Growth, Trade and Climate Change: How the Mutual Effects of Trade and Climate Change shape the World Economy?

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Abstract

This paper examines the link between trade, growth and the environment in a setting where the effect of climate change on the economies is considered. Global air pollution is indeed responsible for climate change and hence for an increasing likelihood of natural disasters (floods, droughts, hurricanes *etc.*). These extreme events damage economic production and are characterized by their unequal repartition across the world. Here, we take it into account in a dynamic model with two countries, North and South. We emphasize that the interactions between pollution and comparative advantages provide new insight regarding the distribution of the gains from trade. In particular, we show that trade does not improve growth anymore for any of the two countries when greenhouse gases stay too long in the atmosphere. We also reveal that even in the extreme case where the North were not affected at all by climate change, it might still have an incentive to reduce global pollution in order to benefit from trade.

1 Introduction

This paper aims at analyzing the mutual interactions between global pollution and the economic activity going through international trade. On one hand, as Grossman & Krueger (1991) identified, international trade may play a crucial role in the way economic activity affects the

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environment, by modifying the size of global production, the composition of economic activity (through countries specialization) and the technology of production (*e.g.* through transmission of knowledge). These elements - called the scale effect, the composition effect and the technical effect respectively - have opposite consequences on the environment, whose signs and levels can evolve across time. For now, it appears that international trade has increased the global emissions and stock of GHG through the scale effect, but the national impact differs according to the country. Indeed, trade has favored specialization in green activities in developed economies, whereas it has induced a specialization in highly-polluting activities in developing countries. In this regard, Managi *et al.* (2009) find that trade has been beneficial to the environment in OECD countries while detrimental for the one in non-OECD countries (especially for SO_2 and CO_2 emissions). Most of the literature on the topic of international trade and pollution focus on explaining this specialization (see Copeland and Taylor , 2004 for a review of the literature). For example, the so-called but discussed pollution haven hypothesis states that the differences in the stringency of environmental regulation are the main driver for trade in dirty goods - by providing a comparative advantage in the polluting production to the developing economies.[1]

On the other hand, the global pollution and especially the stock of greenhouse gases in the atmosphere (hereafter GHG, *e.g.* carbon dioxide, methane, nitrous oxide, or ozone) may have considerable consequences for the economy. Indeed, the substantial amounts of GHG in the atmosphere are responsible for a global climate change which consists in an increase in temperature but also in an increasing occurrence of extreme events (IPCC , 2014). A report of the United Nations Environment Programme and the World Trade Organization recall that "as greenhouse gas emissions and temperatures increase, the impacts from climate change are expected to become more widespread and to intensify" and that "even with small increases in average temperature, the type, frequency and intensity of extreme weather - such as hurricanes, typhoons, floods, droughts, and storms - are projected to increase" (Tamiotti et al , 2009, p viii). This kind of events entails a loss in terms of well-being and generates direct production losses. Climate change seems therefore to represent a threat to human activities that should be considered.

Moreover, all countries are not equal in front of the damages generated by global climate change. A large number of studies highlight the higher vulnerability of the poorest countries to climate change (see *e.g.* IPCC , 2014). The main reasons identified stem from their low-income

[1]See *e.g.* Levinson and Taylor (2008) for explanations of the discussion on the pollution haven hypothesis validity.

preventing them to adapt to such a weather change but also from geographical components (latitude *etc.*). For example, it appears that countries already hot are more exposed (see Steen's report, 2006 or Mendelsohn *et al.* , 2006). These disparities in terms of vulnerability to environmental damages imply that climate change becomes a factor of comparative advantages. Thus, it affects the economy directly through damages and indirectly by modifying its terms of trade. Even if some countries are relatively preserved from the direct consequences of climate change, the cost of global pollution may be transmitted across regions through international trade. Despite a large literature on trade and the environment, this feature is generally omitted from the analysis. An exception is the contribution of Ollivier (2016), where the heterogeneous impact of the pollution on agents' welfare is taken into account in a static model. In this way, the author emphasizes that both North and South can have the comparative advantage in the dirty sector.

According to these numerous interactions between trade, growth and the environment, this relationship change over time. The comparative advantages evolve with the stock of pollution, with the knowledge accumulated in each economy *etc.*, which all shape the long-run behavior of the world economy. Therefore, contrary to what is usually done in this literature, we want to study this relationship in a dynamic framework.

The aim of our paper is, therefore, to reassess the link between trade, growth and the environment in a dynamic setting where the unequal repartition of the effect of climate change on the economy is considered. In particular, we wonder if a developed country, which is by nature less vulnerable to climate change, has an interest in helping a developing country to reduce its emissions, which is more affected by global warming. To answer this question, we formalize a model with two countries, North and South, that can trade two goods - a green good and a brown good whose production generates pollution emissions. The stock of pollution is responsible for damages unequally distributed around the world. There is a risk - increasing with the pollution stock - that extreme events destroy a share of the production, which is larger for the South.

We emphasize that the interactions between pollution and comparative advantages provide new insight regarding the distribution of the gains from trade. In particular, we show that trade does not improve growth anymore for any of the two countries when greenhouse gases stay too long in the atmosphere. Moreover, we reveal that, even in the extreme case where the North were not affected at all by climate change, it might still have an incentive to reduce global pollution in order to benefit from trade.

2 The model

Consider a Ricardian world that consists of two large (industrialized) countries, the North N and the South S. They differ with respect to their total factor productivity and their vulnerability to climate change. They are identical in size, technologies and preferences.

2.1 Production and Pollution

In each competitive economy there are three sectors, one representative firm for each sector and each firm producing one good. The three goods consist in a brown manufactured good produced in quantity $Y_{b,t}$, a consumption good (relatively green) produced in quantity $Y_{g,t}$ and an education services good produced in quantity $Y_{e,t}$. The two first goods are tradable while education services are not. The brown manufactured good is taken as a numeraire. Each sector uses physical capital K_t and human capital H_t, both perfectly mobile between sectors. We assume that the brown good is used to invest in physical capital. The three goods are assumed to be produced with a Cobb-Douglas technology in each country $i \in \{N, S\}$.

$$Y^i_{b,t} = A^i(K^i_{b,t})^{\alpha_b}(H^i_{b,t})^{1-\alpha_b}, Y^i_{g,t} = A^i(K^i_{g,t})^{\alpha_g}(H^i_{g,t})^{1-\alpha_g}, Y^i_{e,t} = A^i(K^i_{e,t})^{\alpha_e}(H^i_{e,t})^{1-\alpha_e} \tag{1}$$

where $0 < \alpha_b, \alpha_e, \alpha_g < 1$ is the distribution parameter for factors and $A^i > 0$ is the total factor productivity in country $i \in \{N, S\}$. In the following, we suppose that the brown manufactured sector is more physical capital intensive than the green and the education sectors.

Assumption 1. $\alpha_b > \alpha_g > \alpha_e$

We assume that the flow of pollution is a by-product of the production of the brown good, so that pollution emissions are defined as:

$$E^i_t = a^i_t Y^i_{b,t} \tag{2}$$

The parameter a^i_t measures the carbon intensity of the brown good, *i.e.* the pollution released per unit of $Y^i_{b,t}$. It is reduced by the current stock of knowledge in the domestic economy $\bar{h}^i$, expressing the ability of the country to have greener technologies, so that:

$$a^i_t = \frac{\theta}{\bar{h}_t^{\,i}} \tag{3}$$

The traditional decomposition of the effects of growth on the environment corresponds to the following: the *scale effect*, the *composition effect* and the *technique effect*. Given our definition of the emission flows, the *scale effect* comes with the increase in the level of the brown production. The *composition effect* is captured by the change in the share of the brown good production in the national income, while the *technique effect* is captured by the change in the emission intensity of brown production a_t^i. All other things being equal, when a_t^i goes down pollution emissions go down as well.

The pollution flow is thus given by this expression:

$$E_t^i = \frac{\theta Y_{b,t}^i}{\bar{h}_t^i} \tag{4}$$

The global stock of pollution, representing the stock of greenhouse gases in the atmosphere, increases with the emission flows of each country and partly leaves the atmosphere through a natural process in a share α.

$$P_{t+1} = (1-\alpha)P_t + \sum_{i \in N,S} E_t^i \tag{5}$$

At each period, this stock of pollution causes a damage that destroys a part $D^i(P_t)$ of production in each sector.

Assumption 2 $D^i(P_t) = \nu^i P_t/(1+\nu^i P_t)$ *with* $\nu^i \in (0, \bar{\nu}^i)$.

The parameter ν^i captures the magnitude of damage. The higher ν^i, the less a country can adapt itself to a given pollution stock. As empirical evidence suggests that developed countries (North) are less vulnerable to climate change than developing countries (South), we assume that the North does not suffer from climate change (i.e $\nu^N = 0$). This assumption enables us to represent the significant difference in terms of vulnerability (due to geographical reasons and ability to adapt) in a simple way. For the North, we hence focus on the effects of climate change that occur through the terms of trade.[2]

2.2 Consumption

Consider an overlapping generations economy, with discrete time indexed by $t = 0, 1, 2, ..., \infty$. At each date t, a new generation of identical agents is born. We assume no population growth and

[2]Note that if we emphasize that international trade is costly for the North in this extreme case, the cost will be even larger by taking into account the direct effects of climate change on the economy.

we normalize to one the population size of each generation. Households in country i live for three periods - childhood, adulthood and old age - but take all decisions during their second period of life. A representative agent born in $t-1$ cares about her consumption when adult and old (c_t^i and d_{t+1}^i respectively), her child's human capital (h_{t+1}^i) and about the current and future level of pollution (P_t and P_{t+1}). Intertemporal preferences of the representative agent are described by the following utility function:

$$U\left(c_t^i, d_{t+1}^i, h_{t+1}^i, P_t, P_{t+1}\right) = \ln c_t^i + \beta \ln d_{t+1}^i + \gamma \ln h_{t+1}^i - \frac{P_t^{1+\sigma}}{1+\sigma} - \frac{P_{t+1}^{1+\sigma}}{1+\sigma} \tag{6}$$

where $\beta > 0$ captures time preferences, $\gamma > 0$ the degree of altruism and $\sigma > 0$.

During childhood, individuals acquire human capital. When adult, they supply inelastically one unit of labor remunerated at wage w_t per unit of human capital h_t^i. They allocate this income to consumption c_t^i, education of children e_t^i and savings s_t^i. When old, agents are retired and use entirely the return on their savings $R_{t+1}^i s_t^i$ to consume d_{t+1}^i.[3] Therefore, the two budget constraints for an adult born in $t-1$ are:

$$p_{e,t}^i e_t^i + p_{g,t}^i c_t^i + s_t^i = w_t^i h_t^i \tag{7}$$

where $p_{e,t}^i$ (*resp.* $p_{g,t}^i$) is the relative price of education services (*resp.* of the green good) in terms of the brown good.

$$p_{g,t+1}^i d_{t+1}^i = s_t^i R_{t+1}^i \tag{8}$$

The human capital of a child born in t (h_{t+1}^i) depends on education spending e_t^i and on parent's human capital h_t^i (*i.e.* intergenerational transmission).

$$h_{t+1}^i = \epsilon (h_t^i)^{1-\mu} (e_t^i)^{\mu} \tag{9}$$

where $\epsilon > 0$ is an efficiency parameter and $\mu \in (0,1)$ is the relative weight of education in human capital accumulation.

[3]Note that we could consider the case where consumption is a composite of brown and green consumptions. It would imply to assume that the brown sector produces a composite good used to save and to consume. However, it would make the analysis much more complex without changing the results (as long as the elasticity of substitution between brown and green consumption goods is one).

Thus, the representative agent solves the following dynamic program:[4]

$$
\begin{aligned}
\max_{s_t^i, e_t^i} \quad & U\left(c_t^i, d_{t+1}^i, h_{t+1}^i, P_t, P_{t+1}\right) \\
s.t. \quad & p_{e,t}^i e_t^i + p_{g,t}^i c_t^i + s_t^i = w_t^i h_t^i \\
& p_{g,t+1}^i d_{t+1}^i = s_t^i R_{t+1}^i \\
& h_{t+1}^i = \epsilon (h_t^i)^{1-\mu} (e_t^i)^{\mu}
\end{aligned} \tag{10}
$$

Solving the first-order conditions give:

$$s_t^i = \frac{\beta}{1+\beta+\gamma\mu} w_t^i h_t^i, \tag{11}$$

$$p_{g,t}^i c_t^i = \frac{1}{1+\beta+\gamma\mu} w_t^i h_t^i \tag{12}$$

$$p_{g,t+1}^i d_{t+1}^i = \frac{\beta}{1+\beta+\gamma\mu} R_{t+1}^i w_t^i h_t^i \tag{13}$$

$$p_{e,t}^i e_t^i = \frac{\gamma\mu}{1+\beta+\gamma\mu} w_t^i h_t^i \tag{14}$$

Note that the presence of pollution in the utility function is usual but without consequences for the analysis because we focus our attention on the decentralized economy. The agent has no impact on the current level of pollution while he does not internalized the impact of her choices on the future environmental quality.

3 The Autarky

In this section, we present the equilibrium and the dynamics for a country i which is sensitive to pollution (i.e $\nu^i > 0$) but not integrated to international trade.

3.1 Equilibrium

At the autarky equilibrium all markets clear in each period. For the sake of simplicity the superscript i is removed in this section.

[4]Under perfect foresight and perfect competition w_t^i and R_{t+1}^i are considered as given by agents.

Definition 1.

i⌋ Households are at their optimum: the FOC (11)-(14) are satisfied;

ii⌋ The labor market clears $H_t = h_t = \bar{h}_t$*;*

iii⌋ Aggregate human capital is accumulated according to $H_{t+1} = H_t^{1-\mu} e_t^{\mu}$*;*

iv⌋ The physical capital accumulation equation is given by $K_{t+1} = H_{t+1}k_{t+1} = s_t$*;*

v⌋ The market clearing condition for the manufactured good is given by $(1 - D(P_t))Y_{b,t} = s_t$*;*

vi⌋ The market clearing condition for the education sector is given by $(1 - D(P_t))Y_{e,t} = e_t$*;*

vii⌋ The market clearing condition for the green sector is given by $(1 - D(P_t))Y_{g,t} = c_t + d_t$*;*

viii⌋ Equation (4) gives the equilibrium value of the pollution flow.

In order to derive the dynamic system that drives the evolution of the economy across times, we first determine the factor prices. The profit of a representative firm in each of the three sectors are represented by

$$\begin{aligned} \Pi_b &= (1 - D(P_t))Y_{b,t} - R_t K_{b,t} - w_t H_{b,t}; \\ \Pi_g &= (1 - D(P_t))Y_{g,t}p_{g,t} - R_t K_{g,t} - w_t H_{g,t}; \\ \Pi_e &= (1 - D(P_t))Y_{e,t}p_{e,t} - R_t K_{e,t} - w_t H_{e,t} \end{aligned} \tag{15}$$

Let us define, $k_{j,t} = K_{j,t}/H_{j,t}$ the capital intensity of sector $j \in \{b, g, e\}$ and $h_{j,t} = H_{j,t}/H_t$ the share of human capital allocated to sector j. We derive from the profit maximization, the following factor prices:

$$\begin{aligned} R_t &= (1 - D(P_t))A_b\alpha_b k_{b,t}^{\alpha_b - 1} = (1 - D(P_t))A_g p_{g,t}\alpha_g k_{g,t}^{\alpha_g - 1} = (1 - D(P_t))A_e p_{e,t}\alpha_e k_{e,t}^{\alpha_e - 1} \\ w_t &= (1 - D(P_t))A_b(1 - \alpha_b)k_{b,t}^{\alpha_b} = (1 - D(P_t))A_g p_{g,t}(1 - \alpha_g)k_{g,t}^{\alpha_g} = (1 - D(P_t))A_e p_{e,t}(1 - \alpha_e)k_{e,t}^{\alpha_e} \end{aligned} \tag{16}$$

Solving the associated first-order conditions (16), gives the optimal demand function for physical and human capital:

$$\frac{k_{g,t}}{k_{b,t}} = \frac{(1-\alpha_b)\alpha_g}{(1-\alpha_g)\alpha_b}, \frac{k_{g,t}}{k_{e,t}} = \frac{(1-\alpha_e)\alpha_g}{(1-\alpha_g)\alpha_e}, \frac{k_{e,t}}{k_{b,t}} = \frac{(1-\alpha_b)\alpha_e}{(1-\alpha_e)\alpha_b} \tag{17}$$

Then, we deduce from equation (16) and (17), that the relative price of the green good $p_{g,t}$ and the relative price of the education service $p_{e,t}$ are:

$$p_{g,t} = \left(\frac{k_{b,t}}{\Lambda_b}\right)^{\alpha_b - \alpha_g} \frac{A_b}{A_g}, \quad p_{e,t} = \left(\frac{k_{b,t}}{\Lambda_e}\right)^{\alpha_b - \alpha_e} \frac{A_b}{A_e}, \tag{18}$$

with

$$\Lambda_b = \left(\frac{\alpha_g}{\alpha_b}\right)^{\frac{\alpha_g}{\alpha_b-\alpha_g}} \left(\frac{1-\alpha_g}{1-\alpha_b}\right)^{\frac{1-\alpha_g}{\alpha_b-\alpha_g}}, \qquad \Lambda_e = \left(\frac{\alpha_e}{\alpha_b}\right)^{\frac{\alpha_b}{\alpha_b-\alpha_e}} \left(\frac{1-\alpha_e}{1-\alpha_b}\right)^{\frac{1-\alpha_b}{\alpha_b-\alpha_e}}$$

From (18), we deduce that the relative price of the education service is a function of the relative price of green good and the physical capital used in brown sector:

$$p_{e,t} = \frac{\Lambda_b^{\alpha_b-\alpha_g}}{\Lambda_e^{\alpha_b-\alpha_e}} k_{b,t}^{\alpha^g-\alpha_e} p_{g,t} \frac{A_e}{A_g} \equiv p_e(p_{g,t}, k_{b,t}) \tag{19}$$

Full employment of factors holds such that $K_t = K_{b,t} + K_{g,t} + K_{e,t}$ and $H_t = H_{b,t} + H_{g,t} + H_{e,t}$. Let us define $k_t = K_t/H_t$ the physical to human capital ratio, then we derive that $k_t = k_{b,t}h_{b,t} + k_{g,t}h_{g,t} + k_{e,t}h_{e,t}$ and $1 = h_{b,t} + h_{g,t} + h_{e,t}$. Using the last two expressions and equation (17), we can express the human capital used in brown sector $h_{b,t}$ as:

$$h_{b,t} = \frac{\frac{k_t}{k_{b,t}}(1-\alpha_g)(1-\alpha_e)\alpha_b - \alpha_g(1-\alpha_b)(1-\alpha_e) - (1-\alpha_b)(\alpha_e-\alpha_g)h_{e,t}}{(1-\alpha_e)(\alpha_b-\alpha_g)} \tag{20}$$

From (1), (11), (16) with conditions $ii\rfloor$ and $v\rfloor$ in Definition 1, the share of human capital allocated to the brown sector is:

$$h_{b,t} = \frac{\beta(1-\alpha_b)}{1+\beta+\gamma\mu} \equiv h_b$$

From (1), (14), (16) with conditions $ii\rfloor$ and $vi\rfloor$ in Definition 1, the share of human capital allocated to the education sector is:

$$h_{e,t} = \frac{\gamma\mu}{1+\beta+\gamma\mu}(1-\alpha_e) \equiv h_e$$

Even if education spending and savings are negatively affected by the pollution stock, the share of human capital allocated to each sector is constant and does not depend on the damage generated by pollution. This is explained by the fact that the demand for education or investment good go down in the same proportion that the net supply of these good when a damage occurs, as we assume that the damage translates into a fall in the returns of factors.

Combine these two equations with (20) we obtain:

$$k_{b,t} = \frac{(1-\alpha_g)\frac{\alpha_b(1+\beta+\gamma\mu)}{1-\alpha_b}}{\beta\alpha_b+\alpha_g+\gamma\mu\alpha_e} k_t \tag{21}$$

Let us now, characterize the dynamical system, namely the physical capital accumulation equation, the human capital equation and the flow of pollution. We derive the physical capital accumulation equation from condition $ii]$ in Definition 1, the agents' optimal choices (11) and equation (21):

$$k_{t+1} = \frac{A_b\beta(1-\alpha_b)(1-D(P_t))^{1-\mu}}{\epsilon A_e^{\mu}(\gamma\mu)^{\mu}[1+\beta+\gamma\mu]^{1-\mu}\left[(1-\alpha_b)\Lambda_b^{\alpha_b-\alpha_e}\right]^{\mu}} \left(\frac{(1-\alpha_g)\frac{\alpha_b(1+\beta+\gamma\mu)}{1-\alpha_b}}{\beta\alpha_b+\alpha_g+\gamma\mu\alpha_e}\right)^{\alpha_b-\mu\alpha_e} k_t^{\alpha_b-\mu\alpha_e} \tag{22}$$

From human capital accumulation function condition, $iii]$ in Definition 1 and education choice (14), we deduce:

$$H_{t+1} = \epsilon\left(\frac{A_e\gamma\mu}{1+\beta+\gamma\mu}\right)^{\mu} k_{b,t}^{\mu\alpha_b}\left[\frac{(1-D(P_t))(1-\alpha_b)}{p_{e,t}}\right]^{\mu} H_t$$

Using this last expression and equations (18) and (21), we can write the human capital accumulation in terms of P_t, H_t and k_t:[5]

$$H_{t+1} = \epsilon\left(\frac{A_e\gamma\mu\Lambda_e^{\alpha_b-\alpha_e}(1-\alpha_b)(1-D(P_t))}{1+\beta+\gamma\mu}\right)^{\mu}\left(\frac{(1-\alpha_g)\frac{\alpha_b(1+\beta+\gamma\mu)}{1-\alpha_b}}{\beta\alpha_b+\alpha_g+\gamma\mu\alpha_e}\right)^{\mu\alpha_e} k_t^{\mu\alpha_e} H_t \tag{23}$$

From (1), (4), (18) and (20), the flow of pollution at the autarky equilibrium is given by

$$E_t = \theta A_b\left(\frac{\alpha_b(1+\beta+\gamma\mu)(1-\alpha_g)k_t}{(1-\alpha_b)[\beta\alpha_b+\alpha_g+\gamma\mu\alpha_e]}\right)^{\alpha_b}\left(\frac{\beta(1-\alpha_b)}{1+\beta+\gamma\mu}\right) \equiv f_E(k_t) \tag{24}$$

3.2 Dynamics and Balanced Growth Path

Then, in the light of the above consideration, we derive the dynamical system for the South economy. From (5), (22), (23) and (24), it reduces to the following system:

$$P_{t+1} \equiv (1-\alpha)P_t + f_E^N(k_t^N) + f_E^S(k_t^S) \tag{A}$$

$$k_{t+1}^S \equiv F_k^S(P_t, k_t^S) \tag{B}$$

$$k_{t+1}^N \equiv F_k^N(k_t^N) \tag{C}$$

$$H_{t+1}^S \equiv F_H^S(P_t, k_t^S)H_t^S \tag{D}$$

Given the transnational aspect of pollution, the evolution of an economy vulnerable to climate change depends on the characteristics of other countries. As a result, the South is affected by the dynamics of capital accumulation in the North, that directly contributes to the pollution stock.

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[5] In the North k_t disappear since the vulnerability is assumed to be null.

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Definition 2. *We define a Balanced Growth Path (BGP) as an equilibrium where the physical and human capital stock grow at a constant and same rate g^i. Thus, along the BGP the per-unit-of-effective-labor variables and the stock of pollution are constant.*

Lemma 1 *From (A) to (D) and Definition 2, along the BGP we obtain:*

$$\bar{k}^S = \left(\frac{A_b^S \mathcal{X}(1-\alpha_b)^{1-\mu}}{A_e^S \Lambda_e^{(\alpha_b-\alpha_e)\mu}} \times \left[\frac{(1-\alpha_g)(1+\beta+\gamma\mu)\alpha_b}{(1-\alpha_b)(\beta\alpha_b+\alpha_g+\gamma\mu\alpha_e)}\right]^{\alpha_b-\alpha_e\mu} \times \left[1-D(\bar{P})\right]^{1-\mu} \right)^{\frac{1}{1-\alpha_b+\mu\alpha_e}}$$

$$\bar{k}^N = \left(\frac{A_b^N \mathcal{X}(1-\alpha_b)^{1-\mu}}{A_e^N \Lambda_e^{(\alpha_b-\alpha_e)\mu}} \times \left[\frac{(1-\alpha_g)(1+\beta+\gamma\mu)\alpha_b}{(1-\alpha_b)(\beta\alpha_b+\alpha_g+\gamma\mu\alpha_e)}\right]^{\alpha_b-\alpha_e\mu} \right)^{\frac{1}{1-\alpha_b+\mu\alpha_e}}$$

$$1+g^S = \left(\frac{\epsilon^{1/\mu}(1-\alpha_b)\gamma\mu\Lambda_b^{\alpha_b-\alpha_e}}{1+\beta+\gamma\mu}\right)^{\frac{\mu(1-\alpha_b)}{1-\alpha_b+\mu\alpha_e}} \times \left(\frac{A_b^S\beta\alpha_b(1-\alpha_g)}{\beta\alpha_b+\alpha_g+\gamma\mu\alpha_e}\right)^{\frac{\mu\alpha_e}{1-\alpha_b+\mu\alpha_e}} \times \left[1-D(\bar{P})\right]^{\frac{\mu(1-\alpha_b+\alpha_e)}{1-\alpha_b+\mu\alpha_e}} \left(A_e^S\right)^{\frac{\mu(1-\alpha_b)}{1-\alpha_b+\mu\alpha_e}}$$

$$\bar{P} = \frac{\theta}{\alpha}\left(\frac{\beta(1-\alpha_b)}{1+\beta+\gamma\mu}\right)\left(\frac{\mathcal{X}}{\Lambda_e^{(\alpha_b-\alpha_e)\mu}} \times \frac{(1-\alpha_g)(1+\beta+\gamma\mu)\alpha_b}{(1-\alpha_b)^{\mu}[\beta\alpha_b+\alpha_g+\gamma\mu\alpha_e]}\right)^{\frac{\alpha_b}{1-\alpha_b+\mu\alpha_e}} \left(\left[\frac{(A_b^N)^{1+\mu\alpha_e}}{(A_e^N)^{\alpha_b}}\right]^{\frac{1}{1-\alpha_b+\mu\alpha_e}} + \left[1-D(\bar{P})\right]^{(1-\mu)\alpha_b}\left[\frac{(A_b^N)^{1+\mu\alpha_e}}{(A_e^N)^{\alpha_b}}\right]^{\frac{1}{1-\alpha_b+\mu\alpha_e}}\right)$$

with

$$\mathcal{X} = \frac{\beta}{\epsilon(\gamma\mu)^{\mu}\left[1+\beta+\gamma\mu\right]^{1-\mu}}$$

Proof. See Appendix ■

In the following, we analyze the exitence of a stable BGP in an economy where pollution stock creates a damage on production. From Lemma 1, we directely deduce the following Proposition:

Proposition 1 *In a country vulnerable to climate change, there is a unique stable BGP characterized by $\bar{k}^S = f_k^S(\alpha,\nu)$, $1+g^S = f_G^S(\alpha,\nu)$ and $\bar{P} = f_P(\alpha,\nu)$. Under the following conditions:*

$$f_G(\alpha,\nu) > 1 \qquad (c_1)$$

this BGP is non-degenerate. With $\partial f_k^S/\partial\alpha > 0$, $\partial f_k^S/\partial\nu > 0$,

The condition to obtain a sustainable BGP in a vulnerable country (c_1) requires a sufficiently low level of damage and hence of the pollution stock. The damage entails by pollution reduces the return of factors. It acts as a negative income effect that translates into a fall in education spending and savings that brakes the accumulation of human capital. As a result, when the damage of pollution is too important, the economy cannot achieve a sustainable state with positive growth in the long run. The cost of climate change depends on two important parameters: the natural absorption of pollution by the environment (α) and the magnitude of damage (ν). We can deduce:

Corollary 1 *When the natural absorption of pollution is too low ($\alpha < \bar{\alpha}$) and/or that the magnitude of damage is too high (ν high), an economy vulnerable to climate change is stuck into a povery trap.*

Proof. The pollution stock is a decreasing function of α and when $\alpha = 0$, $\bar{P}$ tends to infinity and the condition (c_1) to observe sustainable BGP cannot be satisfied. ■

When the natural absorption of carbon emission by Nature is not sufficient the critical threshold of pollution under which the economy can perpetually grow is undertaken.

Finally, the magnitude of the damage, that is captured by ν, is determining to achieved a long-term sustainable state. This parameter can be viewed as an indicator of the capacity to adapt to climate change or as an indicator of the exposure of a country to clilate change. As long as a country cannot protect to environmental damage, the production looses generate by pollution are too high to ensure a positive rate of growth in the long run.

4 World economy with free-trade

How international trade affects the growth rate of each country and the global stock of pollution? This section examines the pattern of specialization and its consequences on growth and pollution when there is free-trade in the brown and green good while production factors, human and physical capital, are immobile across countries. Our objective in this section is to examine the conditions under which the world trading equilibrium leads to a higher or a lower long-term growth rate than the Autarky equilibrium, by focusing on the channel of pollution. For this aim, we consider the situation where without damages generated by climate change, openness to trade improves the growth rate of each country.

4.1 The trade structure

With free trade in the output of the green and brown sectors, the world relative price of the green good in terms of the brown good at each t is equal to $p_{g,t}^{W}$ and is common to North and South. The dynamic trade structure that we consider is similar to those proposed by Yenokyan *et al.* (2014), in which we include pollution issues.

Given the heterogeneity between countries, we cannot observe an imperfect specialization of both countries simultaneously. Indeed, the factor price equalization across sector, *i.e* the equality given by equation (16), cannot be satisfied for the North and the South if the relative price of good is equal between countries. Thus, two scenarios emerge: a perfect specialization of the world, where each country produces a tradable good (and its education services) and an imperfectly specialized world where one country produces the two tradable goods while the other is specialized in the production of a unique tradable good.

To conduct our analysis, we consider that the Autarky BGP defines the initial conditions for the world economy with international trade. As previously mentioned, the world economy is formed by two countries that exhibit different sectoral factor productivities and are unequal as regards the negative consequences of climate change. Without loss of generality, we formulate the following assumptions for the rest of the analysis, in order to ensure the existence of trade and to concentrate our attention to specific cases.

First, we assume that the growth rate is initially higher in the North than in the South. To this aim, we consider the case where the North is more productive in all sectors.

Assumption 3 . $g^N > g^S \Leftrightarrow A_j^N > A_j^S \ \forall j$

Proof. Directly from Lemma 1 ■

Then, we focus on initial conditions such that both economies are along a long-term sustainable state before openness to trade, i.e the condition given in Proposition 1 is satisfied. In this context, we going to examine if international trade can deteriorate this situation.

Assumption 4 . $f_G(\alpha, \nu) > 1$

Finally, we formulate an assumption to direct the initial comparative advantage. More precisely, we assume that the productivity in the sector producing education services is sufficiently high in the North such that this country has a comparative advantage to produce the tradable good intensive in human capital, i.e the green good.

Assumption 5 . $\bar{p}_g^N < \bar{p}_g^S \Leftrightarrow A_e^N > \bar{A}_e^N$

Proof. From (18) and Lemma 1 we have

$$\bar{p}_g^N = \left(\frac{A_b^N \mathcal{X} (1-\alpha_g)(1+\beta+\gamma\mu)\alpha_b}{A_e^N \Lambda_e^{(\alpha_b-\alpha_e)\mu} \left[\beta\alpha_b + \alpha_g + \gamma\mu\alpha_e\right](1-\alpha_b)^{\mu}} \right)^{\frac{\alpha_b-\alpha_g}{1-\alpha_b+\mu\alpha_e}} \left(\frac{1}{\Lambda_b}\right)^{\alpha_b-\alpha_g} \frac{A_b^N}{A_g^N} \tag{25}$$

$$\bar{p}_g^S = \left(\frac{A_b^S \mathcal{X} (1-\alpha_g)(1+\beta+\gamma\mu)\alpha_b(1-D(\bar{P}))^{1-\mu}}{A_e^S \Lambda_e^{(\alpha_b-\alpha_e)\mu} \left[\beta\alpha_b - +\alpha_g + \gamma\mu\alpha_e\right](1-\alpha_b)^{\mu}} \right)^{\frac{\alpha_b-\alpha_g}{1-\alpha_b+\mu\alpha_e}} \left(\frac{1}{\Lambda_b}\right)^{\alpha_b-\alpha_g} \frac{A_b^S}{A_g^S} \tag{26}$$

■

In Autarky, the pollution stock does not affect the North, given the simplifying assumption that the damage is infinitely small for this region. Reversely, the stock of pollution creates a damage in the South that favors the green sector and translates into a lower relative price of green good. This is because the damage affects more heavily physical than human capital accumulation and that the brown good is physical capital intensive. Indeed, there is a linear relationship between savings and the stock of physical capital while the stock of human capital is a decreasing returns to scale function of education spendings ($\mu < 1$). Given these characteristics, the fall of income induced by the damage creates a distortion that favors the stock of human capital. As the green good is intensive in this factor, the relative price goes down. We assume that the productivity in the education sector is more stringent in the North such that, despite the negative effect of damage on the relative price of good for the South, the green good is relatively less expensive in the North than in the South.

The equilibrium with free trade is dependent on the world price p_g^W. Since education good is nontraded between countries the equilibrium for education sector remains determined by the market clearing condition $v]$ in Definition 1. Reversely, the equilibrium on the green and brown goods market are now governed by the trade balanced condition:

$$\chi_{b,t}^i + p_{g,t}^W \chi_{g,t}^i = 0 \tag{27}$$

where $\chi_{b,t}^i$ is the net export of the brown good in country i at time t and $\chi_{g,t}^i$ is the net export of the green good in country i at time t. Since the net export of goods of one country are the net export of the other country, we have:

$$\chi_{b,t}^N + \chi_{b,t}^S = 0, \;\; \chi_{g,t}^N + \chi_{g,t}^S = 0 \tag{28}$$

The key variable that guarantees world general equilibrium with international trade is the world relative price $p_{g,t}^{W}$. The world price has to be between the prices that prevail in countries if they decide not to specialize, $p_{g,t}^{i'}$. As the two countries cannot simultaneously produce both goods we note $p_{g,t}^{N'}$ the price that prevails in the North if it produces both goods while the South produces only one and $p_{g,t}^{S'}$ the price in the South if it decides to produce both goods while the North produce only one. The trade pattern will depend on the value of the world relative price $p_{g,t}^{W}$ compare with $p_{g,t}^{N'}$ and $p_{g,t}^{S'}$.

Let us focus first on the trade pattern along the balanced growth path.

4.2 Balanced growth path in the world economy

In our endogenous growth model, when a country is not perfectly specialized it necessarily grows in the long run at a higher rate than the specialized one. Indeed, if the specialized country grows faster, its demand for the good not produced at home grows at a higher rate than the supply of this good. Such situation cannot be stable and the world relative price equilibrium adjusts until a stable situation, where both countries grow at the same rate or where the unspecialized country grows faster, is achieved. Given the fact that the unspecialized country grows at a higher rate in the long run, this country dictates the world relative price. If the North produces both goods it grows at a higher rate than the South and the world relative price is given by its Autarky relative price, i.e we have $\bar{p}_g^{N'} = \bar{p}_g^{N} = \bar{p}_g^{W}$. For the South, the situation is more complex as the pollution stock, and hence the damage, is not the same in the international context with trade than in Autraky. The pattern of specialization for the South depends on the level of the pollution stock that would be achieved when the South produces both goods while the North is specialized. Given Assumptions 3 and 5, the case where the South is imperfectly specialized is not a stable situation because this country cannot grow at a higher growth rate than the North. In line with Yenokyan et al. (2014), we define the different situations that can characterize the long-term equilibrium with international trade and pollution.

Definition 3 *Under Assumptions 3 and 5, the BGP with international trade satisfied Definition 2 and is characterized by a constant world relative price of good $\bar{p}_g^{W}$ with one of these situations:*

a. An interior situation where the North and the South are perfectly specialized.

a.1. The North produces the green good while the South is specialized in the brown production: $\bar{p}_g^{N} < \bar{p}_g^{W} < \bar{p}_g^{S'}$

a.2. The South produces the green good while the North is specialized in the brown production: $\bar{p}_g^{S'} < \bar{p}_g^W < \bar{p}_g^N$

b. A corner situation where the South is perfectly specialized in the production of the brown good while the North produces both goods: $\bar{p}^N = \bar{p}_g^W < \bar{p}^{S'}$.

The case where the South specializes in the production of green good, $\bar{p}_g^{S'} < \bar{p}_g^N$ (that corresponds to a reversal of comparative advantages) while the North produces both goods is excluded. A reversal of comparative advantage requires that openness to trade increases sufficiently the stock of pollution such that the South becomes relatively more productive in the green production. The situation where the North produces both goods and the South only the green good necessarily entails a pollution stock lower than in the Autraky case and hence is not compatible with a reversal of comparative advantage.

4.3 Trade pattern along the balance growth path

To identify the pattern of specialization in the long run and its implications in terms of growth and pollution we have to determine the world relative price $\bar{p}_g^W$. In the corner case, it is given by $\bar{p}_g^N$ (equation (25)). In the Interior case, it must fall between $\bar{p}_g^N$ and $\bar{p}_g^{S'}$ and it is determined by free trade equilibrium with perfect specialization. Without loss of generality, we present the case $a.1$ where the North produces the green good while the South produces the brown good. Both countries continue to produce the good used to accumulate human capital Y_e.

The equilibrium on the goods markets with consumer's FOC and balance trade equations give the following expressions:

$$k_{g,t}^T = \left(\frac{\alpha_g(1+\beta+\gamma\mu)}{(1+\beta)\alpha_g + \alpha_e\gamma\mu} \right) k_t^{ST} \equiv \mathcal{A}_1 k_t^{NT}$$

$$k_{b,t}^T = \left(\frac{\alpha_b(1+\beta+\gamma\mu)}{(1+\beta)\alpha_b + \alpha_e\gamma\mu} \right) k_t^{ST} \equiv \mathcal{A}_2 k_t^{ST}$$

The equalization of factor's return between education and consumption sectors in the North and between education and manufactured sectors in the South allows to obtain:

$$p_{e,t}^{NT} = p_{g,t}^W \frac{A_g^N}{A_e^N} \left(\frac{\alpha_g}{\alpha_e}\right)^{\alpha_e} \left(\frac{1-\alpha_g}{1-\alpha_e}\right)^{1-\alpha_e} (k_{g,t}^T)^{\alpha_g-\alpha_e} \equiv \frac{A_g^N}{A_e^N} p_{g,t}^W \mathcal{B}_1 (k_{g,t}^T)^{\alpha_g-\alpha_e}$$

$$p_{e,t}^{ST} = \frac{A_b^S}{A_e^S} \left(\frac{\alpha_b}{\alpha_e}\right)^{\alpha_e} \left(\frac{1-\alpha_b}{1-\alpha_e}\right)^{1-\alpha_e} (k_{b,t}^T)^{\alpha_b-\alpha_e} \equiv \frac{A_b^S}{A_e^S} \mathcal{B}_2 (k_{b,t}^T)^{\alpha_b-\alpha_e}$$

Combine these expressions with the equilibrium physical capital markets in each country gives:

$$k_{t+1}^{NT} = \frac{A_g^N}{A_e^{N\mu}} \mathcal{X}(1-\alpha_g)^{1-\mu} \mathcal{B}_1^{\mu} p_{g,t}^W \left(\mathcal{A}_1 k_t^{NT}\right)^{\alpha_g - \mu\alpha_e}$$

$$k_{t+1}^{ST} = \frac{A_b^S}{A_e^{S\mu}} (1-D(P_t))^{1-\mu} \mathcal{X} \mathcal{B}_2^{\mu} \left(\mathcal{A}_2 k_t^{ST}\right)^{\alpha_b - \mu\alpha_e}$$

From Definition 3, along the BGP, we have:

$$\bar{k}_g^T = \mathcal{A}_1 \left(\frac{A_g^N}{A_e^{N\mu}} \mathcal{X}(1-\alpha_g)^{1-\mu} \mathcal{B}_1^{\mu} p_g^W \mathcal{A}_1 \right)^{\frac{1}{1-\alpha_g+\mu\alpha_e}}$$

and

$$\bar{k}_b^T = \mathcal{A}_2 \left(\frac{A_b^S}{A_e^{S\mu}} (1-\alpha_b)(1-D(\bar{P}))^{1-\mu} \mathcal{X} \mathcal{B}_2^{\mu} \mathcal{A}_2 \right)^{\frac{1}{1-\alpha_b+\mu\alpha_e}}$$

The world capital market equilibrium equation confirms that the only way to observe stationary world price with perfect specialization is to have growth rate equalization between countries:

$$g^{NT}(\bar{p}_g^W) = g^{ST}(\bar{p}_g^W) = g^W$$

with

$$\begin{aligned} g^{NT}(\bar{p}_g^W) &= \left(\frac{\epsilon^{1/\mu}\gamma\mu A_e^N}{\mathcal{B}_1}\right)^{\frac{\mu(1-\alpha_g)}{1-\alpha_g+\mu\alpha_e}} \left(\frac{1-\alpha_g}{1+\beta+\gamma\mu}\right)^{\frac{\mu(1-\alpha_g+\alpha_e)}{1-\alpha_g+\mu\alpha_e}} \left(A_g^N \beta p_g^W \mathcal{A}_1\right)^{\frac{\mu\alpha_e}{1-\alpha_g+\mu\alpha_e}} \\ g^{ST}(\bar{p}_g^W) &= \left(\frac{\epsilon^{1/\mu}\gamma\mu A_e^S}{\mathcal{B}_2}\right)^{\frac{\mu(1-\alpha_b)}{1-\alpha_b+\mu\alpha_e}} \left(\frac{(1-\alpha_b)(1-D(\bar{P}))}{1+\beta+\gamma\mu}\right)^{\frac{\mu(1-\alpha_b+\alpha_e)}{1-\alpha_b+\mu\alpha_e}} \left(A_b^S \beta \mathcal{A}_2\right)^{\frac{\mu\alpha_e}{1-\alpha_b+\mu\alpha_e}} \end{aligned} \quad (29)$$

The relative price of the green good does not directly affect the growth rate in the South. This is because this country does not produce green good, such that the price of education is not directly linked through the price of green good. Reversely, in the North the price of education and hence the accumulation of human capital evolves with $\bar{p}_g^W$.

We can remark that the interior case (situation $a.1$ or $a.2$) characterizes a convergence between heterogeneous countries, that can be accompanied by growth benefits or growth losses, compare with Autarky solution.

Remark 1 *When there is a perfect specialization (case a. in Definition 3), international trade leads to growth rate convergence between heterogeneous countries. Compare with the Autraky*

- *in the situation a.1, the growth rate increases for both countries.*

- *in the situation a.2, the evolution of pollution leads to a reversal of comparative advantage* *that is growth damaging for both countries.*

In the first situation, presented in this section, the North specialized in the green production while the South in the brown. In this case, trade is growth enhancing for the two countries. In the second situation, there is a reversal of comparative advantage such that trade decreases the growth rate for both economies. If the North produces the brown good while the South produces the green one, the world relative price is lower than the two Autarky relative prices. This situation corresponds to a case where trade entails an equality of growth rate between the two countries but is also growth damaging for both.

The stock of pollution in a world with international trade and perfect specialization depends on the production of brown good, i.e on the share of human capital allocated to the brown sector h_b^T and the physical to human capital ratio in this sector k_b^T. As the share of human capital allocated to the education sector is not affected by international trade, with perfect specialization the share of human capital in the brown sector is higher than in Autarky and is given by:

$$h_b^T = \frac{1+\beta+\alpha_e\gamma\mu}{1+\beta+\gamma\mu}$$

As a result, the stock of pollution is given by the solution of this equation:

$$\bar{P}^W = \frac{\theta}{\alpha}\mathcal{A}_2\left(\frac{A_b^S}{A_e^{S\mu}}(1-\alpha_b)(1-D(\bar{P}))^{1-\mu}\mathcal{X}\mathcal{B}_2^{\mu}\mathcal{A}_2\right)^{\frac{\alpha_b}{1-\alpha_b+\mu\alpha_e}}\frac{1+\beta+\alpha_e\gamma\mu}{1+\beta+\gamma\mu} \quad (30)$$

Equation (30) allows to conclude that there is a unique value of the pollution stock at the steady state. Combine equations (29) and (30), we conclude that there is a unique relative price $\bar{p}_g^W \equiv f_p(\alpha,\nu)$ that guarantees the equality of the growth rate and hence the possible existence of a BGP with perfect specialization. The world relative price decreases with the pollution stock, thus it increases with α and decreases with ν.

Now, we have to check the admissibility of this equilibrium, i.e if the world relative price obtained effectively satisfies perfect specialization: $\bar{p}^N < \bar{p}_g^W < \bar{p}^{S'}$ or $\bar{p}^{S'} < \bar{p}_g^W < \bar{p}^N$. From Remark 1, we know that the first inequality correspond to a growth enhancing situation for the two economies. It occurs if and only if the stock of pollution achieved with international trade is sufficiently low. To avoid a violation of the inequality, the natural regeneration of Nature (α) has to be high enough and/or the vulnerability to climate change (ν) has to be low enough. If it is not the case, the damage is too important for the South such that the relative price that guarantees equality of the growth rate is lower than the Autarky relative price of the North and the economy switch to the interior situation $a.2$ where we observe a reversal of the comparative advantage or to the corner solution b. We can thus formulate the following Lemma to summarize our mathematical results:

Lemma 2 *Under Assumption 1 to 5, there exists two critical thresholds $\nu_1(\alpha)$ and $\nu_2(\alpha)$, with $\nu_1(\alpha) < \nu_2(\alpha)$ and $\nu_1' > 0$ and $\nu_2' > 0$, such that*

- *When $\nu < \nu_1(\alpha)$, the world economy converges to a BGP with $\bar{p}^N < \bar{p}_g^W < \bar{p}^{S'}$ and $g^{NT} = g^{ST} = g^W$*

- *When $\nu_1(\alpha) < \nu < \nu_2(\alpha)$, the world economy converges to a BGP with $\bar{p}^N = \bar{p}_g^W < \bar{p}^{S'}$ and $g^N = g^{NT} < g^{ST}$*

- *When $\nu_2(\alpha) < \nu$ the world economy converges to a BGP with $\bar{p}^{S'} < \bar{p}_g^W < \bar{p}^N$ and $g^{NT} = g^{ST} = g^W$*

When the value of $\bar{p}_g^W$ is such that $\bar{p}_g^W < \bar{p}_g^N < \bar{p}^{S'}$ then $\bar{p}_g^W = \bar{p}_g^N$, the world relative price tends to the Autraky relative price of the North. The North produces both goods and grows at the same rate than before openness to trade (i.e $g^{NT} = g^N$). This result has significant implications because it illustrates the fact that the benefits of trade are questioned when damage of pollution are considered, even for countries that are not vulnerable to climate change. Here, the benefits from trade are canceled by the low level of productivity in the South, entails by pollution. When pollution is too high, it becomes costly for the South to produce the brown good. This cost is transferred to the North by trade. Damage entails a fall in the world relative price of green good which conduces the North to produce both goods and to get back to its Autarky growth rate.

From Lemma 2 and Remark 1 we deduce the following results:

Proposition 2 *Under Assumption 1 to 5*

- *When $\nu < \nu_1(\alpha)$ openness to trade is growth enhancing for the two countries and leads to an equal distribution of GDP in the world.*

- *When $\nu_1(\alpha) < \nu < \nu_2(\alpha)$ openness to trade cannot be growth enhancing for the non-vulnerable country. It can increase the growth rate of the vulnerable country but it will grow at a lower rate than the non-vulnerable forever.*

- *When $\nu_2(\alpha) < \nu$ openness to trade leads to an equal distribution of GDP in the world but is growth damaging for the two countries.*

When the cost of climate change are low, the result such that international trade leads to growth benefits for all members stay valid. When the natural regeneration of pollution is low and/or that one country that participate to international trade is sufficiently vulnerable by climate change this result does not longer occur. When the vulnerability and the absorption of carbon by Nature are such that the critical threshold $\nu_2(\alpha)$ is not achieved, trade does not affect the North economy while it can improves or decreases the growth rate in the South. Nevertheless, it is never promote an equal distribution of GDP across countries. When the vulnerability and the absorption of carbon by Nature are sufficiently high such that the critical threshold $\nu_2(\alpha)$ is achieved, openness to trade is damaging, even for the economy that does not suffer from climate change. In this context, we wonder if a transfer from the North to the South can allow to escape this poor scenario and to keep the benefits from international trade.

5 Transfers from the non-vulnerable to the vulnerable country

In light with the recent recommendation of international community, we examine in this section if a transfer from the North to the South can be growth improving for both countries, while taking into account the trade channel. More precisely, we wonder if a transfer in terms of green technology from the North to the South, that enables the South to reduce its emissions, could be an interesting policy in terms of environment and economic performances.

TBD

References

Copeland, B.R. and Taylor, M.S. (2004), "Trade, Growth and the Environment", *Journal of Economic Literature* 42, 7-71.

Glomm, G., and Ravikumar, B. (1992), "Public versus Private Investment in Human Capital: Endogenous Growth and Income Inequality", *Journal of Political Economy* 100(4), 818-833.

Gradus, R. and Smulders, S. (1993), "The Trade-off between Environmental Care and Long-term Growth: Pollution in three Prototype Growth Models", *Journal of Economics*, 58, 25-51.

Grossman, G. M. and Krueger, A. B. (1991), "Environmental Impacts of a North American Free Trade Agreement", *National Bureau of Economic Research (ed.)*, Working Paper 3914, Cambridge MA.

Intergovernmental Panel on Climate Change (2014), *Climate Change 2014: Impacts, Adaptation, and Vulnerability*, Cambridge University Press.

John, A.A. and Pecchenino, R.A. (1997), "International and Intergenerational Environmental Externalities," *The Scandinavian Journal of Economics* 99 (3), 371-387.

Levinson, A. and Taylor, S. (2008), "Unmasking the Pollution Haven Effect", *International Economic Review* 49(1), 223-254.

Managi, S., Hibiki, A. and Tsurumi, T. (2009), "Does Trade Openess Improve Environmental Quality?", *Journal of Environmental Economics and Management* 58(3), 346-363.

Mendelsohn, R., Dinar, A. and Williams, L. (2006), "The Distributional Impact of Climate Change on Rich and Poor Countries", *Environment and Development Economics* 11(2), 159-178

Ollivier, H. (2016), "North-South Trade and Heterogeneous Damages from Local and Global Pollution", *Environmental and Resource Economics*, online March 2015, DOI 10.1007/s10640-015-9902-4.

Pautrel, X. (2008), "Reconsidering the Impact of the Environment on Long-run Growth when Pollution Influences Health and Agents have a Finite-lifetime", *Environmental and Resource Economics*, 40, 37-52.

Pautrel, X. (2012), "Environmental policy, Education and Growth: a Reappraisal when Lifetime is Finite", *Macroeconomic Dynamics*, 16(5), 611-685.

Tamiotti, L., Teh, R., K, V., Olhoff, A., Simmons, B. and Abaza, H. (2009), *Trade and Climate Change. - A report by the United Nations Environment Programme and the World Trade Organization.* WTO and UNEP. Lausanne, Switzerland.