CESifo WORKING PAPERS

10825 2023

December 2023

Environmental Policies and Stagnation in a Two-Country Economy

Masako Ikefuji, Yoshiyasu Ono

CESifo

Impressum:

CESifo Working Papers
ISSN 2364-1428 (electronic version)
Publisher and distributor: Munich Society for the Promotion of Economic Research - CESifo GmbH
The international platform of Ludwigs-Maximilians University's Center for Economic Studies and the ifo Institute
Poschingerstr. 5, 81679 Munich, Germany
Telephone +49 (0)89 2180-2740, Telefax +49 (0)89 2180-17845, email office@cesifo.de
Editor: Clemens Fuest
https://www.cesifo.org/en/wp
An electronic version of the paper may be downloaded
· from the SSRN website: www.SSRN.com
· from the RePEc website: www.RePEc.org
· from the CESifo website: https://www.cesifo.org/en/wp

CESifo *Working Paper No. 10825*

Environmental Policies and Stagnation in a Two-Country Economy

Abstract

Global warming is a serious and acute threat to our planet, but, when negotiating the allocation of permissible carbon emissions, conflicts of interest exist between developed and developing countries. Developing countries insist that global warming is the result of prolonged pollution emissions by developed countries, while developed countries demand that developing countries make efforts comparable to their own to reduce carbon emissions. They both generally believe that stricter emission limits will burden their economies because of the extra abatement costs required. We use a two-country model with wealth preferences and find that the effects of a country's emission limit on the two countries' real consumption and pollution emissions differ, depending on the combination of their business situations. If both countries achieve full employment, one country's stricter emission limit decreases both countries' real consumption, as expected. However, if one country faces aggregate demand stagnation and the other achieves full employment, a stricter emission limit imposed by the stagnant country increases both countries' real consumption.

JEL-Codes: F130, F410, F420, Q520, Q560, Q580.

Keywords: persistent unemployment, wealth preferences, pollution, emission restriction, clean technology transfer.

Masako Ikefuji
Osaka School of International Public Policy
Osaka University / Japan
ikefuji.osipp@osaka-u.ac.jp

Yoshiyasu Ono
Institute of Social and Economic Research
Osaka University / Japan
ono@iser.osaka-u.ac.jp

November 2023
This work was financially supported by the Asahi Glass Foundation, the JSPS KAKENHI Grants (JP20H05631, JP20H01477), and the program of the Joint Usage/Research Center for "Behavioral Economics" at ISER of Osaka University.

1. Introduction

Most countries have come to regard global warming as one of the most serious threats to human beings. This common understanding led 187 countries and regions to adopt the 2015 Paris agreement, an international treaty intended to limit global warming by reducing global emissions.[3] However, when negotiating the allocation of permissible carbon emissions, conflicts of interest exist, particularly between developed and developing countries. Developing countries insist that global warming is a result of prolonged pollution emissions by developed countries, while developed countries demand that developing countries make efforts comparable to their own to reduce carbon emissions. They both believe that stricter emission limits will burden their economies due to the extra abatement costs required. This is particularly the case when the countries face stagnation.

However, if a country faces aggregate demand stagnation, a stricter emission limit induces firms to hire more labor to abate pollution, which mitigates deflation, urges households to consume more, and stimulates business activity. Ikefuji and Ono (2021) find that this property holds in a closed-economy setting with demand stagnation caused by households' wealth preferences.[4] The current paper extends their analysis to an open-economy setting using a two-country model with secular stagnation caused by wealth preferences.[5] It incorporates pollution emissions in the model, and examines one country's own and international spillover effects of its pollution emission limit on the two countries' consumption and pollution emissions under different combinations of their business activities: full employment in both countries, stagnation in one country and full employment in the other, and stagnation in both countries. The results show that the effects are mixed depending on the combination of their business activities.

For example, if one country faces aggregate demand stagnation and the other achieves full employment, which may describe the current situation for developed and developing countries, a stricter pollution emission limit by the stagnant country leads to greater consumption in both

[3] The USA withdrew from the agreement under the Trump administration, but returned in 2021 under the Biden administration.

[4] A secular demand stagnation model of this type was first presented by Ono (1994, 2001). Recent extensions include Ono and Ishida (2014), Michau (2018), and Michaillat and Saez (2022). Using a model in which the marginal utility of wealth remains strictly positive, these authors find that secular demand stagnation occurs and examine the effects of various monetary and fiscal policies. Illing et al. (2018); Mian et al. (2021); and Hashimoto et al. (2023) also analyze wealth preference models.

[5] See Ono (2006, 2014, 2018) for a two-country model with wealth preferences of this type.

countries. This is because a stricter emission limit induces domestic firms to hire more labor for abatement, which mitigates deflation and stimulates households to increase consumption. Consequently, the country's current account worsens and its currency depreciates, which implies an improvement in the other country's terms of trade. Thus, if the latter achieves full employment, it will also be better off — that is, there is no conflict of interest with respect to consumption between the two countries. This is in contrast to the case where both countries are in full employment and a tradeoff exists between consumption and the environment; in this case, a stricter emission limit decreases pollution emissions at the cost of less output and lower consumption.

Much has been written about the environment in an open-economy context.[6] In the absence of self-enforcing international environmental agreements, the question of whether free trade liberalization is good or bad for the environment has particularly been noted, leading to many studies that focus on the existence of carbon leakage. Carbon leakage refers to the situation where a country's unilateral climate policy causes other countries to increase carbon emissions. These studies focus on how one country's environmental policy affects the other country's production reallocation from clean to dirty sectors. For example, Copeland and Taylor (1994) employ a two-country model with a continuum of goods and show that a higher pollution tax imposed by the higher-income country causes more pollution-intensive production to move to the lower-income country with a less stringent environmental policy (the pollution haven effect).[7]

More recent studies discuss the possibility of negative carbon leakage, where a unilateral climate policy may decrease carbon emissions in other countries through production reallocation from dirty to clean sectors. These studies include Baylis et al. (2014) under perfect competition and Baccianti and Schenker (2022) under Cournot competition. Di Maria and Smulders (2004), Hémous (2016), Acemoglu et al. (2014), and Gerlagh and Kuik (2014) introduce directed technical change to a North-South economy with clean and dirty sectors and show that international technology spillovers from North to South are necessary for negative carbon leakage to occur.

[6] See the reviews by Jayadevappa and Chhatre (2000), Rauscher (2005), and Cherniwchan et al. (2017).

[7] Babiker (2005) numerically analyzes the strategic interaction among energy-intensive production firms in a Cournot oligopoly model and finds significant carbon leakage from the OECD countries to developing countries. Levinson and Taylor (2008) estimate the pollution haven effect using data on U.S. manufacturing sector imports from Canada and Mexico.

While we focus on how emission restrictions affect employment, real consumption, and pollution emissions in the policy-setting country and the other country, we also discuss positive and negative carbon leakage in various combinations of the two countries' employment situations. We find that a stricter emission limit causes negative carbon leakage to occur when both countries face stagnation because it decreases the other country's employment, output and pollution emissions. However, the policy-setting country may increase pollution emissions despite a stricter emission limit because the stricter limit creates new employment for abatement, thereby stimulating aggregate demand, which leads to increased employment and output. An international transfer of superior abatement technology in this case also reduces the recipient country's pollution emissions by decreasing employment and output. Thus, the mechanism of negative carbon leakage presented in the current paper is quite different from the conventional one via intersectoral reallocation of production. It works through changes in employment and output in the presence of aggregate demand shortages.

The remainder of this paper is organized as follows. Section 2 presents the model and characterizes the steady state under different combinations of full employment (F) and stagnation (S) in the two countries. Sections 3 and 4 investigate the effects of a pollution emission limit when both countries attain full employment (FF), and when they face stagnation (SS), respectively. Section 5 considers the case where the policy-setting country is in stagnation and the other country is in full employment (SF) and vice versa (FS). Section 6 examines the effects of transfers of abatement and cleaner production technologies in the four cases: FF, SS, SF and FS. It also discusses the first-best policy for the stagnant country. Section 7 concludes.

2. The model

We consider an open economy with two countries, h and f, and firms of country h specialize in commodity 1 while firms of country f specialize in commodity 2. The two countries have the same population, which is normalized to unity.

Households

Households in the two countries have the following lifetime utility:

$$U^h = \int_0^\infty \left[\hat{u}\left(c_1^h, c_2^h\right) + v(m^h) - q(z^h + z^f)\right] \exp(-\rho s) ds,$$

$$U^f = \int_0^\infty \left[\hat{u}\left(c_1^f, c_2^f\right) + v(m^f) - q(z^f + z^h)\right] \exp(-\rho s) ds, \qquad (1)$$

$$u' > 0,\ u'' < 0;\ v' > 0,\ v'' < 0;\ q' > 0,\ q'' > 0,$$

where superscript j $(j = h, f)$ of a variable implies that the variable belongs to country j, $\hat{u}(c_1^j, c_2^j)$ is the utility of consumption on the two commodities c_1^j and c_2^j, $v(m^j)$ is the utility of real money holdings m^j, and $q(z^h + z^f)$ is the disutility of global pollution $z^h + z^f$, such as greenhouse gas.

We assume that $\hat{u}(.,.)$ is homothetic; hence, once real aggregate consumption c^j is given at each point in time, the optimal levels of c_1^j and c_2^j satisfy

$$p_1(\omega)c_1^j = \gamma(\omega)c^j, \;\; p_2(\omega)c_2^j = [1-\gamma(\omega)]c^j,$$
$$p_1(\omega)c_1^j + p_2(\omega)c_2^j = c^j,$$
$$1 > \gamma(\omega) > 0, \;\; \gamma'(\omega) > 0, \tag{2}$$

where ω is the relative price of commodity 2 to commodity 1, $p_i(\omega)$ is the real price of commodity i $(i = 1, 2)$, and $\gamma(\omega)$ is the share of consumption expenditure on commodity 1. Real prices $p_1(\omega)$ and $p_2(\omega)$ are respectively the same between the two countries because both households have the same utility function, as shown by (1), and no tariff is imposed in the two countries.

As proved in Appendix A, the real and nominal prices satisfy

$$p_1(\omega) = \frac{P_1^h}{P^h} = \frac{P_1^h/\varepsilon}{P^f}, \;\; p_2(\omega) = \frac{P_2^f}{P^f} = \frac{\varepsilon P_2^f}{P^h} = \omega p_1(\omega),$$
$$p_1'(\omega) = -\frac{(1-\gamma)p_1}{\omega} < 0, \quad p_2'(\omega) = \frac{\gamma p_2}{\omega} = \gamma p_1 > 0,$$
$$P^h = \varepsilon P^f, \quad \pi^h = \frac{\dot{\varepsilon}}{\varepsilon} + \pi^f, \tag{3}$$

where P^j is country j's consumer price index, P_i^j is the nominal price of commodity i measured in terms of country j's currency, ε is the nominal exchange rate, and π^j is the inflation rate of P^j. From the non-arbitrage condition between home and foreign assets, we have

$$R^h = \frac{\dot{\varepsilon}}{\varepsilon} + R^f,$$

where R^j is country j's nominal interest rate. Therefore, from the last equation of (3), we find

$$R^h - \pi^h = r = R^f - \pi^f, \tag{4}$$

that is, the real interest rate r is internationally the same.

As a result of the intratemporal optimal allocation of consumption given by (2), the utility of consumption is represented as a function of only c^j:

$$u(c^j) \equiv \hat{u}\left(\frac{\gamma(\omega)c^j}{p_1(\omega)}, \frac{(1-\gamma(\omega))c^j}{p_2(\omega)}\right),$$

because $\hat{u}(c_1^j, c_2^j)$ is homothetic and unaffected by the relative price ω if the consumer price index is properly defined. Thus, the lifetime utility given in (1) of a representative household in each country is rewritten as follows:

$$U^h = \int_0^\infty [u(c^h) + v(m^h) - q(z^h + z^f)] \exp(-\rho s) ds,$$
$$U^f = \int_0^\infty [u(c^f) + v(m^f) - q(z^f + z^h)] \exp(-\rho s) ds, \tag{5}$$

which is to be maximized subject to the flow and stock budget equations:

$$\dot{a}^j = ra^j + w^j \ell^j - c^j - R^j m^j, \quad a^j = m^j + b^j, \tag{6}$$

Where a^j is total assets, b^j is international lending-borrowing, $w^j (= W^j/P^j)$ is the real wage, and ℓ^j is the realized labor supply in country j. The first-order optimality condition is

$$\rho + \eta^j \frac{\dot{c}^j}{c^j} + \pi^j = R^j = \frac{v'(m^j)}{u'(c^j)}, \tag{7}$$

where $\eta^j \equiv -u''(c^j)c^j/u'(c^j)$ is the elasticity of the marginal utility of consumption. The transversality condition is

$$\lim_{t \to \infty} a^j(t) \exp(-\int_0^t r(s) ds) = 0. \tag{8}$$

Firms

All firms are competitive, and firms in country h (country f) produce commodity 1 (commodity 2). They utilize labor ℓ_p^j $(j = h, f)$ to produce y_i^j $(i = 1, 2)$ of commodity i with constant labor productivity A_i, and emit pollution e^j:

$$y_1^h = A_1 \ell_p^h, \quad y_2^f = A_2 \ell_p^f,$$
$$e^h = \delta_1 A_1 \ell_p^h, \quad e^f = \delta_2 A_2 \ell_p^f, \tag{9}$$

Where δ_i $(i = 1, 2)$ is the ratio of pollution emissions to output. Each government limits pollution emissions per output to φ_i, so that net actual emissions z^j and pollution abatement $e^j - z^j$ satisfy

$$z^h = \varphi_1 y_1^h = \varphi_1 A_1 \ell_p^h, \quad e^h - z^h = (\delta_1 - \varphi_1) A_1 \ell_p^h = \sigma_1 \ell_a^h,$$
$$z^f = \varphi_2 y_2^f = \varphi_2 A_2 \ell_p^f, \quad e^f - z^f = (\delta_2 - \varphi_2) A_2 \ell_p^f = \sigma_2 \ell_a^f, \tag{10}$$

where ℓ_a^j is labor input for abatement in country j and σ_i is labor productivity of abatement of pollution emitted when producing commodity i. Therefore, total employment $\ell^j (= \ell_p^j + \ell_a^j)$ in country j is

$$\ell^h = \left(1 + \frac{(\delta_1 - \varphi_1) A_1}{\sigma_1}\right) \ell_p^h, \quad \ell^f = \left(1 + \frac{(\delta_2 - \varphi_2) A_2}{\sigma_2}\right) \ell_p^f. \tag{11}$$

Obviously, if $\delta_i \leq \varphi_i$, implying that the unrestricted emission rate is lower than the emission limit set by the government, firms are not required to abate pollution; thus, the environmental policy is not in effect and $\ell^f = \ell_p^f$ in (11). However, in the following, we focus on the case where the environmental policy is in effect (i.e., $\delta_i > \varphi_i$).

Using (9)–(11), we find that firm output and profits in country j ($j = h, f$) are

$$y_1^h = \hat{A}_1 \ell^h,\ p_1 y_1^h - w^h \ell^h = \left(p_1 \hat{A}_1 - w^h\right)\ell^h,\ \text{ where } \hat{A}_1 \equiv \frac{A_1}{1+\frac{(\delta_1-\varphi_1)A_1}{\sigma_1}},$$

$$y_2^f = \hat{A}_2 \ell^h,\ p_2 y_2^f - w^f \ell^f = \left(p_2 \hat{A}_2 - w^h\right)\ell^f,\ \text{ where } \hat{A}_2 \equiv \frac{A_2}{1+\frac{(\delta_2-\varphi_2)A_2}{\sigma_2}}. \tag{12}$$

$\hat{A}_i$ is effective labor productivity with emission limit φ_i, which satisfies

$$\frac{\partial \hat{A}_i}{\partial \varphi_i} = \frac{(\hat{A}_i)^2}{\sigma_i} > 0,\ \frac{\partial \hat{A}_i}{\partial A_i} = \left(\frac{\hat{A}_i}{A_i}\right)^2 > 0,\ \frac{\partial \hat{A}_i}{\partial \delta_i} = -\frac{(\hat{A}_i)^2}{\sigma_i} < 0,\ \frac{\partial \hat{A}_i}{\partial \sigma_i} = (\delta_i - \varphi_i)\left(\frac{\hat{A}_i}{\sigma_i}\right)^2 > 0; \tag{13}$$

that is, a stricter emission limit ($\varphi_i \downarrow$) decreases effective labor productivity $\hat{A}_i$, whereas $\hat{A}_i$ increases with an improvement in the production technology ($A_i \uparrow$), cleaner production technology with less pollution emissions ($\delta_i \downarrow$), and an improvement in abatement technology ($\sigma_i \uparrow$). Because of the linear technology, real wage w^j must satisfy

$$w^h = p_1(\omega)\hat{A}_1,\ \ w^f = p_2(\omega)\hat{A}_2, \tag{14}$$

so that profits are zero for all firms.

Markets

We assume, for simplicity, that both governments keep nominal money stock M^j constant over time so that

$$\dot{m}^j = -\pi^j m^j \quad \text{for } j = h, f. \tag{15}$$

Applying (4), (7), (14), and (15) to (6) yields each country's current account:

$$\dot{b}^h = rb^h - c^h + p_1 \hat{A}_1 \ell^h, \quad \dot{b}^f = rb^f - c^f + p_2 \hat{A}_2 \ell^f. \tag{16}$$

The world total lending-borrowing is zero:

$$b^h + b^f = 0.$$

For simplicity, we treat the case in the neighborhood of

$$(b^h, b^f) = (0,0), \tag{17}$$

where we can ignore the effect through a change in the exchange rate on the real value of each country's net assets, which generally depends on the asset portfolio. This effect is beyond the scope of the present analysis.

From (2) and (12), the international markets of the two commodities satisfy

$$\psi_1(\omega)(c^h + c^f) = \hat{A}_1\ell^h, \quad \psi_2(\omega)(c^h + c^f) = \hat{A}_2\ell^f, \tag{18}$$

$$\text{where} \quad \psi_1(\omega) = \frac{\gamma(\omega)}{p_1(\omega)}, \ \psi_1' > 0, \ \psi_2(\omega) = \frac{1-\gamma(\omega)}{p_2(\omega)}, \ \psi_2' < 0.$$

In the labor market of each country, nominal wage W^j perfectly adjusts when $\ell^j = 1$, while it adjusts in a sluggish manner depending on the deflationary gap when $\ell^j < 1$. Thus,

If $\ell^j = 1$, W^j perfectly adjusts.

$$\text{If } \ell^j < 1, \quad \frac{\dot{W}^j}{W^j} = \alpha^j(\ell^j - 1). \tag{19}$$

Steady state

In steady state, c^j and $w^j (= W^j/P^j)$ are constant so that we have from (4) and (7)

$$r = \rho, \quad \pi^j = \frac{\dot{W}^j}{W^j} \ \text{ for } j = h, f. \tag{20}$$

We therefore obtain, from (7), (10), (12), (16), (17), and (18),

$$\frac{1-\gamma(\omega)}{\omega\gamma(\omega)} = \frac{\hat{A}_2\ell^f}{\hat{A}_1\ell^h}, \quad c^h = p_1(\omega)\hat{A}_1\ell^h, \quad c^f = p_2(\omega)\hat{A}_2\ell^f,$$

$$z^h = \varphi_1\hat{A}_1\ell^h, \quad z^h = \varphi_2\hat{A}_2\ell^f.$$

$$\rho + \pi^j = \frac{v'(m^j)}{u'(c^j)} \ \text{ for } j = h, f. \tag{21}$$

Moreover, if both countries achieve full employment ($\ell^h = 1$, $\ell^f = 1$) in the steady state, we have from (21)

$$\frac{1-\gamma(\omega)}{\omega\gamma(\omega)} = \frac{\hat{A}_2}{\hat{A}_1}, \quad c^h = p_1(\omega)\hat{A}_1, \quad c^f = p_2(\omega)\hat{A}_2,$$

$$z^h = \varphi_1\hat{A}_1, \quad z^f = \varphi_2\hat{A}_2.$$

$$\rho = \frac{v'(m^j)}{u'(c^j)} \ \text{ for } j = h, f. \tag{22}$$

However, if households have insatiable preference for money (or financial wealth) holdings; namely,

$$\lim_{m\to\infty} v'(m^j) = \beta > 0, \tag{23}$$

aggregate demand shortages can occur, as found by Ono (1994, 2001).[8] More precisely, in order for the solution of m^h and m^f in (22) to exist, it must hold that

$$\rho = \frac{v'(m^h)}{u'(p_1(\omega)\hat{A}_1)}\left(> \frac{\beta}{u'(p_1(\omega)\hat{A}_1)}\right),$$

$$\rho = \frac{v'(m^f)}{u'(p_2(\omega)\hat{A}_2)}\left(> \frac{\beta}{u'(p_2(\omega)\hat{A}_2)}\right),$$

[8] See Ono et al. (2004) for an empirical analysis of insatiable preferences for money (or financial wealth).

where ω is obtained from the first equation in (22). Therefore, full employment is reached in each country if and only if

$$p_1(\omega)\hat{A}_1 < u'^{-1}(\frac{\beta}{\rho}), \quad p_2(\omega)\hat{A}_2 < u'^{-1}(\frac{\beta}{\rho}).$$

Otherwise, stagnation occurs in each country. Therefore, we find the conditions for each combination of the two countries' business activities to appear as follows:[9]

$$\begin{aligned}
&\text{FF } (\ell^h = 1, \ell^f = 1):\ p_1(\omega)\hat{A}_1 < u'^{-1}(\tfrac{\beta}{\rho}),\ \ p_2(\omega)\hat{A}_2 < u'^{-1}(\tfrac{\beta}{\rho}),\\
&\text{SS } (\ell^h < 1, \ell^f < 1):\ p_1(\omega)\hat{A}_1 \geq u'^{-1}(\tfrac{\beta}{\rho}),\ \ p_2(\omega)\hat{A}_2 \geq u'^{-1}(\tfrac{\beta}{\rho}),\\
&\text{SF } (\ell^h < 1, \ell^f = 1):\ p_1(\omega)\hat{A}_1 \geq u'^{-1}(\tfrac{\beta}{\rho}),\ \ p_2(\omega)\hat{A}_2 < u'^{-1}(\tfrac{\beta}{\rho}),\\
&\text{FS } (\ell^h = 1, \ell^f < 1):\ p_1(\omega)\hat{A}_1 < u'^{-1}(\tfrac{\beta}{\rho}),\ \ p_2(\omega)\hat{A}_2 \geq u'^{-1}(\tfrac{\beta}{\rho}),
\end{aligned} \tag{24}$$

where F and S imply full employment and stagnation, respectively, and the first and second letters denote the employment situation of countries h and f, respectively.

3. Full employment in both countries

Let us first consider the case where both countries achieve full employment (case FF) and analyze the effects of country h's emission limit φ_1 on the two countries' real consumption and pollution emissions. Obviously, the effects of country f's emission limit φ_2 on the two countries' real consumption and pollution emissions are symmetrically treated.

Using $p_1'(\omega)$ and $p_2'(\omega)$ in (3), (13), and the steady-state conditions in case FF given by (22), we obtain the effects of changes in $\hat{A}_1$ and φ_1 on the two countries' real consumption and pollution emissions:

$$\begin{gathered}
\hat{A}_1 \frac{d\omega}{d\hat{A}_1} = \frac{\omega\gamma(1-\gamma)}{\gamma(1-\gamma)+\gamma'\omega} > 0,\\
\frac{dc^h}{d\hat{A}_1} = \left(\frac{\gamma^2(1-\gamma)+\gamma'\omega}{\gamma(1-\gamma)+\gamma'\omega}\right) p_1 > 0,\ \ \frac{dc^f}{d\hat{A}_1} = \left(\frac{(1-\gamma)^2\gamma}{\gamma(1-\gamma)+\gamma'\omega}\right) p_1 > 0,\\
\frac{dc^j}{d\varphi_1} = \frac{dc^j}{d\hat{A}_1}\frac{(\hat{A}_1)^2}{\sigma_1} > 0 \quad \text{for } j = h, f,\\
\frac{\partial z^h}{\partial \hat{A}_1}\Big|_{\varphi_1=\text{const.}} = \varphi_1 > 0,\ \ \frac{dz^h}{d\varphi_1} = \hat{A}_1\left(1 + \frac{\varphi_1\hat{A}_1}{\sigma_1}\right) > 0,\\
\frac{\partial z^f}{\partial \hat{A}_1}\Big|_{\varphi_1=\text{const.}} = 0,\ \ \frac{dz^f}{d\varphi_1} = 0.
\end{gathered} \tag{25}$$

[9] Ono (2014, 2018) shows these conditions for the four cases to appear.

These are summarized as follows:

Proposition 1: When both countries attain full employment, a country's stricter emission limit and higher effective productivity yield the following effects on the real price (p) and output (y) of each product, pollution emissions (z), and real consumption (c) in the two countries:

	Policy-setting country (F)			The other country (F)		
	p	$y,\ z$	c	p	$y,\ z$	c
Stricter emission limit	$+$	$-$	$-$	$-$	0	$-$
Higher effective productivity	$-$	$+$	$+$	$+$	0	$+$

(F) implies full employment.

Proposition 1 shows the standard properties of the own and spillover effects of country h's stricter emission limit φ_1. It naturally lowers $\hat{A}_1$ and decreases country h's production, pollution emissions and real consumption. Consequently, the relative price of commodity 1 rises and country f's real consumption decreases through a deterioration in its terms of trade. Its pollution emissions are unchanged because its output is unchanged at the full-employment level. Thus, there is naturally a tradeoff between the environment and both countries' real consumption.

4. Stagnation in both countries

We now turn to the case where both countries face persistent unemployment in the steady state, that is, case SS in (24), and examine the effects of a change in country h's emission limit φ_1 on the two countries' consumption, employment, and pollution emissions. Obviously, the effects of a change in country f's emission limit φ_2 are symmetrically treated.

When aggregate demand shortages appear ($\ell^j < 1$) in both countries, from (19) and (20), their consumer price indices P^j keep declining, making $v'(m^j)$ converge to β, as shown by (23). Then, the Euler equation (7) reduces to

$$\rho + \alpha^j(\ell^j - 1) = \frac{\beta}{u'(c^j)} \quad \Rightarrow \quad \ell^j = \ell^j(c^j),\ \ \ell^{j\prime}(c^j) > 0. \tag{26}$$

In this state, from (15), (19), and (20),

$$-\frac{\dot{m}^j}{m^j} = \pi^j = \alpha^j\left(\ell^j - 1\right) < 0.$$

Because $m^j = a^j$ from (6) and (17), a^j continues to expand at the following rate:

$$-\pi^j = \rho - \beta/u'\left(c^j\right) > 0.$$

Nevertheless, the transversality condition given by (8) is valid because $r = \rho$, as shown by (20), and the expansion rate of a^j, which is $-\pi^j$, is lower than ρ, as seen from the above equation.

Substituting $\ell^j\left(c^j\right)$ given by (26) into ℓ^j in (18) yields

$$\psi_1(\omega)(c^h + c^f) = \hat{A}_1\ell^h(c^h) \;\Rightarrow\; c^h = g^h\left(c^f; \omega, \hat{A}_1\right),$$
$$\psi_2(\omega)(c^h + c^f) = \hat{A}_2\ell^f(c^f) \;\Rightarrow\; c^f = g^f\left(c^h; \omega, \hat{A}_2\right). \tag{27}$$

The intersection of the two functions in (27) gives the two countries' real consumption in the stagnation steady state. As proved in Appendix B, for the intersection to exist, it must be valid that

$$\Omega \equiv (1-\gamma)p_1\hat{A}_1\ell^{h\prime}(p_2\hat{A}_2\ell^{f\prime} - 1) + \gamma p_2\hat{A}_2\ell^{f\prime}(p_1\hat{A}_1\ell^{h\prime} - 1) > 0. \tag{28}$$

Let $c^j\left(\omega; \hat{A}_1, \hat{A}_2\right)$ represent c^j at the intersection of the two functions in (27):

$$c^j\left(\omega; \hat{A}_1, \hat{A}_2\right) \quad \text{for } j = h, f.$$

Totally differentiating the two equations in (27) and rearranging the results gives $\partial c^h/\partial\omega$:

$$\frac{\Omega}{c^h + c^f}\frac{\partial c^h(\omega; \hat{A}_1, \hat{A}_2)}{\partial\omega} = (p_2\hat{A}_2\ell^{f\prime} - 1)\left(\gamma' + \frac{\gamma(1-\gamma)}{\omega}\right). \tag{29}$$

The steady-state ω is determined so that the current account $\dot{b}^h$ given by (16) is in balance. We assume the Marshall-Lerner condition: country h's current account improves if ω increases (or equivalently, country f's current account improves if ω decreases). Thus, substituting c^j in (27) into $\dot{b}^h$ in (16), differentiating the result with respect to ω, and applying (3) and (29) to the result yields

$$\text{Marshall-Lerner condition:}\quad \frac{\partial\dot{b}^h}{\partial\omega} = (p_1\hat{A}_1\ell^{h\prime} - 1)\frac{\partial c^h}{\partial\omega} - \left(\frac{1-\gamma}{\omega}\right)p_1\hat{A}_1\ell^h > 0, \tag{30}$$

where $\partial c^h/\partial\omega$ is given by (29), in which $\gamma' > 0$ from (2) and $\Omega > 0$ from (28). Therefore, we have

$$\left(p_1\hat{A}_1\ell^{h\prime} - 1\right)\left(p_2\hat{A}_2\ell^{f\prime} - 1\right) > 0.$$

This property and (28) give the following properties:

$$p_1\hat{A}_1\ell^{h\prime} - 1 > 0, \;\; p_2\hat{A}_2\ell^{f\prime} - 1 > 0, \;\; \frac{\partial c^h}{\partial\omega} > 0. \tag{31}$$

Totally differentiating the two equations in (27), rearranging the results, and using (31) gives

$$\Omega \frac{\partial c^h(\omega;\hat{A}_1,\hat{A}_2)}{\partial \hat{A}_1} = -\left(p_2\hat{A}_2\ell^{f\prime} - (1-\gamma)\right)p_1\ell^h < 0,$$

$$\Omega \frac{\partial c^f(\omega;\hat{A}_1,\hat{A}_2)}{\partial \hat{A}_1} = -p_1\ell^h(1-\gamma) < 0. \tag{32}$$

From (16), where $r = \rho$, which is seen from (20), (17), (31), and (32), we have

$$\frac{\partial \dot{b}^h}{\partial \hat{A}_1} = \left(p_1\hat{A}_1\ell^{h\prime} - 1\right)\frac{\partial c^h(\omega;\hat{A}_1,\hat{A}_2)}{\partial \hat{A}_1} + p_1\ell^h = \frac{p_1\ell^h(1-\gamma)(p_2\hat{A}_2\ell^{f\prime}-1)}{\Omega} > 0. \tag{33}$$

From this property and the Marshall-Lerner condition (30), we obtain

$$\frac{d\omega}{d\hat{A}_1} = -\frac{\partial \dot{b}^h/\partial \hat{A}_1}{\partial \dot{b}^h/\partial \omega} < 0. \tag{34}$$

In other words, a decrease in the effective productivity of commodity 1 ($\hat{A}_1 \downarrow$) leads to a higher relative price for commodity 2. From (31), (32), and (34), we obtain

$$\frac{dc^h}{d\hat{A}_1} = \underbrace{\frac{\partial c^h(\omega;\hat{A}_1,\hat{A}_2)}{\partial \omega}}_{(+)} \cdot \underbrace{\frac{d\omega}{d\hat{A}_1}}_{(-)} + \underbrace{\frac{\partial c^h(\omega;\hat{A}_1,\hat{A}_2)}{\partial \hat{A}_1}}_{(-)} < 0,$$

$$\frac{dc^f}{d\hat{A}_1} = -\left(\frac{1-\gamma}{\omega}\right)p_1\hat{A}_1\ell^h \underbrace{\frac{\partial c^f}{\partial \hat{A}_1}}_{(-)} \Big/ \underbrace{\frac{\partial \dot{b}^h}{\partial \omega}}_{(+)} > 0. \tag{35}$$

Note that the effects of a change in $\hat{A}_1$ on ω and c^h in case SS, shown by (34) and (35), are opposite to those in case FF, shown by (25), where both countries achieve full employment. In case FF, a decrease in $\hat{A}_1$ lowers the output of commodity 1 because full employment is in place, and raises its relative price ($\omega \downarrow \rightarrow p_1(\omega) \uparrow$). The former effect dominates the latter so that real consumption $c^h = p_1(\omega)\hat{A}_1$ decreases. In case SS, a decrease in $\hat{A}_1$ deteriorates country h's current account $\dot{b}^h$, as shown by (33), and leads country h's currency to depreciate so much that the relative price of commodity 1 declines ($\omega \uparrow \rightarrow p_1(\omega) \downarrow$), as shown by (34). Consequently, in country h, employment and output increase, which stimulates consumption c^h, and the current account balance is restored. Country f's consumption c^f decreases in both cases FF and SS but the mechanism is quite different. In case FF, a decrease in $\hat{A}_1$ raises the relative price of commodity 1, deteriorates country f's terms of trade, and reduces c^f, while in case SS, it increases the relative price of commodity 2 and reduces country f's employment and consumption.

We next examine the effects on pollution emissions z^h and z^f in case SS. Because country h's output y_1^h is $\hat{A}_1\ell^h$ from (12), and real consumption c^h equals $p_1y_1^h$ from (16) where $\dot{b}^h = 0$ and (17), using $p_1'(\omega)$ in (3), (34), and the first equation in (35), we find

$$\frac{dy_1^h}{d\hat{A}_1} = \frac{d\left(\frac{c^h}{p_1}\right)}{d\hat{A}_1} = \frac{1}{p_1}\frac{dc^h}{d\hat{A}_1} + \left(\frac{1-\gamma}{\omega}\right)\frac{\partial\omega}{\partial \hat{A}_1}c^h < 0. \tag{36}$$

From (10), the two countries' pollution emissions z^h and z^f are

$$z^h = \varphi_1 y_1^h, \quad z^f = \varphi_2 \hat{A}_2 \ell^f(c^f).$$

Therefore, from (13), (35), and (36) we obtain

$$\frac{\partial z^h}{\partial \hat{A}_1}|_{\varphi_1=\text{const.}} = \varphi_1 \frac{dy_1^h}{d\hat{A}_1} < 0, \quad \frac{\partial z^f}{\partial \hat{A}_1} = \varphi_2 \hat{A}_2 \ell^{f\prime} \frac{dc^f}{d\hat{A}_1} > 0,$$

$$\frac{\partial z^h}{\partial \varphi_1} = y_1^h + \varphi_1 \frac{dy_1^h}{d\hat{A}_1} \frac{\hat{A}_1{}^2}{\sigma_1} \gtreqless 0, \quad \frac{\partial z^f}{\partial \varphi_1} = \frac{\hat{A}_1{}^2}{\sigma_1} \frac{\partial z^f}{\partial \hat{A}_1} > 0.$$

Noting that a stricter emission limit φ_1 decreases effective productivity $\hat{A}_1$ from (13), we summarize the above results as follows:

Proposition 2: When both countries face aggregate demand stagnation, a country's stricter emission limit and higher effective productivity yield the following effects on the real price (p) and output (y) of each product, pollution emissions (z), and real consumption (c) in the two countries:

	Policy-setting country (S)				The other country (S)			
	p	y	z	c	p	y	z	c
Stricter emission limit	−	+	±	+	+	−	−	−
Higher effective productivity	+	−	−	−	−	+	+	+

(S) implies stagnation.

Proposition 2 shows that in case SS a reduction in a country's emission limit decreases the other country's consumption and output, thereby reducing its pollution emissions. A stricter emission limit yields negative carbon leakage by deteriorating the other country's business activity.

5. Environmental policies under asymmetric business activities

This section considers the asymmetric case where country h faces stagnation and the other country achieves full employment, which is case SF in (24). We examine the effects of changes in the two countries' emission limits on their real consumption and pollution emissions.

In case SF, where $\ell^h < 1$ and $\ell^f = 1$, from (18) we find

$$\psi_1(\omega)(c^h + c^f) = \hat{A}_1 \ell^h(c^h) \;\Rightarrow\; c^h = g^h(c^f; \omega, \hat{A}_1),$$

$$\psi_2(\omega)(c^h + c^f) = \hat{A}_2,$$

where ω is determined so that the current account given by (16) is in balance. Therefore, using (17), the definition of $\psi_i(\omega)$ in (18), and (20), we find

$$c^h + c^f = \frac{p_2(\omega)\hat{A}_2}{1-\gamma(\omega)}, \quad \ell^h(c^h) = \left(\frac{\hat{A}_2}{\hat{A}_1}\right)\frac{\omega\gamma(\omega)}{1-\gamma(\omega)},$$

$$\dot{b}^h = -c^h + p_1(\omega)\hat{A}_1\ell^h(c^h) = 0, \tag{37}$$

where $\ell^h(c^h)$ is given by (26). The three equations determine c^h, c^f and ω. By partially differentiating the current account $\dot{b}^h$ with respect to ω, using $p_1'(\omega)$ in (3), and assuming the Marshall-Lerner condition, we obtain

$$\text{the Marshall-Lerner condition: } \frac{\partial \dot{b}^h}{\partial \omega} = \left(p_1\hat{A}_1\ell^{h\prime} - 1\right)\frac{\partial c^h}{\partial \omega} - \frac{(1-\gamma)p_1}{\omega}\hat{A}_1\ell^h > 0,$$

$$\frac{\partial c^h}{\partial \omega} = \left(\frac{\hat{A}_2}{\hat{A}_1\ell^{h\prime}}\right)\frac{\omega\gamma}{1-\gamma}\left(\frac{1}{\omega} + \frac{\gamma'}{(1-\gamma)\gamma}\right) = \left(\frac{\ell^h}{\ell^{h\prime}}\right)\left(\frac{1}{\omega} + \frac{\gamma'}{(1-\gamma)\gamma}\right) > 0,$$

$$p_1\hat{A}_1\ell^{h\prime} - 1 > 0, \tag{38}$$

where the last property is found to hold from the other two properties.

The stagnant country's environmental policy

Let us initially consider how a change in the stagnant country h's emission limit affects the two countries' real consumption and pollution emissions. Given the relationship between $\hat{A}_1$ and c^h represented by the second equation in (37), we find that $\dot{b}^h$ given by the third equation in (37) satisfies

$$\frac{\partial \dot{b}^h}{\partial \hat{A}_1} = \frac{\ell^h}{\hat{A}_1\ell^{h\prime}} > 0.$$

The Marshall-Lerner condition in (38) and the above property give

$$\frac{d\omega}{d\hat{A}_1} = -\frac{\partial \dot{b}^h}{\partial \hat{A}_1} \Big/ \frac{\partial \dot{b}^h}{\partial \omega} < 0,$$

implying that a decrease in $\hat{A}_1$ leads to an improvement in country f's terms of trade ($\omega \uparrow$). This benefits country f because it is in full employment. It also benefits the stagnant country because a higher ω (or equivalently, a lower relative price of commodity 1) improves the relative competitiveness of commodity 1 to commodity 2 and increases the stagnant country's output and real consumption.

Let us mathematically obtain the properties mentioned above. From (12) and (37), the output of commodity 1 is

$$y_1^h = \frac{c^h}{p_1}.$$

Therefore, totally differentiating the three equations in (37) and using (38) leads to

$$\frac{dc^h}{d\hat{A}_1} = -\left(\frac{\hat{A}_2}{\hat{A}_1}\right)\left(\frac{\ell^h}{\ell^{h\prime}}\right)\left(\frac{\omega\gamma'}{(1-\gamma)^2} + \frac{\gamma^2}{1-\gamma}\right)p_1\left(\frac{1}{\frac{\partial b^h}{\partial \omega}}\right) < 0,$$

$$\frac{dy_1^h}{d\hat{A}_1} = \frac{d\left(\frac{c^h}{p_1}\right)}{d\hat{A}_1} = \frac{1}{p_1}\frac{dc^h}{d\hat{A}_1} + \left(\frac{1-\gamma}{\omega}\right)\frac{\partial \omega}{\partial \hat{A}_1}c^h < 0,$$

$$\frac{dc^f}{d\hat{A}_1} = -\left(\frac{\hat{A}_2}{\hat{A}_1}\right)\left(\frac{\ell^h}{\ell^{h\prime}}\right)\gamma p_1\left(\frac{1}{\frac{\partial b^h}{\partial \omega}}\right) < 0. \tag{39}$$

From (13), a stricter emission limit of country h lowers $\hat{A}_1$. Therefore, the effects of a decrease in $\hat{A}_1$ obtained above can be reinterpreted as the effects of a stricter emission limit of country h, which is stagnant in the present case.

As for pollution emissions z^h and z^f in case SF, from (21) we have

$$z^h = \varphi_1 y_1^h, \;\; z^f = \varphi_2 \hat{A}_2. \tag{40}$$

Using (13), (39), and (40), we obtain the effects of a change in $\hat{A}_1$ on z^h and z^f when φ_1 is constant, and the effects of a change in φ_1 on them which include the effects through changes in $\hat{A}_1$. They are

$$\frac{\partial z^h}{\partial \hat{A}_1}|_{\varphi_1=\text{const.}} = \varphi_1 \frac{dy_1^h}{d\hat{A}_1} < 0, \quad \frac{\partial z^f}{\partial \hat{A}_1}|_{\varphi_1=\text{const.}} = 0,$$

$$\frac{\partial z^h}{\partial \varphi_1} = y_1^h + \varphi_1 \frac{dy_1^h}{d\hat{A}_1}\frac{\hat{A}_1{}^2}{\sigma_1}\hat{A}_1 \gtreqless 0, \quad \frac{\partial z^f}{\partial \varphi_1} = 0. \tag{41}$$

The following proposition summarizes the results of (39) and (41).

Proposition 3: When a country faces stagnation and the other country achieves full employment, the stagnant country's stricter emission limit and higher effective productivity yield the following effects on the real price (p) and output (y) of each product, pollution emissions (z), and real consumption (c) in the two countries:

	Policy-setting country (S)				The other country (F)			
	p	y	z	c	p	y	z	c
Stricter emission limit	−	+	±	+	+	0	0	+
Higher effective productivity	+	−	−	−	−	0	0	−

From Proposition 3, if a country faces aggregate demand stagnation and the other country achieves full employment (which may currently be the case for developed and developing countries), a stricter emission limit by the stagnant country deteriorates the exchange rate and lowers the relative price of its output, which increases its employment and real consumption. The other country, which is in full employment, also achieves higher real consumption because its terms of trade improve. Thus, there is no international conflict of interest with respect to real consumption. However, the stagnant country's pollution emissions may increase in spite of a stricter emission limit because its output increases.

The full-employment country's environmental policy

Next, we obtain the effects of the full-employment country's stricter emission limit. In the present setting, the full-employment country is country f, whose emission limit is φ_2, and the stagnant country is country h. Therefore, we examine the effects of changes in $\hat{A}_2$ and φ_2.

Totally differentiating the three equations in (37) and rearranging the results leads to

$$\frac{d\omega}{d\hat{A}_2} = -\left(p_1\hat{A}_1\ell^{h\prime} - 1\right)\left(\frac{\ell^h}{\hat{A}_2\ell^{h\prime}}\right)\left(\frac{1}{\frac{\partial \dot{b}^h}{\partial \omega}}\right) < 0,$$

$$\frac{dc^h}{d\hat{A}_2} = -\left(\frac{\ell^h}{\ell^{h\prime}}\right)\gamma p_1\left(\frac{1}{\frac{\partial \dot{b}^h}{\partial \omega}}\right) < 0,$$

$$\frac{dc^f}{d\hat{A}_2} = \left(\frac{\ell^h}{\ell^{h\prime}}\right)\left(\frac{\omega\gamma'}{(1-\gamma)\gamma}\left(p_1\hat{A}_1\ell^{h\prime} - 1\right) - (1-\gamma)\right)p_1\left(\frac{1}{\frac{\partial \dot{b}^h}{\partial \omega}}\right) \gtreqless 0, \qquad (42)$$

where $\ell^{h\prime} > 0$ from (26), and $\partial\dot{b}^h/\partial\omega > 0$ from (38). A rise in $\hat{A}_2$ lowers the relative price of commodity 2, which deteriorates the relative competitiveness of commodity 1 and worsens country h's employment and real consumption. The effect on c^f is ambiguous because a rise in $\hat{A}_2$ reduces the relative price of commodity 2 but expands its output in country f under full employment. If both countries achieve full employment, the latter effect dominates the former, benefiting country f. However, when country h faces stagnation, the reduction in ω is so large that the former effect may dominate the latter; that is, the effect on c^f is ambiguous, as shown by the last equation in (42). From (13), country f's stricter emission limit decreases $\hat{A}_2$; hence, its effects are opposite to those mentioned above.

As for the two countries' pollution emissions, from (13), (40) and (42), we obtain

$$\frac{\partial z^h}{\partial \hat{A}_2} = \varphi_1\hat{A}_1\ell^{h\prime}(c^h)\frac{dc^h}{d\hat{A}_2} < 0, \quad \frac{\partial z^h}{\partial \varphi_2} = \frac{\partial z^h}{\partial \hat{A}_2}\frac{(\hat{A}_2)^2}{\sigma_2} < 0,$$

$$\frac{\partial z^f}{\partial \hat{A}_2}\Big|_{\varphi_2=\text{const.}} = \varphi_2 > 0, \quad \frac{\partial z^f}{\partial \varphi_2} = \hat{A}_2 + \varphi_2\frac{\partial \hat{A}_2}{\partial \varphi_2} > 0.$$

A decrease in φ_2, implying a stricter emission limit by country f, naturally reduces country f's pollution emissions but expands country h's pollution emissions because it increases country h's production; that is, carbon leakage occurs.

Noting that country f is the policy-setting country and attains full employment in the present case, we summarize the above results as follows:

Proposition 4: When one country achieves full employment and the other country faces stagnation, the full-employment country's stricter emission limit and higher effective productivity yield the following effects on the real price (p) and output (y) of each product, pollution emissions (z), and real consumption (c) in the two countries:

	Policy-setting country (F)				The other country (S)			
	p	y	z	c	p	y	z	c
Stricter emission limit	+	−	−	±	−	+	+	+
Higher effective productivity	−	+	+	±	+	−	−	−

A stricter emission limit by the full-employment country reduces its output, resulting in less pollution emissions. It raises the relative price so that the stagnant country's commodity is more competitive, causing its output, pollution emissions, employment and real consumption to increase. Thus, carbon leakage occurs, and world pollution emissions may increase even though the full-employment country reduces its pollution emission limit. The country's output is less, but its relative price rises so that its real consumption may increase.

6. Discussion

Let us finally discuss the effects of clean technology transfer on the source and recipient countries' real consumption and pollution emissions, and the first-best pollution emission limit of the stagnant country.

Clean technology transfer

In international negotiations of global warming countermeasures, a typical policy option is to transfer clean technologies. This lowers pollution emissions generated by production ($\delta \downarrow$) and improves the efficiency of abatement ($\sigma \uparrow$) in the recipient country. This subsection examines how such technology transfers affect real consumption and pollution emissions in the two countries. The effects of the transfers are regarded as the effects of an improvement in the recipient country's effective productivity, as is clear from (13). Thus, having Propositions 1–4 in mind, we summarize the effects as follows:

Proposition 5: If country h transfers a superior clean technology to country f so that δ^f decreases and/or σ^f increases, the following effects appear in the two countries:

	Source country			Recipient country		
Cases	p	$y,\ z$	c	p	$y,\ z$	c
FF	$+$	0	$+$	$-$	$+$	$+$
SS	$-$	$+$	$+$	$+$	$-$	$-$
SF	$+$	$-$	$-$	$-$	$+$	$\pm$
FS	$-$	0	$-$	$+$	$-$	$-$

Note that when the recipient country is in full employment (cases FF and SF), it emits more pollution, even though the source country transfers a superior technology of abatement and a cleaner production technology. This happens because the recipient country leaves its pollution emission limit per output unchanged. The recipient country's firms can then reduce the amount of labor for abatement and reallocate the extra labor to production, thus increasing effective productivity. If a stricter emission limit is set so that effective productivity does not change when the technology is transferred, real consumption is unchanged in both countries and the recipient country emits less pollution. Thus, the source country should require the recipient country with full employment to impose a stricter emission limit when transferring superior abatement and cleaner production technologies.

A large number of clean technology transfers have been implemented through Clean Development Mechanism (CDM) projects under the Kyoto Protocol in order to assist developing countries in achieving sustainable development (see Dechezleprêtre et al., 2009). Jaraitė et al. (2022) evaluate the CDM in Indian manufacturing and find that firms registered with CDM projects increase carbon emissions as well as outputs — findings consistent with our results in the case where the recipient country is in full employment. There is also empirical evidence that the impact of CDM on carbon emissions and sustainable development in recipient countries is ambiguous and politically charged.[10] This suggests that source countries should

[10] Zhang et al. (2018) show that the impact of CDM projects on carbon emissions becomes negative in China as the levels of energy-use technology and carbon emissions reduction technology become higher. Various

require recipient countries to impose stricter limits on polluting emissions when transferring clean technologies.

When the recipient country faces stagnation (cases SS and FS), a technology transfer decreases its pollution emissions even if its emission limit is unchanged. This is because the transfer increases the recipient country's effective productivity, which improves its current account, raises the relative price of its product, and decreases its output and pollution emissions.

Among the above four cases, case SF is arguably the most likely — a transfer from a developed country under stagnation to a developing country with full employment. Such a transfer harms the source country because the relative price of its product increases and its output decreases. The recipient country's real consumption may decrease even though its output and pollution emissions increase because the relative price of its product declines. Thus, from Proposition 3, it is better for the stagnant country to lower its own emission limit than to transfer a clean technology because the former increases real consumption in both countries. In this case, however, pollution emissions in the stagnant country may increase because its output is stimulated. If the stagnant country transfers a clean technology, it should do so under the condition that the recipient country sufficiently decreases its pollution emission limit, as mentioned below Proposition 5.

First-best policy

Propositions 2 and 3 show that the stagnant country's stricter emission limit creates new employment for abatement, which increases real consumption, output, and pollution emissions in that country, whether the other country is in full employment or stagnation. Moreover, the country can achieve the same output with less pollution emissions by lowering the emission limit enough to make firms allocate all residual labor to abatement, leading to less pollution emissions with the same output level. Therefore, the stagnant country can achieve the first-best combination of real consumption and pollution emissions by lowering its emission limit. More precisely, we have the following proposition:

Proposition 6: The stagnant country's first-best policy is to decrease its emission limit enough to achieve full employment. If the emission limit is stricter than the optimal level under full

impacts of CDM projects on sustainable development (social equality, economic growth, and environmental protection) are discussed in Mori-Clement (2019).

employment, the emission limit that just allows the country to reach full employment is the first-best optimal. If the emission limit is looser than the optimal level under full employment, the first-best optimal level equals the optimal level under full employment, which is stricter than the emission limit that just achieves full employment.

7. Conclusions: international emission coordination

In the case of full employment in both countries, a country's small restriction on pollution emissions should benefit both countries if pollution emissions are very harmful and significantly spill over beyond its borders. This is because in this case the harm due to a decrease in net productivity is smaller than the benefit due to less pollution emissions. However, when negotiating the optimal emission limit of each country, a conflict of interest arises because their optimal emission limits differ.

If a country is in stagnation, a stricter emission limit creates new employment for abatement, which stimulates the country's real consumption and production, depreciating the exchange rate and lowering the relative price of its product. Thus, if the other country is in full employment, that country receives the benefit of improved terms of trade and increases real consumption — that is, there is no conflict of interest between the two countries. The stagnant country should further decrease its emission limit until it reaches full employment. Once both countries achieve full employment, however, they face a conflict of interest when determining their individual emission limits, as discussed above.

The first-best policy must be strict enough to achieve full employment in both countries because if there is unemployment, both countries are better off by allocating all the unemployed to abatement. The necessary negotiation is based on the assumption that both countries achieve full employment.

Appendices

Appendix A: Proof of (3)

Under homothetic utility $\hat{u}(.,.)$, once real aggregate consumption c^j is given at each point in time, the optimal levels of c_1^j and c_2^j satisfy

$$\frac{\hat{u}_2\left(c_1^j,c_2^j\right)}{\hat{u}_1\left(c_1^j,c_2^j\right)} = \frac{\hat{u}_2\left(1,c_2^j/c_1^j\right)}{\hat{u}_1\left(1,c_2^j/c_1^j\right)} = \frac{p_2(\omega)}{p_1(\omega)} = \omega, \tag{A1}$$

from which we obtain (2). The consumer price index is chosen so that a change in the relative price ω will not affect the level of $\hat{u}(.,.)$. Inserting $c_1^{(*)}$ and $c_2^{(*)}$, given in (2), into $\hat{u}(.,.)$ then gives

$$\hat{u}\left(\frac{\gamma(\omega)}{p_1(\omega)}c^{(*)}, \frac{1-\gamma(\omega)}{p_2(\omega)}c^{(*)}\right) = \phi\left(c^{(*)}\right)\hat{u}\left(\frac{\gamma(\omega)}{p_1(\omega)}, \frac{1-\gamma(\omega)}{p_2(\omega)}\right) \equiv u\left(c^{(*)}\right),$$

$$\frac{d\hat{u}\left(\frac{\gamma(\omega)}{p_1(\omega)}, \frac{1-\gamma(\omega)}{p_2(\omega)}\right)}{d\omega} = \hat{u}_1 \frac{d\left(\frac{\gamma(\omega)}{p_1(\omega)}\right)}{d\omega} + \hat{u}_2 \frac{d\left(\frac{1-\gamma(\omega)}{p_2(\omega)}\right)}{d\omega} = 0. \quad \text{(A2)}$$

Because $\hat{u}_2/\hat{u}_1 = \omega = p_2(\omega)/p_1(\omega)$ from (A1), the second equation in (A2) yields

$$p_1'(\omega) = -\frac{(1-\gamma)p_1}{\omega} < 0, \quad p_2'(\omega) = \frac{\gamma p_2}{\omega} = \gamma p_1 > 0,$$

which are shown in (3).

Appendix B: Proof of (28)

Given c^f, if c^h is such that $\ell^h(c^h) = 1$ in the first equation of (27), the demand for commodity 1 (the left-hand side) is lower than its supply (the right-hand side). Otherwise, full employment should be reached. Thus, for the stagnation steady state to exist, the left-hand side of the equation must be less inclined with respect to c^h than the right-hand side. The second equation must also satisfy the same property. Therefore, using ψ_1 and ψ_2 in (18), and g^h and g^f in (27), we obtain

$$\frac{\partial g^h(c^f;\omega,\hat{A}_1)}{\partial c^f} = \frac{p_1\hat{A}_1\ell^{h\prime}-\gamma}{\gamma} > 0, \quad \frac{\partial g^f(c^h;\omega,\hat{A}_1)}{\partial c^h} = \frac{p_2\hat{A}_2\ell^{f\prime}-(1-\gamma)}{1-\gamma} > 0. \quad \text{(A3)}$$

Moreover, the two functions satisfy

$$\text{if } c^f = 0, \text{ then } c^h = g^h\left(0;\omega,\hat{A}_1\right) > 0 = c^f;$$

$$\text{if } c^h = 0, \text{ then } c^f = g^f\left(0;\omega,\hat{A}_2\right) > 0 = c^h;$$

because household consumption must be positive even if the other country's consumption is zero. From these properties, the two functions are illustrated as shown in Figure 1. Therefore, if the intersection point of the two functions exists, at that point it must be valid that

$$\frac{\partial g^h}{\partial c^f} < \frac{1}{\left(\frac{\partial g^f}{\partial c^h}\right)}.$$

From (A3), this condition is equivalent to (28).

REFERENCES

Acemoglu, D., P. Aghion, and D. Hémous (2014) "The Environment and Directed Technical Change in a North-South Model", *Oxford Review of Economic Policy*, Vol. 30, pp. 513-

530.

Babiker, M. H. (2005) “Climate Change Policy, Market Structure, and Carbon Leakage”, *Journal of International Economics*, Vol. 65, pp. 421-445.

Baccianti, C. and O. Schenker (2022) “Cournot, Pigou, and Ricardo Walk into a Bar: Unilateral Environmental Policy and Leakage with Market Power and Firm Heterogeneity”, *Journal of the Association of Environmental and Resource Economists*, Vol. 9, No. 6, pp. 1161-1195.

Baylis, K., D. Fullerton, and D. H. Karney (2014) “Negative Leakage”, *Journal of the Association of Environmental and Resource Economists*, Vol. 1, No. 1/2, pp. 51-73.

Cherniwchan, J., B. R. Copeland, and M. S. Taylor (2017) “Trade and the Environment: New Methods, Measurements, and Results”, *Annual Review of Economics*, Vol. 9, pp. 59-85.

Copeland, B. R. and M. S. Taylor (1994) “North-South Trade and the Environment”, *Quarterly Journal of Economics*, Vol. 109, No. 3, pp. 755-787.

Dechezleprêtre, A., M. Glachant, and Y. Ménière (2009) “Technology Transfer by CDM Projects: A Comparison of Brazil, China, India and Mexico”, *Energy Policy*, Vol. 37, pp.703-711.

Di Maria, C. and S. A. Smulders (2004) “Trade Pessimists vs Technology Optimists: Induced Technical Change and Pollution Havens”, *Advances in Economic Analysis & Policy*, Vol. 4, Issue 2, Article 7.

Gerlagh, R. and O. Kuik (2014) “Spill or Leak? Carbon Leakage with International Technology Spillovers: A CGE Analysis”, *Energy Economics*, Vol. 45, pp. 381-388.

Hashimoto, K., Y. Ono, and M. Schlegl (2023) “Structural Unemployment, Underemployment, and Secular Stagnation”, *Journal of Economic Theory*, Vol. 209, Article 105641.

Hémous, D. (2016) “The Dynamic Impact of Unilateral Environmental Policies”, *Journal of International Economics*, Vol. 103, pp. 80-95.

Ikefuji, M. and Y. Ono (2021) “Environmental Policies in a Stagnant Economy”, *Economic Modelling*, Vol. 102, Article 105574.

Illing, G., Y. Ono, and M. Schlegl (2018) “Credit Booms, Debt Overhang and Secular Stagnation”, *European Economic Review*, Vol. 108, pp. 78-104.

Jayadevappa, R. and S. Chhatre (2000) “International Trade and Environmental Quality: A Survey”, *Ecological Economics*, Vol. 32, pp. 175-194.

Jaraitė, J., O. Kurtyka, and H. Ollivier (2022) “Take a Ride on the (not so) Green Side: How do CDM Projects Affect Indian Manufacturing Firms’ Environmental Performance?”, *Journal of Environmental Economics and Management*. Vol. 114, Article 102684.

Levinson, A. and M. S. Taylor (2008) “Unmasking the Pollution Haven Effect”, *International Economic Review*, Vol. 49, No.1, pp. 223-254.

Mian, A. R., L. Straub, and A. Sufi (2021) “The Saving Glut of the Rich”, NBER Working Paper 26941.

Michaillat, P. and E. Saez (2022) “An Economic Business-Cycle Model”, *Oxford Economic Papers*, Vol. 74, Issue 2, pp. 382-411,

Michau, J.-B. (2018) “Secular Stagnation: Theory and Remedies”, *Journal of Economic Theory*, Vol. 176, pp. 552-618.

Mori-Clement, Y. (2019) “Impacts of CDM Projects on Sustainable Development: Improving Living Standards across Brazilian Municipalities?”, *World Development*, Vol. 113, pp.222-236.

Ono, Y. (1994) *Money, Interest, and Stagnation*, Oxford: Clarendon Press.

—— (2001) “A Reinterpretation of Chapter 17 of Keynes’s General Theory: Effective Demand Shortage under Dynamic Optimization”, *International Economic Review*, Vol. 42, No. 1, pp. 207-236.

—— (2006) “International Asymmetry in Business Activity and Appreciation of a Stagnant Country's Currency”, *Japanese Economic Review*, Vol. 57, No. 1, pp. 101-120.

—— (2014) “International Economic Interdependence and Exchange-rate Adjustment under Persistent Stagnation”, *Japanese Economic Review*, Vol. 65, No. 1, pp. 70-92.

—— (2018) “Macroeconomic Interdependence between a Stagnant and a Fully Employed Country”, *Japanese Economic Review*, Vol. 69, No. 4, pp. 450-477.

—— and J. Ishida (2014) “On Persistent Demand Shortages: A Behavioral Approach”, *Japanese Economic Review*, Vol. 65, No. 1, pp. 42-69.

——, K. Ogawa, and A. Yoshida (2004) “Liquidity Preference and Persistent Unemployment with Dynamic Optimizing Agents”, *Japanese Economic Review*, Vol. 55, No. 4, pp. 355-371.

Rauscher, M. (2005) “International Trade, Foreign Investment, and the Environment”, in Mäler, K.-G. and J. R. Vincent (Eds.), *Handbook of Environmental Economics*, Vol. 3, Amsterdam: Elsevier, pp. 1403-1456.

Zhang, Y-J., Y-F. Sun and J. Huang (2018) “Energy Efficiency, Carbon Emission Performance, and Technology Gaps: Evidence from CDM Project Investment”, *Energy Policy*, Vol. 115, pp. 119-130.

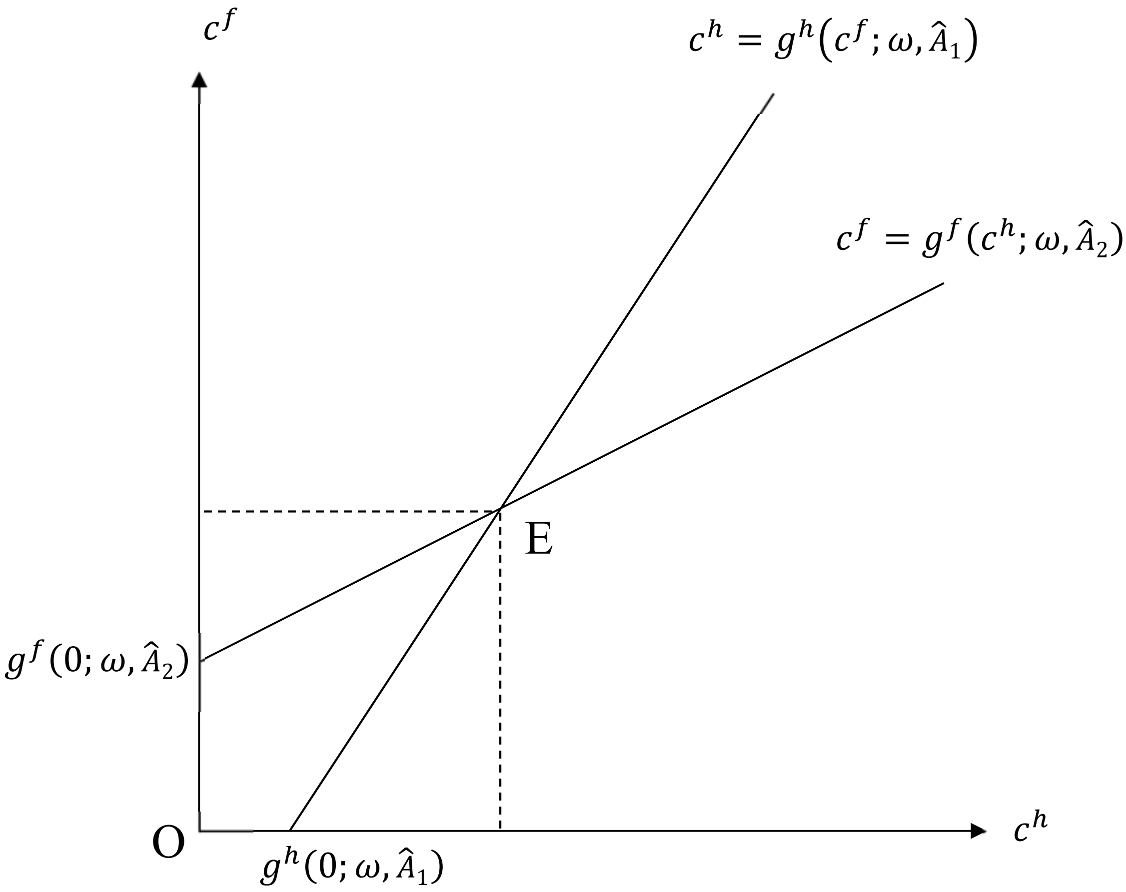

Figure 1: Interdependence of Consumption