. However, most existing studies apply closed models for a single country.

The conflict between developed countries in the Global North (North) and developing countries in the Global South (South) persists at international conferences on controlling greenhouse gas emissions. While there is a shared recognition of the differentiated responsibilities of North and South, disagreements often arise over specific emission control measures. Conflicts of interest between North and South, how to resolve them, and how to promote cooperation are key to resolving this problem.

Since Taylor (1981), research has been conducted using a structuralist North–South model, which focuses on the structural differences between the North and South. Murshed (1995) introduces a North–South permit trading market for greenhouse gases into an earlier conventional model (Murshed, 1992). He discusses the impact of changes in the emission efficiency of the two regions on the economies of the North and South. In Murshed (1992), price adjustments are made in the South's goods market, and the adjustment variable is the terms of trade. In the Northern goods markets, quantity adjustments are made, and output is the adjustment variable. The main conclusions of this paper are as follows. Emission efficiency in the South tends to decrease the terms of trade in the South while increasing output in the North. Conversely, emission efficiency in the North tends to decrease terms of trade in the South while decreasing output in the North. In other words, the results show that efficiency in the South benefits the North, while emission efficiency in the North does not benefit the South. Based on the above results, additional policies, such as debt cancellation from the North to the South, are needed to bring the South into the emissions trading market. This study is limited to a constant short-term analysis of capital and does not discuss its impact on income distribution, such as wages and profits.

*Nagoya Gakuin University, Department of Economics, e-mail: taro-abe@ngu.ac.jp

Razmi (2016) constructs a structuralist North–South model that considers the long run as capital changes and explicitly impacts income distribution, including wages and profits. The study discusses the impact of emission regulations in the respective North and South on the North–South economy, with and without an international permit market. The main conclusion is that when an international permit market exists, a tradeoff arises between an international distribution and environmental regulation because, under certain conditions, the relative capital stock of the emission-regulated country is reduced[1]. Without an international permit market, tighter emission controls in the North will cause technological progress that reduces emissions in the North to maintain the desired capacity utilization rate. However, because the desired long-term utilization rate remains unchanged, the distributional relationship within the North and South countries remains unchanged. Because the North's economy cannot influence the permit market, emission permit prices also remain unchanged. As a result, the profit rates in North and South remain unchanged, and the capital ratio between North and South is unaffected; thus, there is no impact on international distribution. Conversely, stricter emission controls in the South will increase the price of emission permits, thereby decreasing the South's profit rate and relative capital ratio. The results differ when an international permit market exists. First, tighter emission controls in the North increase the price of emission permits through an international permit market. This situation increases the South's profit rate and capital ratio because of the income transfer from the North to the South through permits trading sales and purchases. In contrast, increasing the price of emission permits promotes technological innovation in the North, which moderates the rise in emission permit costs and reduces the capital ratio in the South. The magnitude of these two effects determines the impact on international distribution. Tighter emission controls in the South have essentially the same result.

The work by Althouse et al. (2020) is based on the Thirlwall (1979) model, representing a homogeneous two-country Keynesian game rather than a structuralist model that assumes a North–South economic asymmetry. The difference is that this approach assumes that the North is primarily responsible for innovations related to environmental technology, which are then transferred to the South. The paper then imposes worldwide greenhouse gas emission constraints and examines the conditions under which sustainable growth is possible. The paper is unique because it assumes technology transfers and pollution exports from the North to the South.

This current paper discusses the impact of North–South greenhouse gas emission regulation. We introduce North-to-South technology transfer and pollution export into the Razmi (2016) model, referencing Althouse et al. (2020). Technology transfer from the North to the South is a promising policy for resolving the North–South conflict over greenhouse gas emission controls. Furthermore, the North may arguably achieve greening by forcing pollution on the South in an ecologically unequal exchange. This argument should be examined in a structuralist North–South model, such as the one presented in this paper.

This paper is organized as follows. Section 2 describes the structure of the model, and Section 3 discusses a case without an international permit market. Section 4 discusses the case with an international permit market, and Section 5 concludes.

2 Structure of the model

This section constructs the model.

First, the production function is assumed to be of the Leontief type as follows.

$$Y_i = min\{\frac{L_i}{a_{Li}}, \frac{K_i}{a_{Ki}}, \frac{E_i}{a_{Ei}}\}; \quad i = N, S \tag{1}$$

Here, Y is production, L is labor, and a_L is labor per one unit of output, K is capital. Furthermore, a_K is capital per one unit of output, E is the annual flow of emission permits, and a_E is emission permits per unit of output. The subscript i denotes N for the North and S for the South. Note that the goods in the North serve as both consumption and investment goods. In contrast, the goods in the South are consumption goods, and capital goods are imported from the North. Both countries also require emission permits per unit of production.

Next, we discuss the demand for consumption in the North. We assume that workers consume all their wages and capitalists put some of their income into savings. Moreover, the government directs all the proceeds from the initial sale of emission permits to consumption. We assume that the spending proportions of workers, capitalists, and the government in the North (concerning their goods) and those in the South are the same. In this case, the demand C_{NN} for goods in the North is

$$C_{NN} = Aq^{\alpha}(1 - s_N\Pi_N)Y_N \tag{2}$$

[1] Dutt (1990) called the decrease in the capital ratio of the South to the North "uneven development." This paper follows this definition for the North–South gap.

Let q be the relative price of goods in the South and Aq^α be the ratio of consumption in the North to goods in the North. Moreover, s_N is the saving rate of capitalists in the North, and Π_N is the profit share of the North.

The North's profit share, Π_N, is as follows.

$$\Pi_N = 1 - \omega_N a_{LN} - q_N^E a_{EN} \tag{3}$$

Here, ω_N represents real wages in the North, and q_N^E represents the relative price of emission permits. Note that both variables are based on goods in the North.

The North's demand, C_{SN}, for the South's good, is as follows.

$$C_{SN} = (1 - Aq^\alpha)(1 - s_N \Pi_N)\frac{Y_N}{q} \tag{4}$$

Workers consume their wages in the South, and capitalists save some of their income. We also assume that the South consumes only their own goods. Thus, the South's consumption C_{SS} of South's goods is as follows.

$$C_{SS} = (1 - s_S \Pi_S) Y_S \tag{5}$$

s_S is the savings rate of capitalists in the South, and Π_S is the South's profit share.

The South's profit share, Π_S, is as follows.

$$\Pi_S = 1 - \bar{\omega}_S a_{LS} - \frac{q_S^E}{q} a_{ES} \tag{6}$$

Here, ω_S represents the real wage in the South, which is constant, assuming abundant surplus labor in the hinterland.

We assume that the North's capital accumulation rate g_N is a positive function of its profit rate $r_N = \frac{\Pi_N Y_N}{K_N}$. Thus, we obtain the following equation.

$$g_N = f(r_N) \tag{7}$$

The South's capital accumulation rate g_S is determined to establish a trade balance equilibrium. The South produces no capital goods and imports capital goods from the North. Thus, we obtain the following equation.

$$g_S = s_S r_S \tag{8}$$

The profit rate r_S in the South is evaluated in terms of goods in the North; therefore, $r_S = \frac{q \Pi_S Y_S}{K_S}$.

Next, the equilibrium conditions for the South's goods market are as follows.

$$Y_S - C_{SS} - C_{SN} = 0 \tag{9}$$

Substituting equation (4)(5) into equation (9), we obtain the following.

$$q_S^S \Pi_S Y_S - (1 - Aq^\alpha)(1 - s_N \Pi_N) Y_N = 0 \tag{10}$$

The goods market equilibrium equation for the North is as follows.

$$Y_N = C_{NN} + g_N K_N + g_S K_S \tag{11}$$

Substituting equations (2)(7) into equation (11), we obtain the following.

$$[1 - Aq^\alpha(1 - s_N \Pi_N)] Y_N - f(\Pi_N \frac{Y_N}{K_N}) K_N - g_S K_S = 0 \tag{12}$$

Using the trade balance equation $g_S K_S = (1 - Aq^\alpha)(1 - s_N \Pi_N) Y_N$, equation (11) can be rewritten as follows.

$$s_N \Pi_N Y_N - f(\Pi_N \frac{Y_N}{K_N}) K_N = 0 \tag{13}$$

Next, we describe the permits trading market. First, emission permits are capped and then used as input in production and as assets for future use. Thus, the emission permits trading market equilibrium can be expressed as follows.

$$\bar{E}_{past} + \bar{E}_{current} - a_{ES} Y_S - a_{EN} Y_N - e_S^d (1 - \frac{q^E}{\bar{q}^E}) = 0 \tag{14}$$

Here, $\bar{E}_{past}$ and $\bar{E}_{current}$ are the limits on the amount of allocated emission permits as past and current limits, respectively. e_S^d is the demand function for emission permits as an asset that can be stored, and $\bar{q}^E$ is the expected long-term trading price of emission permits. The difference between the expected and actual prices affects the demand for emission permits as an asset.

In the following, we consider cases with and without an international permits trading market. Equation (14) represents the case where North and South participate in the international permits trading market. Without an international permits trading market, we assume permit trading occurs in the South; thus, we use the following equation instead of equation (14).

$$\bar{E}_{past} + \bar{E}_{current} - a_{ES}Y_S - e_S^d(1 - \frac{q_S^E}{\bar{q}_S^E}) = 0 \tag{15}$$

In this case, the emission permit price is determined in the South and changes from q^E to q_S^E in equation (15).

3 Act I: No international permit trade

This section considers the case where there is no international permit trade. In this case, the amount of emission permits constrains production in the North, while capital constrains production in the South.

First, we aggregate the equations.

We have the following from equation (10).

$$S(q, \omega_N, q_S^E) \equiv s_S \Pi_S \frac{k}{a_{KS}} - (1 - Aq^\alpha)(1 - s_N \Pi_N)\frac{\bar{e}_N}{q a_{EN}} = 0 \tag{16}$$

We have the following from equation (13).

$$N(q, \omega_N, q_S^E) \equiv s_N \Pi_N \frac{\bar{e}_N}{a_{EN}} - f(\Pi_N \frac{\bar{e}_N}{a_{EN}}) = 0 \tag{17}$$

We have the following from equation (15).

$$E(q, \omega_N, q_S^E) \equiv \bar{e}_{past} + \bar{e}_S - \frac{a_{ES}}{a_{KS}}k - e_S^d(1 - \frac{q_S^E}{\bar{q}_S^E}) = 0 \tag{18}$$

The dynamic equation for the North–South capital ratio is then as follows.

$$\hat{k} = g_S - g_N \tag{19}$$

Furthermore, the dynamic equation for the environmentally conservative innovation in the North is as follows.

$$\hat{a}_{EN} = \eta(\frac{\bar{e}_N}{a_{EN}} - \mu) \tag{20}$$

Here, μ is the desired utilization rate that the firm uses as a benchmark. If this utilization rate is lower than the actual utilization rate, environmentally conservative innovations occur to increase it; the incentive is to surpass environmental constraints.

The following presents the dynamic equation for environmentally conservative innovation in the South.

$$\hat{a}_{ES} = -c - \sigma\frac{a_{ES}}{a_{EN}} + b g_N \tag{21}$$

The formulation of this equation follows Althouse et al. (2020). The first term on the right-hand side represents the South's original capacity for technological innovation. The second term on the right-hand side represents the technological spillover from the North to the South; the larger the North–South technology gap, the greater the spillover effect. The third term on the right-hand side represents the transfer of pollution from the North to the South; as the North's growth rate increases, the South's greenhouse gas emissions per output increase. This situation is referred to as the international rebound effect. Althouse et al. (2020) indicate that increased resource use due to growth in the North increases pollution and resource-intensive (i.e., greenhouse gas emission-intensive) production in other regions. This current paper is new in that it introduces equation (21) into the Razmi (2016) model. That is, a_{ES} is endogenized.

The above model includes eight endogenous variables (q, ω_N, q_S^E, k, a_{EN}, a_{ES}, Π_N and Π_S) and eight equations—(3)(6)(16)–(21). The decision relations are as follows. First, if k, a_{EN}, and a_{ES} take appropriate values, then (18) determines q_S^E. Then, (3) and (18) determine Π_N and ω_N, and (6) and (16) determine Π_S and q. Then, from (19)–(21), k, a_{EN} and a_{ES} move and the model changes.

Table 1 presents the results of the comparative statistics.[2].

Table 1: Comparative statics, Act I

	k	a_{EN}	a_{ES}
e_N	$\pm$	$+$	$+$
e_S	$+$	0	0
c	$+$	0	$-$
σ	$+$	0	$-$
b	$-$	0	$+$

The increase in e_N implies a relaxation of emission restrictions in the North; a_{EN} increases because emissions per output in the North increase accordingly. This situation reduces the technology gap between the North and South, weakening the spillover effect and increasing emissions per output in the South, which increases a_{ES}. The increase in e_N increases the South's profit rate by increasing the North's production and the South's exports. Conversely, increases in a_{EN} and a_{ES} result in higher emission rights costs, which decrease the South's profit rate. Therefore, the impact on k depends on which of these two effects is larger. In Razmi (2016), a_{ES} is unchanged because a_{ES} is not endogenized, and the emissions trading market is not affected; thus, k is unchanged.

The increase in e_S implies a relaxation of emission restrictions in the South, and the emission permit market is correspondingly oversupplied; thus, emission permit prices decrease, the profit rate in the South increases, and k increases. These effects are completed in the South's economy and do not change the North's emissions per output, a_{EN}. Thus, no new technology spillovers or pollution transfers from the North occur; therefore, the South's emissions per output, a_{ES}, remain unchanged.

An increase in c implies an upsurge in the South's technological innovation, which decreases the South's emissions per output a_{ES}. This situation increases k because the South's profit rate increases.

An increase in σ implies a more substantial spillover effect; therefore, the result is the same as an increase in c.

An increase in b implies a transfer of pollution from the North to the South; therefore, the emissions per output a_{ES} in the South increase.

4 Act II: Introducing international trade in permits

This section considers the case of an international permit trading market. First, emission permits are traded internationally; hence, emission permits do not constrain the North's production. We follow Razmi (2016) and assume that the amount of capital constrains the North's production. The North can procure emission permits for production on the international permit trading market.

Emission permits are traded internationally; therefore, the goods market equilibrium equations for the North and South differ slightly from those in the previous section. The goods market equilibrium equation for the South becomes [3].

$$S(q, w_N, q^E) \equiv s_S \Pi_S \frac{k}{a_{KS}} - \frac{(1 - Aq^\alpha)(1 - s_N \Pi_N)}{q a_{KN}} - \frac{Aq^\alpha}{q a_{KN}} q^E \psi = 0 \tag{22}$$

Note that $\psi = a_{EN} - e_N a_{KN}$.

The goods market equilibrium equation for the North is as follows.

$$N(q, w_N, q^E) \equiv \frac{s_N \Pi_N}{a_{KN}} - f\left(\frac{\Pi_N}{a_{KN}}\right) - h = 0 \tag{23}$$

Here, h is the capital account balance valued at the North's capital and is constant.

The equilibrium equation for the permit trading market is as follows.

$$E(q, w_N, q^E) \equiv \bar{e}_{past} + \bar{e}_S + \bar{e}_N - \frac{a_{ES}}{a_{KS}} k - \frac{a_{EN}}{a_{KN}} - e_S^d\left(1 - \frac{q^E}{\bar{q}^E}\right) = 0 \tag{24}$$

[2]See Appendix 1 for the calculation process.

[3]See Appendix 2 for the derivation of this equation.

The dynamic equation for the North–South capital ratio k is as follows.

$$\hat{k} = s_S r_S - f(\frac{\Pi_N}{a_{KN}}) \tag{25}$$

The dynamic equation for the North emission efficiency a_{EN} is as follows.

$$\hat{a}_{EN} = \theta(\Lambda - q^E a_{EN}) \tag{26}$$

Here, Λ is the baseline expected emission cost. Equation (26) shows that as the real emission cost rises, firms increase their emission efficiency to reach the baseline expected emission. Without an international permit trading market, emission permits would constrain production in the North; however, this is no longer the case, and technological progress depends on price factors.

The dynamic equation for the southern emission efficiency a_{ES} is as follows.

$$\hat{a}_{ES} = -c - \sigma\frac{a_{ES}}{a_{EN}} + bf(\frac{\Pi_N}{a_{KN}}) \tag{27}$$

The model is completed with eight endogenous variables (q, ω_N, q^E, k, a_{EN}, a_{ES}, Π_N and Π_S) and eight equations: (3)(6)(22)–(27).

The decision relationship is as follows. First, we assume that k, a_{EN} and a_{ES} take appropriate values. Then, q^E is determined from (24) equation. Therefore, (3) and (23) determine Π_N and ω_N and (6) determines Π_S. Next, q is determined by (22). Then, k, a_{EN} and a_{ES} move from (25)–(27), and the entire model moves.

Table 2 presents the results of the comparative statistics.[4].

Table 2: Comparative statics, Act II

	k	a_{EN}	a_{ES}
e_N	$-$	$+$	$+$
e_S	$\pm$	$+$	$+$
c	$-$	$+$	$-$
σ	$-$	$+$	$-$
b	$+$	$-$	$+$

As e_N increases, the demand for goods in the South decreases as the North pays more emission rights costs to the South, and the terms of trade q in the South decreases. This works to decrease the profit rate in the South. An increase in e_N also means a loosening of the North's emissions constraints, so that the emissions price q^E falls, thereby affecting the South's emissions revenues and the North's incentives for eco-efficient technological progress. These effects also affect the South's profit rate, but we assume that this effect is not very large. This assumption is based on the realistic assumption that the price elasticity of demand for emission permits is quite large. Thus, the effect of reduced terms of trade in the South ultimately outweighs the other effects. As a result, the relative amount of capital in the South also decreases. The decrease in q^E reduces the incentive for emission efficiency in the North and increases the North's per-unit emissions a_{EN}. An increase in a_{EN} reduces the North–South technology gap and weakens spillover effects, thus increasing per-unit emissions a_{ES} in the South.

An increase in e_S decreases the emission permits price, q^E, and the profit rate in the South. In contrast, a decline in q^E reduces the North's incentive for eco-efficient technological progress, increasing the North's per-unit emissions, which; this rise, in turn, increases q^E. This effect also increases the rate of profit in the South. The larger of these two effects determines the impact on k. These results are the same as that of Razmi (2016).

An increase in c leads to a decrease in a_{ES}. Thus, the emission rights price, q^E, decreases since demand in the emissions trading market falls; therefore, k, which represents the relative capital accumulation in the South, also decreases. Decreasing permit prices weakens the incentive for technological progress in the North and increases emissions per unit.

The σ and b results can be interpreted similarly to c.

5 Conclusion

This paper introduced the Razmi (2016) model, including technology transfers from the North regarding environmental technologies in the South. This approach allows us to investigate how the impact

[4]See Appendix 3 for the calculation results.

of tighter emission controls in the North and South differs depending on the presence or absence of an international permits trading market.

If an international permit trading market exists, tighter emission controls in the North, i.e., a decrease in e_N, increases the South's profit rate and relative capital accumulation due to higher the terms of trade q in the South. Conversely, without an international permit trading market, tighter emission controls in the North reduce Northern production, reducing the South's profit rate.

Tighter emission regulations in the South increase emission permit prices; however, an international emission permit trading market increases revenues for the South from the emission permit trading market and higher production costs. Higher emission permit prices also lead to environmental cost-saving technological progress in the North, which decreases the price of emission permits and depresses the South's rate of profit. Thus, the greater of these two effects determines the impact on the South's relative capital accumulation. Without an international permits trading market, the South's relative capital ratio decreases because higher permit prices depress the South's profit rate due to higher production costs. These results are generally the same as those of Razmi (2016).

Improvements in autonomous environmental technology in the South decrease emission permit prices; however, with a sufficiently large international emission permit trading market, the South's rate of relative capital accumulation decreases because revenues from the North decline. Without an international permits trading market, the relative rate of capital accumulation in the South increases because the drop in permit prices reduces the cost of production and increases the rate of profit in the South.

If spillovers from the North proceed with and without an international permits trading market, the results would be the same as if environmental technology in the South were to improve autonomously.

As the South's per-unit greenhouse gas emissions increase, emissions of pollution exports increase the price of emission permits. Then, if a sufficiently large international permits trading market exists, permit revenues from the North to the South increase, and the South's profit rate rises. As a result, the South's relative rate of capital accumulation increases. Conversely, if no international permit trading market exists, the cost of production increases and the rate of profit in the South declines. As a result, the relative rate of capital accumulation in the South increases.

The above results reveal that, with a sufficiently large international permits trading market, policies promoting technological progress in the South and reducing pollution exports increase the North–South gap. In other words, Southern countries may not favor policies that promote emission-saving technological progress and technology transfer from the North to the South or reduce pollution exports in the South. Conversely, without an international permit trading market, such policies may be acceptable to Southern countries, but Northern countries may resist them.

Note that this paper did not consider the case of a small permit trading market to clarify the effect of an international permit trading market. This issue can be addressed in future research.

Appendix 1

We next investigate the Jacobian in the vicinity of equilibrium.

From South's goods market equilibrium equation, the following equation holds.

$$\frac{\partial q}{\partial k} = \frac{-\frac{s_S}{a_{KS}}[(1-\bar{\omega}_S a_{LS})q - q_S^E a_{ES}] + \frac{s_S k a_{ES}}{a_{KS}}\frac{\partial q_S^E}{\partial k}}{s_S(1-\bar{\omega}_S a_{LS})\frac{k}{a_{KS}} + (1-s_N\Pi_N)\frac{\bar{e}_N}{a_{EN}}Aq^{\alpha-1}} < 0 \tag{28}$$

From the permit trading market, the following equation holds.

$$\frac{\partial q_S^E}{\partial k} = \frac{a_{ES}\bar{q}_S^E}{a_{KS}e_S^{d'}} > 0 \tag{29}$$

Therefore, the following equation holds.

$$a_{11} = \frac{s_S}{a_{KS}}[(1-\bar{\omega}_S a_{LS})\frac{\partial q}{\partial k} - a_{ES}\frac{\partial q_S^E}{\partial k}] < 0 \tag{30}$$

From South's goods market equilibrium equation, the following equation holds.

$$\frac{\partial q}{\partial a_{EN}} = -\frac{(1-Aq^{\alpha})\bar{e}_N[s_N a_{LN}\frac{1-\omega_N a_{LN}}{a_{EN}a_{LN}} + 1 - s_N(1-\omega_N a_{LN})]}{(a_{EN})^2[s_S(1-\bar{\omega}_S a_{LS})\frac{k}{a_{KS}} + (1-s_N\Pi_N)\frac{\bar{e}_N}{a_{EN}}Aq^{\alpha-1}]} < 0 \tag{31}$$

Therefore, the following equation holds.

$$a_{12} = \frac{s_S}{a_{KS}}(1-\bar{\omega}_S a_{LS})\frac{\partial q}{\partial a_{EN}} < 0 \tag{32}$$

From South's goods market equilibrium equation, the following equation holds.

$$\frac{\partial q}{\partial a_{ES}} = \frac{\frac{s_S k}{a_{KS}}(a_{ES}\frac{\partial q_S^E}{\partial a_{ES}} - q_S^E)}{s_S(1-\bar{\omega}_S a_{LS})\frac{k}{a_{KS}} + (1-s_N\Pi_N)\frac{\bar{e}_N}{a_{EN}}Aq^{\alpha-1}} < 0 \tag{33}$$

From the permit trading market, the following equation holds

$$\frac{\partial q_S^E}{\partial a_{ES}} = \frac{k\bar{q}_S^E}{a_{KS}e_S^{d'}} > 0 \tag{34}$$

Therefore, the following equation holds.

$$a_{13} = \frac{s_S}{a_{KS}}(1-\bar{\omega}_S a_{LS})\frac{\partial q}{\partial a_{ES}} - \frac{s_S}{a_{KS}}(\frac{\partial q_S^E}{\partial a_{ES}}a_{ES} + q_S^E) < 0 \tag{35}$$

$$a_{21} = 0 \tag{36}$$

$$a_{22} = -\eta\frac{\bar{e}_N}{a_{EN}^2} < 0 \tag{37}$$

$$a_{23} = 0 \tag{38}$$

$$a_{31} = 0 \tag{39}$$

$$a_{32} = \frac{\sigma a_{ES}}{(a_{EN})^2} > 0 \tag{40}$$

$$a_{33} = -\frac{\sigma}{a_{EN}} < 0 \tag{41}$$

Next, we consider the stability conditions.

$$a_{11} + a_{22} + a_{33} < 0 \tag{42}$$

$$\begin{vmatrix} a_{11} & a_{12} \\ a_{22} & a_{23} \end{vmatrix} + \begin{vmatrix} a_{11} & a_{13} \\ a_{31} & a_{33} \end{vmatrix} + \begin{vmatrix} a_{22} & a_{23} \\ a_{32} & a_{33} \end{vmatrix} = a_{11}a_{22} + a_{11}a_{33} + a_{22}a_{33} > 0 \tag{43}$$

$$|det| = a_{11}a_{22}a_{33} < 0 \tag{44}$$

Therefore, the stability condition is satisfied.

Comparative statics of e_N

From South's goods market equilibrium equation, the following equation holds.

$$\frac{\partial q}{\partial e_N} = \frac{\frac{1-Aq^{\alpha}}{a_{EN}}(1-s_N\Pi_N)}{s_S(1-\bar{\omega}_S a_{LS})\frac{k}{a_{KS}} + (1-s_N\Pi_N)\frac{\bar{e}_N}{a_{EN}}Aq^{\alpha-1}} > 0 \tag{45}$$

Therefore, the following equation holds.

$$b_1 = -\frac{s_S}{a_{KS}}(1-\omega_S a_{LS})\frac{\partial q}{\partial e_N} < 0 \tag{46}$$

$$b_2 = -\frac{\eta}{a_{EN}} \tag{47}$$

$$b_3 = 0 \tag{48}$$

$$\frac{dk}{de_N} = \frac{\begin{vmatrix} b_1 & a_{12} & a_{13} \\ b_2 & a_{22} & 0 \\ 0 & a_{32} & a_{33} \end{vmatrix}}{|det|} = \frac{b_1a_{22}a_{33} + b_1a_{13}a_{32} - b_2a_{12}a_{33}}{|det|} \tag{49}$$

$$\frac{da_{EN}}{de_N} = \frac{\begin{vmatrix} a_{11} & b_1 & a_{13} \\ 0 & b_2 & 0 \\ 0 & 0 & a_{33} \end{vmatrix}}{|det|} = \frac{a_{11}b_2a_{33}}{|det|} > 0 \tag{50}$$

$$\frac{da_{ES}}{de_N} = \frac{\begin{vmatrix} a_{11} & a_{12} & b_1 \\ 0 & a_{22} & b_2 \\ 0 & a_{32} & 0 \end{vmatrix}}{|det|} = \frac{-a_{11}b_2a_{32}}{|det|} > 0 \tag{51}$$

Comparative statics of e_S

$$c_1 = -\frac{\frac{s_S}{a_{KS}}\frac{a_{ES}\bar{q}_S^E}{e_S^{d'}}(1 - s_N\Pi_N)\frac{\bar{e}_N}{a_{EN}}Aq^{\alpha-1}}{S_q} < 0 \tag{52}$$

$$S_q = s_S(1 - \bar{\omega}_S a_{LS})\frac{k}{a_{KS}} + (1 - s_N\Pi_N)\frac{\bar{e}_N}{a_{EN}}Aq^{\alpha-1} > 0 \tag{53}$$

$$c_2 = 0 \tag{54}$$

$$c_3 = 0 \tag{55}$$

$$\frac{dk}{de_S} = \frac{\begin{vmatrix} c_1 & a_{12} & a_{13} \\ 0 & a_{22} & 0 \\ 0 & a_{32} & a_{33} \end{vmatrix}}{|det|} = \frac{c_1a_{22}a_{33}}{|det|} > 0 \tag{56}$$

$$\frac{da_{EN}}{de_S} = 0 \tag{57}$$

$$\frac{a_{ES}}{de_S} = 0 \tag{58}$$

Comparative statics of c

$$d_1 = 0, d_2 = 0, d_3 = 1 \tag{59}$$

$$\frac{dk}{dc} = \frac{\begin{vmatrix} 0 & a_{12} & a_{13} \\ 0 & a_{22} & 0 \\ 1 & a_{32} & a_{33} \end{vmatrix}}{|det|} = -\frac{a_{22}a_{13}}{|det|} > 0 \tag{60}$$

$$\frac{da_{EN}}{dc} = \frac{\begin{vmatrix} a_{11} & 0 & a_{13} \\ 0 & 0 & 0 \\ 0 & 1 & a_{33} \end{vmatrix}}{|det|} = 0 \tag{61}$$

$$\frac{da_{ES}}{dc} = \frac{\begin{vmatrix} a_{11} & a_{12} & 0 \\ 0 & a_{22} & 0 \\ 0 & a_{32} & 1 \end{vmatrix}}{|det|} = \frac{a_{11}a_{22}}{|det|} < 0 \tag{62}$$

Comparative statics of σ
It is basically the same as the comparative statics of c.

Comparative statics of b
The comparative statics of c and σ are the same, except that the signs are opposite.

Appendix 2

First, the goods market in the South can be written as follows.

$$qY_S = (1-s_S\Pi_S)qY_S + Y_Nq^E(E_N - \bar{E}_N) + (1-Aq^\alpha)(1-s_N\Pi_N)Y_N - (1-Aq^\alpha)Y_Nq^E(E_N - \bar{E}_N) \tag{63}$$

The first term on the right-hand side of equation (63) is the South's demand for the consumption of goods. The second term on the right-hand side is the expenditure by the South's government on goods. In other words, the South's expenditure on goods directs emission permit payments from the

North to the South's government. The third term on the right-hand side is the North's demand for goods in the South. The fourth term on the right-hand side represents the reduced demand for goods in the South due to permit payments from the North to the South's government.

Transforming equation (63), we obtain the following.

$$s_S \Pi_S Y_S - \frac{(1-Aq^{\alpha})(1-s_N\Pi_N)}{q} Y_N - \frac{Aq^{\alpha}}{q} Y_N q^E \left(\frac{E_N}{Y_N} - \frac{\bar{E}_N}{Y_N}\right) = 0 \tag{64}$$

Dividing both sides of this equation by K_N, we obtain equation (22).

Appendix 3

From the balance of payments equilibrium equation, we obtain $s_S r_S = \frac{(1-Aq^{\alpha})(1-s_N\Pi_N)+Aq^{\alpha}q^E\psi}{a_{KN}k}$. In the following, we use this equation to find the Jacobian in the neighborhood of the equilibrium value.

$$b_{11} = \frac{1}{a_{KN}k^2}\{[A\alpha q^{\alpha-1}(q^E\psi - 1 + s_N\Pi_N)\frac{dq}{dk} + Aq^{\alpha}\psi\frac{dq^E}{dk}]k - (1-Aq^{\alpha})(1-s_N\Pi_N) - Aq^{\alpha}q^E\psi\} \tag{65}$$

$$\frac{dq}{dk} = \frac{-\frac{s_S\Pi_S}{a_{KS}} + [\frac{s_S k a_{ES}}{a_{KS}q} + \frac{Aq^{\alpha}\psi}{q a_{KN}}]\frac{dq^E}{dk}}{S_q} \tag{66}$$

$$S_q = \frac{1}{q^2}\{s_S q^E k\frac{a_{ES}}{a_{KS}} + (1-s_N\Pi_N)\frac{1-(1-\alpha)Aq^{\alpha}}{a_{KN}} + \frac{(1-\alpha)q^E Aq^{\alpha}\psi}{a_{KN}}\} > 0 \tag{67}$$

$$\frac{dq^E}{dk} = \frac{a_{ES}\bar{q}^E}{a_{KS}e_S^{d'}} \tag{68}$$

Assume that the price elasticity of demand for emission permits $e_S^{d'}$ is relatively large and the value of $\frac{dq^E}{dk}$ is negligibly small. We also assume sufficient permit trading and that $q^E\psi - 1 + s_N\Pi_N > 0$. Thus, $\frac{dq}{dk} < 0$ and $b_{11} < 0$. The above assumptions are also used in the following calculations.

$$b_{12} = \frac{1}{a_{KN}k}[A\alpha q^{\alpha-1}(q^E\psi - 1 + s_N\Pi_N)\frac{dq}{da_{EN}} + Aq^{\alpha}\psi]\frac{dq^E}{da_{EN}} > 0 \tag{69}$$

$$\frac{dq^E}{da_{EN}} = \frac{\bar{q}^E}{a_{KN}e_S^{d'}} > 0 \tag{70}$$

$$\frac{dq}{da_{EN}} = \frac{(\frac{s_S k a_{ES}}{a_{KS}q} + \frac{Aq^{\alpha}\psi}{q a_{KN}})\frac{dq^E}{da_{EN}}}{S_q} > 0 \tag{71}$$

$$b_{13} = \frac{1}{a_{KN}k}[A\alpha q^{\alpha-1}(q^E\psi - 1 + s_N\Pi_N)\frac{dq}{da_{ES}} + Aq^{\alpha}\psi]\frac{dq^E}{da_{ES}} > 0 \tag{72}$$

$$\frac{dq^E}{da_{ES}} = \frac{k\bar{q}^E}{a_{KS}e_S^{d'}} > 0 \tag{73}$$

$$\frac{dq}{da_{ES}} = \frac{(\frac{s_S k a_{ES}}{a_{KS}q} + \frac{Aq^{\alpha}\psi}{q a_{KN}})\frac{dq^E}{da_{ES}}}{S_q} > 0 \tag{74}$$

$$b_{21} = -\theta a_{EN}\frac{dq^E}{dk} < 0 \tag{75}$$

$$b_{22} = -\theta(a_{EN}\frac{dq^E}{da_{EN}} + q^E) < 0 \tag{76}$$

$$b_{23} = -\theta a_{EN}\frac{dq^E}{da_{ES}} < 0 \tag{77}$$

$$b_{31} = 0 \tag{78}$$

$$b_{32} = \frac{\sigma a_{ES}}{(a_{EN})^2} > 0 \tag{79}$$

$$b_{33} = -\frac{\sigma}{a_{EN}} < 0 \tag{80}$$

Thus, the following stability conditions hold in the neighborhood of the equilibrium value.

$$b_{11}+b_{22}+b_{33}<0 \tag{81}$$

$$\begin{vmatrix} b_{11} & b_{12} \\ b_{22} & b_{23} \end{vmatrix} + \begin{vmatrix} b_{11} & b_{13} \\ b_{31} & b_{33} \end{vmatrix} + \begin{vmatrix} b_{22} & b_{23} \\ b_{32} & b_{33} \end{vmatrix} = b_{11}b_{23}-b_{12}b_{22}+b_{11}b_{33}+b_{22}b_{33}-b_{23}b_{32}>0 \tag{82}$$

$$|det|= \begin{vmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{vmatrix} = b_{11}b_{22}b_{33}+b_{21}b_{32}b_{13}-b_{11}b_{23}b_{32}-b_{12}b_{21}b_{33}<0 \tag{83}$$

Comparative statics of e_N

From South ' s goods market equilibrium equation, the following equation holds.

$$\frac{dq}{de_N}=\frac{(\frac{s_S k a_{ES}}{a_{KS}q}+\frac{Aq^\alpha \psi}{q a_{KN}})\frac{dq^E}{de_N}-\frac{Aq^\alpha q^E}{q}}{S_q}<0 \tag{84}$$

From the permits trading market, the following equation holds

$$\frac{dq^E}{de_N}=-\frac{\bar{q}^E}{e_S^{d'}}<0 \tag{85}$$

Thus, the sign of the following equation is determined.

$$c_1'=-\frac{d(s_S r_S)}{de_N}=-\frac{1}{a_{KN}k}[(q^E\psi-1+s_N\Pi_N)A\alpha q^{\alpha-1}\frac{dq}{de_N}+Aq^\alpha\psi\frac{dq^E}{de_N}-Aq^\alpha q^E a_{KN}]>0 \tag{86}$$

$$c_2'=\theta a_{EN}\frac{dq^E}{de_N}<0 \tag{87}$$

$$c_3'=0 \tag{88}$$

$$\frac{dk}{de_N}=\frac{\begin{vmatrix} c_1' & b_{12} & b_{13} \\ c_2' & b_{22} & b_{23} \\ 0 & b_{32} & b_{33} \end{vmatrix}}{|det|}=\frac{c_1'(b_{22}b_{33}-b_{23}b_{32})+c_2'(b_{13}b_{32}-b_{12}b_{33})}{|det|} \tag{89}$$

$$\begin{aligned} c_1'(b_{22}b_{33}-b_{23}b_{32})+c_2'(b_{13}b_{32}-b_{12}b_{33}) &= -\frac{1}{a_{KN}k}[A\alpha q^{\alpha-1}(q^E\psi-1+s_N\Pi_N)\times \\ \frac{(\frac{s_S k a_{ES}}{a_{KS}q}+\frac{Aq^\alpha\psi}{q a_{KN}})\frac{dq^E}{de_N}-\frac{Aq^\alpha q^E}{q}}{S_q} &+ Aq^\alpha\psi\frac{dq^E}{de_N}-Aq^\alpha\bar{q}^E a_{KN}]\frac{\theta\sigma}{a_{EN}}(a_{EN}\frac{dq^E}{da_{EN}}+q^E+a_{ES}\frac{dq^E}{da_{ES}}) \\ +\theta a_{EN}\frac{dq^E}{de_N}\frac{\sigma}{a_{KN}k a_{EN}}(\frac{a_{ES}}{a_{EN}}+1)[A\alpha q^{\alpha-1}(q^E\psi-1+s_N\Pi_N) &\frac{(\frac{s_S k a_{ES}}{a_{KS}q}+\frac{Aq^\alpha\psi}{q a_{KN}})\frac{dq^E}{da_{EN}}}{S_q}+Aq^\alpha\psi\frac{dq^E}{da_{EN}}] \end{aligned} \tag{90}$$

Here, assuming that the price elasticity of GHG permits trading as an asset is relatively large, the effects of $\frac{dq^E}{de_N}$, $\frac{dq^E}{da_{EN}}$, and $\frac{dq^E}{da_{ES}}$ can be ignored. Therefore, $c_1'(b_{22}b_{33}-b_{23}b_{32})+c_2'(b_{13}b_{32}-b_{12}b_{33})>0$ and $\frac{dk}{de_N}<0$.

$$\frac{da_{EN}}{de_N}=\frac{\begin{vmatrix} b_{11} & c_1' & b_{13} \\ b_{21} & c_2' & b_{23} \\ 0 & 0 & b_{33} \end{vmatrix}}{|det|}=\frac{b_{33}(b_{11}c_2'-b_{21}c_1')}{|det|} \tag{91}$$

$$\begin{aligned} b_{11}c_2'-b_{21}c_1' &= \frac{\theta a_{EN}}{a_{KN}k}[A\alpha q^{\alpha-1}(q^E\psi-1+s_N\Pi_N)(\frac{dq}{dk}\frac{dq^E}{de_N}-\frac{dq^E}{dk}\frac{dq}{de_N}) \\ &-\frac{(1-Aq^\alpha)(1-s_N\Pi_N)+Aq^\alpha q^E\psi}{k}\frac{dq^E}{de_N}-\frac{dq^E}{dk}(Aq^\alpha\psi\frac{dq^E}{de_N}-Aq^\alpha\bar{q}^E a_{KN})]>0 \end{aligned} \tag{92}$$

Therefore, $\frac{da_{EN}}{de_N} > 0$.

$$\frac{da_{ES}}{de_N} = \frac{\begin{vmatrix} b_{11} & b_{12} & c_1' \\ b_{21} & b_{22} & c_2' \\ 0 & b_{33} & 0 \end{vmatrix}}{|det|} = \frac{b_{32}(b_{21}c_1' - b_{11}c_2')}{|det|} \tag{93}$$

$$\begin{aligned} b_{21}c_1' - b_{11}c_2' = & \frac{\theta a_{EN}}{a_{KN}k}[A\alpha q^{\alpha-1}(q^E\psi - 1 + s_N\Pi_N)(\frac{dq^E}{dk}\frac{dq}{de_N} - \frac{dq^E}{de_N}\frac{dq}{dk}) \\ & -Aq^\alpha q^E a_{KN}\frac{dq^E}{dk} + \frac{(1-Aq^\alpha)(1-s_N\Pi_N)}{k^2}\frac{dq^E}{de_N} + \frac{Aq^\alpha \bar{q}^E\psi}{k^2}\frac{dq^E}{de_N}] < 0 \end{aligned} \tag{94}$$

Therefore, $\frac{da_{ES}}{de_N} > 0$.

Comparative statics of e_S

From South's goods market equilibrium equation, the following equation holds.

$$\frac{dq}{de_S} = \frac{(\frac{s_S k a_{ES}}{a_{KS}q} + \frac{Aq^\alpha\psi}{q a_{KN}})\frac{dq^E}{de_S}}{S_q} < 0 \tag{95}$$

From the permit trading market, the following equation holds

$$\frac{dq^E}{de_S} = -\frac{\bar{q}^E}{e_S^{d'}} < 0 \tag{96}$$

Thus, the sign of the following equation becomes

$$d_1' = -\frac{d(s_S r_S)}{de_S} = -\frac{A\alpha q^{\alpha-1}(-1 + s_N\Pi_N + q^E\psi)\frac{dq}{de_S} + Aq^\alpha\psi\frac{dq^E}{de_S}}{a_{KN}k} > 0 \tag{97}$$

$$d_2' = \theta a_{EN}\frac{dq^E}{de_S} < 0 \tag{98}$$

$$d_3' = 0 \tag{99}$$

$$\frac{dk}{de_S} = \frac{\begin{vmatrix} d_1' & b_{12} & b_{13} \\ d_2' & b_{22} & b_{23} \\ 0 & b_{32} & b_{33} \end{vmatrix}}{|det|} = \frac{d_1'(b_{22}b_{33} - b_{23}b_{32}) + d_2'(b_{13}b_{32} - b_{12}b_{33})}{|det|} \tag{100}$$

If θ is large and the effect of d_2' is sufficient, $\frac{dk}{de_S} < 0$.

$$\frac{da_{EN}}{de_S} = \frac{\begin{vmatrix} b_{11} & d_1' & b_{13} \\ b_{21} & d_2' & b_{23} \\ 0 & 0 & b_{33} \end{vmatrix}}{|det|} = \frac{d_2'b_{11}b_{33} - d_1'b_{21}b_{33}}{|det|} > 0 \tag{101}$$

$$\frac{da_{ES}}{de_S} = \frac{\begin{vmatrix} b_{11} & b_{12} & d_1' \\ b_{21} & b_{22} & d_2' \\ 0 & b_{32} & 0 \end{vmatrix}}{|det|} = \frac{d_1'b_{21}b_{32} - d_2'b_{11}b_{32}}{|det|} > 0 \tag{102}$$

Comparative statics of c

$$e_1' = 0, e_2' = 0, e_3' = 1 \tag{103}$$

$$\frac{dk}{dc} = \frac{\begin{vmatrix} e_1' & b_{12} & b_{13} \\ e_2' & b_{22} & b_{23} \\ e_3' & b_{32} & b_{33} \end{vmatrix}}{|det|} = \frac{b_{12}b_{23} - b_{22}b_{13}}{|det|} < 0 \tag{104}$$

$$\frac{da_{EN}}{dc} = \frac{\begin{vmatrix} b_{11} & e'_1 & b_{13} \\ b_{21} & e'_2 & b_{23} \\ 0 & e'_3 & b_{33} \end{vmatrix}}{|det|} = \frac{b_{13}b_{21} - b_{11}b_{23}}{|det|} > 0 \tag{105}$$

$$\frac{da_{ES}}{dc} = \frac{\begin{vmatrix} b_{11} & b_{12} & e'_1 \\ b_{21} & b_{22} & e'_2 \\ 0 & b_{23} & e'_3 \end{vmatrix}}{|det|} = \frac{b_{11}b_{22} - b_{12}b_{21}}{|det|} < 0 \tag{106}$$

Comparative statics of σ and b
This comparison is omitted since the calculation is the same as that for c.

References

[1] Ando, Y. (2021). "Impacts of environmental tax on demand formation: A post-keynesian analysis with pollution emissions", *Political Economy Quarterly*, 58-1: 40-53 (in Japanese).

[2] Althouse, J., Guarini, G., and Gabriel Porcile, J (2020). "Ecological macroeconomics in the open economy: Sustainability, unequal exchange and policy coordination in a center-periphery model", *Ecological Economics*, 172.

[3] Dutt, A. K. (1990). *Growth, Distribution and Uneven Development.* Cambridge: Cambridge University Press.

[4] Murshed, S. M. (1992). *Economic Aspects of North-South Interaction.* London: Academic Press.

[5] Murshed, S. M. (1995). "Tradable permits in greenhouse gas emissions: A macroeconomic analysis in the north-south context", *Seoul Journal of Economics*, 8-3: 347-365.

[6] Razmi, A. (2016). "North-south interactions in the presence of trade in environmental permits: a structuralist investigation", *Cambridge Journal of Economics*, 40-4: 541-574.

[7] Taylor, L. (1981). "South-north trade and southern growth: Bleak prospects from the structuralist point of view", *Journal of International Economics*, 11-4: 589-602.

[8] Thirlwall, A. P. (1979). "The balance of payments constraint as an explanation of international growth rate differences", *Banca Nazionale del Lavoro*, 32, issue 128: 45-53.