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TK DIFFUSION UNDER MARKET-BASED INSTRUMENTS BETWEEN DIFFERENT ENVIRONMENTAL COUNTRIES

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ABSTRACT

Using an endogenous Schumpeterian R&D growth model, this paper intends to analyse how international trade of intermediate goods can affect the structure and diffusion of technological knowledge between ecological and dirty countries. Each country is assumed to have different environmental quality levels and different available technological knowledge and to be able of conducting R&D activities (innovative in ecological-country and imitative in dirty-country). We concluded that under international trade, there is a higher probability of successful imitation that improves the Dirty-country ability to benefit from Ecological-country innovations. This induces an efficient allocation of production in the Dirty-country, where marginal cost is lower, and increases the ecological goods production in the Ecological-country. Furthermore, subsidies, by promoting technological knowledge progress, lead to a permanent increase in the world steady-state growth rate.

INTRODUCTION

Over the past century, anthropogenic Greenhouse Gases (GHG) emissions, in particular carbon dioxide (CO_2) emissions, have increased significantly compared to the rather steady level of the pre-industrial era. Developed countries have been the main responsible for these high concentration levels, as they emit far larger amounts of CO_2 *per capita* than the world average. However, more recently, some growing economies are significantly increasing their emissions *per capita*, while developed countries are decreasing. Between 1990 and 2013, for instance, China has strongly increased its *per capita* CO_2 emissions by more than three times, while the United States has reduced by 16% (IEA, 2015). Fig. 1 and 2 show the evolution of the GDP (PPP) and the CO_2 emissions for USA and China between 1990 and 2013. Considering CO_2 emissions per GDP, it is clear that China is the largest emitter, see Fig. 3.

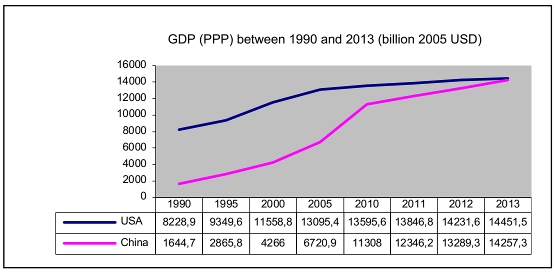

Figure 1: GDP (PPP) 1990-2013

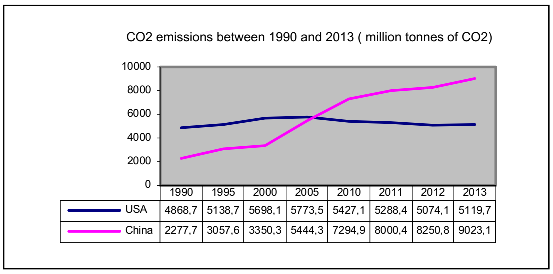

Figure 2: CO_2 Emissions 1990-2013

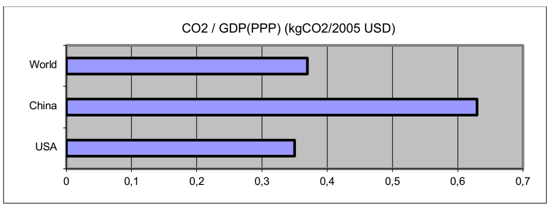

Figure 3: CO_2 / GDP (PPP) in 2011 (kg CO_2 / 2005 USD)

The Kyoto Protocol, which entered into force in February 2005, is so far the most binding multinational agreement to mitigate climate change. Despite its large participation (192 countries), the Kyoto Protocol is limited in addressing the global emissions. The United States remains outside of the Protocol's jurisdiction and developing countries do not face emissions targets.
Since "eco-friendly" technologies enhance the environmental sustainability by inducing more ecological goods production, the future slow-down in the growth of CO_2 emissions will depend strongly on the technology and its diffusion.
In line with this thought, this paper develops an endogenous R&D growth model where technological knowledge (TK) diffusion between developed (ecological) and developing (dirty) countries is analyzed to ascertain how it affects the ecological goods production and consequently, the CO_2 concentrations.
This model is based on Schumpeter´s notion of creative destruction, the competitive process by which firms are constantly looking for new ideas and innovations that will make rival's ideas obsolete, destroying the previous profits.
In most literature, TK diffusion has been studied for one country alone. Very few papers have analyzed the interaction between two or more countries (e.g., Di Maria and Smulders, 2004 and Acemoglu and Zilibotti, 2001). Di Maria and Smulders (2004) studied the role of endogenous technology and technology spillovers in explaining cross-country differences in pollution. Acemoglu and Zilibotti (2001) analysed cross-country productivity differences and found that they persist even when all countries have access to the same set of technologies due to the technology-skill mismatch in less developed countries.
This study also aims to analyse the contributions of environmental policies in producing relatively more ecological goods, with fewer CO_2 concentrations. Therefore, a tax on dirty intensive resources and a subsidy on ecological intensive resources are introduced. Both countries produce final goods (FG) using labor and intermediate goods (IGs). The ecological country has higher environmental quality and is endowed with a higher initial level of both ecological resources and high-skilled labor. Its TK is more ecologically advanced and its R&D activities result in innovations that improve the ecological IGs quality. The dirty country has a marginal cost advantage in producing FGs and its R&D activities result in imitations of the Ecological-country innovations (Grossman and Helpman, 1991). We consider that Ecological-country consumers have preferences for ecological goods, whereas Dirty-country consumers are indifferent between ecological or dirty goods. This reasoning is in line with Maslow's well-known hierarchy-of-needs (Maslow, 1970). Indeed, since developed countries have higher consumption levels, they are more prone to possess and environmental conscience, preferring environmental goods. However, developing countries with lower consumption levels, are more concerned with satisfying their basic needs (WCED, 1987), willing to consume more commodities without caring about their ethical/green consumption profile.
The remainder of the paper is organized as follows. Section 2 provides a brief literature review. Section 3 presents the Ecological and Dirty countries' economies. Section 4 introduces the international trade. Section 5 analyses the steady-state equilibrium and section 6 concludes.

LITERATURE REVIEW

In the literature of endogenous growth, R&D activity is essential to technological knowledge progress. At the theoretical level, the first-generation of comprehensive, well-articulated general equilibrium growth models based on R&D that seek to explore the role of technological knowledge change in the economic growth process, were introduced in the 1980s – see Grossman and Helpman (1991), Barro and X. Sala-i-Martin (1997). This new growth theory allowed for the endogeneity of technological change where economic agents can affect the pace of technological change and where technology is essentially interpreted as "knowledge" (e.g., Vollebergh and Kemfert, 2005). With the changing concepts of technological knowledge in economic theory together with their implications for sustainability, became possible to analyse the link between environmental policy and technological knowledge.
Indeed, despite the complexity introduced by considering environment in endogenous growth models, a new growth literature emerged with new insights on the environment-growth relation – e.g., Grimaud and Rougé (2008). However, to the best of our knowledge, none of the existing works (and thus none of the quoted studies) develop a coherent framework for the analysis of the effect of different environmental policies on the technological-knowledge bias and the consequent induced effects among different endowed environmental countries.
Bovenberg and Smulders (2006), for example, incorporated two public inputs into production in an endogenous growth model: the environment and the abatement knowledge. They show that if environment acts as a public consumption good, a reduced pollution harms the productivity of man-made production factors, depressing growth. Conversely, if the environment acts as a public input into production, the enhanced quality of the environment improves productivity, offsetting the adverse growth effect of lower pollution.
Under the assumption of no scale effects and that energy demand is inelastic, some authors, like Peretto (2009) found that the tax has no effect on the steady-state growth rate, though it has important transitional effects. Bovenberg and Smulders (2006), for example, consider a pollution tax, but not other distorting taxes.

Fullerton and Kim (2008) combine various elements from prior models to construct a single endogenous growth model with endogenous determination of pollution and environmental quality. They assume three assets in the economy: private capital (physical and human), public abatement knowledge (R&D) and the environmental quality (natural capital). They show that with abatement more effective than actual pollution, having higher pollution tax may mean lower growth, even with higher welfare. They also show the conditions under which it has the opposite effects (higher growth but lower welfare).
Groth and Schou (2007), in contrast, use a simple general endogenous growth model where the non-renewable resource enters the "growth engine" to study the effects of subsidies and taxation on capital and resources. Unlike the typical results from partial equilibrium analysis, they found that a tax on capital gains is of rather importance for long-run growth. The same is true for a time-varying tax on resource use. These results also contrast with the general belief within endogenous growth literature that interest income taxes hamper growth, whereas investment subsidies promote growth. The authors show that this conventional view rests on growth models where non-renewable natural resources are ignored, but not when the non-renewable resource is an essential input in the sector generating long-run growth.

THE NATIONAL ECONOMY MODEL

Each country has three productive sectors: the FGs, the IGs and the R&D. Following closely Meireles et al. (2012), each perfectly competitive FG $n \in [0,1]$ is produced by Ecological or Dirty technology. Firms producing with ecological technology can only use non-polluting IGs and skilled-labor (E) contributing to reduce pollution. Those producing with dirty technology can only use polluting IGs and unskilled-labor (D) contributing to raise pollution. Also, the skilled-labor has an absolute productivity advantage over unskilled-labor ($e>d\geq 1$) and the former is relatively more productive in producing FGs indexed by larger n. This implies that, in equilibrium, there will be a threshold FG $\bar{n} \in [0,1]$, such that only dirty (ecological) technology will be used to produce FGs indexed by $0\leq n\leq \bar{n}$ ($\bar{n} < n\leq 1$):

$$\bar{n} = \left\{ \left[\left(\frac{A_E}{A_D} \right)^{1/\alpha} \frac{e}{d} \frac{E}{D} \frac{Q_E}{Q_D} \right]^{1/2} + 1 \right\}^{-1} \tag{1}$$

$$Q_D(t) \equiv \int_0^J q^{k(j,t)(1-\alpha)/\alpha}\, dj \text{ and } Q_E(t) \equiv \int_J^1 q^{k(j,t)(1-\alpha)/\alpha}\, dj \tag{2}$$

A is the exogenous productivity level, reflecting the dirty environment (A_D) or the ecological environment (A_E).
Aggregate quality indexes in Equation (2) evaluate the TK and $Q_E/Q_D \equiv B$ measures the (ecological) TK bias. Equation (1) is a "proxy" for environmental quality. Small $\bar{n}$ means a relatively higher level of ecological goods production and thus, a better environmental quality and vice-versa.
Since Ecological country consumers prefer ecological goods, firms are induced to produce these goods. Notwithstanding, government can decide for relatively more ecological goods production as they lead to a decrease in GHG emissions. In the Dirty country, however, consumers are indifferent between both kinds of goods, so firms do not have the incentive to produce relatively more ecological goods. Thus, government needs to encourage ecological goods production. From an efficiency perspective, market-based instruments are preferable to command-and-control instruments, since they equalize marginal abatement costs across firms, yielding statically efficient outcomes (e.g., Baumol and Oates, 1994). Furthermore, market-based instruments are believed to be more effective in inducing technological change as they offer a permanent incentive to use fewer environmental commodities.
Therefore, assuming that government can subsidise the E-IGs and tax the D-IGs, the MC after a subsidy or tax is ($MC+\varphi_x$), where φ_x denotes subsidies ($-s_x$) or taxes (τ_x). Thus, the profit maximization price of IG firms yields $p = (1+\varphi_x)/(1-\alpha)$ and the limit pricing $p = q(1+\varphi_x)$, where $(1+\varphi_x)<q(1+\varphi_x) \leq [(1+\varphi_x)/(1-\alpha)]$. In turn, the price indexes ratio of ecological and dirty FGs is $p(t) = p_E(t)/p_D(t) = [\bar{n}(t)/(1-\bar{n}(t))]^{\alpha}$. Thus, small $\bar{n}$ implies more FGs produced with ecological technology and hence, a small relative price of these goods. Consequently, the demand for E-IGs is low, discouraging their R&D (Acemoglu, 2002).
The instantaneous probability of a successful innovation is given by:

$$pb(k,j,t) = rs(k,j,t)\beta q^{k(j,t)} \xi^{-1} q^{-(1/\alpha)k(j,t)} M^{-1} \tag{3}$$

(i) $rs(k,j,t)$ is FGs devoted to R&D; (ii) $\beta q^{k(j,t)}$, with $\beta>0$, is the positive learning effect of accumulated TK from past R&D; (iii) $\xi^{-1} q^{-(1/\alpha)k(j,t)}$, with $\xi>0$, is the adverse effect from the increasing complexity of quality improvements; (iv) M^{-1}, with $M=D$ if $0\leq j\leq J$ and $M=E$ if $J<j\leq 1$, is the adverse effect of market size.

Under free entry R&D equilibrium, the expected reward for pursuing the $(k+1)^{th}$ successful research, must equal the after subsidy cost of research $pb(j,k,t)\,V(k+1,j,t) = (1-s_r)\,rs(k,j,t)$ where s_r is an ad-valorem subsidy to R&D that results in a decrease in R&D costs which can be specific to *E*- or *D*-R&D. The TK growth rate equilibrium (Q_M) is given by the path:

$$E(\Delta Q_M/Q_M) = \dot{Q}_M/Q_M = \underbrace{\left[\frac{\beta_L}{\xi_L}\frac{(1+\varphi_{x,M})}{(1-s_{r,M})}\frac{(q-1)}{q}\left(\frac{p_{M,L}\,A_{M,L}(1-\alpha)}{(1+\varphi_{x,M})}\right)^{1/\alpha} M_L - r(t)\right]}_{pb_{M,L}}\left[q^{(1-\alpha)/\alpha}-1\right] \tag{4}$$

From Equation (4), it is clear that R&D equilibrium rates reply negatively to both interest rate and exogenous tax rate of dirty-IGs, $\tau_{x,D}$, and positively to an increase in the exogenous subsidy rates of both *M*-R&D, $s_{r,M}$, and ecological-IGs, $s_{x,E}$. Thus, the direction of the TK is driven by the price channel and can be affected by government.
The utility function for the individual in the *m*-country ($m = D, E$) is given by:

$$U_m(a,t) = \int_0^\infty \left[\frac{c(a,t)^{1-\theta}-1}{1-\theta}\right]\exp(-\rho t)\,dt \tag{5}$$

$c(a,t)$ is the consumption of *Y* by $a \in [0,1]$ individuals, where ($a \le \overline{a}$) $a > \overline{a}$ are (un)skilled-workers assumed to perform better using (*D*-)*E*-technology.
The solution for the individual's consumption path is the standard Euler equation:

$$\dot{c}(a,t)/c(a,t) = \dot{c}(t)/c(t) = \dot{C}(t)/C(t) = (1/\theta)\,[(1-\tau_k)\,r(t) - \rho\,] \tag{6}$$

TECHNOLOGICAL DIFFUSION BETWEEN DIRTY AND CLEAN COUNTRIES

With International Trade (IT) in IGs, the Dirty-country (*F*-country) has access to the same TK as the Ecological-country (*L*-country), either by imitation of the latest innovations, or by importing state-of-the-art IGs. However, the *F*-country has lower marginal costs in producing imitated *L*-country top IGs and so it can underprice them. Thus, IGs can be produced by the innovator, after a successful innovation, or by the *F*-country, after a lower priced successful imitation. The greater the probability of imitation, the faster the *L*-country firms will need to obtain the next successful innovation to capture the world market.
With IT, there will be three types of IG firms: IG firms of *L*-countries facing *L*-country competition, IG firms of *L*-countries facing *F*-country competition and IG firms of *F*-countries facing *L*-country competition.
The structure of FGs production in the *F*-country, is now, affected by the ratio $Q_{E,L}/Q_{D,L}$:

$$\overline{n}_F = \left\{\left[\left(\frac{A_{E,F}}{A_{D,F}}\right)^{1/\alpha}\frac{e}{d}\,\frac{E_F}{D_F}\,\frac{Q_{E,L}}{Q_{D,L}}\right]^{1/2}+1\right\}^{-1} \tag{7}$$

Since TK gap is always favorable to the *L*-country in either specific knowledge – $Q_{M,L}>Q_{M,F}$, as the developing country always lags behind, the *F*-country enjoys an immediate increase in its aggregate product, *Y*, inducing convergence between countries. However, the *L*-country always produces more *E*-FG than the *F*-country ($\overline{n}_F > \overline{n}_L$). Thus, differences in the structure of the FGs production are only determined by differences in national technological environment, A_M, and national labor levels, *M*, see Equation (7).
The instantaneous probability of the successful imitation of the IG top environmental quality that transfers its production to the *F*-country, is given by:

$$pb_F(k,j,t) = rs_F(k,j,t)\cdot\beta_F\,q^{k_F(j,t)}\cdot\xi_F^{-1}q^{-(1/\alpha)\,k_F(j,t)}\cdot(M_F+M_L)^{-\zeta_F}\cdot H_N(j,t)\cdot H_T(j,t)\cdot f\big(\widetilde{Q}_M(t),h\big)^{-\overline{\sigma}+\widetilde{Q}_M(t)} \tag{8}$$

(i) $\beta_L > \beta_F > 0$, i.e., learning by past innovations should have greater effects than learning by past imitations; (ii) $k = k_L \ge k_F$, i.e., both countries use the state-of-the-art IGs in their FG production; (iii) $\xi_L > \xi_F > 0$, i.e., complexity cost of imitation is assumed to be lower than innovation, as new ideas are progressively more complex to implement; (iv) $\zeta_F = \zeta_L > 0$, is the adverse effect of market size, assumed to be the same in both country types; (v) $H_N(j,t)\cdot H_T(j,t)\cdot f\big(\widetilde{Q}_M(t),h\big)^{-\overline{\sigma}+\widetilde{Q}_M(t)}$, with $0<\widetilde{Q}_M(t)<1$ and $\overline{\sigma}>0$, is a catching-up term, specific to the Dirty country. Terms $H_N(j,t)$ and $H_T(j,t)$ are exogenous variables that capture positive effects of imitation capacity. As in Aghion et al. (2004), the former embodies the imitation productivity level dependent on national causes. The latter is the imitation productivity level dependent on external causes (Grossman and Helpman, 1991). The quadratic imitation function, $f\big(\widetilde{Q}_M(t),h\big)$, capturing the backwardness advantage is given by Papageorgiou (2002):

$$f\left(\widetilde{Q}_M(t),h\right)=\begin{cases}0 & , 0<\widetilde{Q}_M(t)\le h\\ -\widetilde{Q}_M(t)^2+(1+h)\,\widetilde{Q}_M(t)-h & , h<\widetilde{Q}_M(t)<1\end{cases} \tag{9}$$

$\widetilde{Q}_M(t)\equiv\left(Q_{M,F}(t)/Q_{M,L}(t)\right)$ is the relative TK level of the Dirty-country and $h\in(0,1)$ is the TK threshold that dictates whether the *D*-country can imitate or not. If the gap is smaller than the threshold, i.e., if $\widetilde{Q}_M(t)$ is above *h*, *D*-countries can benefit from the backwardness advantage, as they find it easier to imitate, grow faster and converge to the *E*-country's income level, as in Barro and Sala-i-Martin (1997). Otherwise, backwardness is no longer an advantage, since *D*-countries show no potential to imitate and grow rapidly. Once affected by the exponent function $\sigma\left(\widetilde{Q}_M,t\right)=-\bar{\sigma}+\widetilde{Q}_M(t)$ in (8-v), $f(\cdot)$ yields an increasing advantage of backwardness.

Under R&D equilibrium, expected revenues must equal spent resources: $pb_m(k,j,t)\,V_m(k,j,t)=\left(1-s_{r,m}\right)rs_m(k,j,t)$.

Therefore, the equilibrium probability of successful innovation in a *M*-specific IG is:

$$pb_L(j,k,t)=\frac{\beta_F}{\xi_F}\,H_D\,H_T\,f\left(\widetilde{Q}_M(t),h\right)^{-\bar{\sigma}+\widetilde{Q}_M(t)}\widetilde{Q}_M(t)\,(1-\alpha)^{1/\alpha}\,\frac{\left(1-MC_F\right)}{\left(1-s_{r,M,F}\right)}\,M*Z_M(t)-r(t) \tag{10}$$

where, $Z_M(t)=\dfrac{M_F}{M_F+M_L}\left(\dfrac{p_{M,F}\,A_{M,F}}{\left(1+\varphi_{x,M,F}\right)}\right)^{1/\alpha}+\dfrac{M_L}{M_F+M_L}\left(\dfrac{p_{M,L}\,A_{M,L}}{\left(1+\varphi_{x,M,F}\right)}\right)^{1/\alpha}$

Equation (10) indicates that the probability, pb_L, of a new IG quality is higher when profits from sales, Z_M, are higher. In turn, profits are higher when both FGs' price indexes, p_M, and the exogenous technological environment, A_M, are higher. It also shows that pb_L is now affected by imitation due to the feedback effect between countries.

From Equation (10), it is clear that R&D equilibrium rates respond negatively to the interest rate and to a raise in the tax rate of *D*-IGs, $\tau_{x,D}$. Conversely, they are encouraged by an increase in the subsidy rates of *M*-R&D, $s_{r,M}$, and *E*-IGs, $s_{x,E}$. Thus, the direction of TK is driven by the price channel and can be affected by the structure of government intervention. The equilibrium growth rate of technological progress, Q_M, is the path of the *L*-country TK:

$$\dot{Q}_{M,L}/Q_{M,L}=pb_{M,L}\left[q^{(1-\alpha)/\alpha}-1\right] \tag{11}$$

From Equation (11), we can conclude that like under no IT (4), the direction of TK is driven by the price channel and can be affected by the structure of government intervention. Also, it is clear that there are feedback effects under IT in IGs. The positive level effect from the innovator to the imitator returns to the innovator, affecting the *L*-country TK through creative destruction. Indeed, dirty-country benefits from innovations through the access to the state-of-the-art IGs, increasing production and the available resources to R&D imitation. Consequently, the imitation shifts IGs production from Ecological to Dirty-countries, where production is more efficient due to the lower *MC*. This induces the Ecological-country to devote fewer resources to IGs production and more resources to R&D.

THE STEADY-STATE EQUILIBRIUM

By assumption, both countries have access to the same state-of-the-art IGs, except labor levels and technological environment, which are country specific. This implies differences in levels but not in growth rates. Thus, the steady-state growth rate and the interest rates must be the same for both country types. The dynamic equilibrium can, then, be described by Q_E and Q_D paths and the stable and unique steady-state endogenous growth rate, $g^*\left(\equiv g_D^*\equiv g_E^*\right)$, is:

$$g^*=\left(\frac{F\dot{G}}{FG}\right)^*=\left(\frac{I\dot{G}}{IG}\right)^*=\left(\frac{R\dot{\&}D}{R\&S}\right)^*=\left(\frac{\dot{Q}_D}{Q_D}\right)^*=\left(\frac{\dot{Q}_E}{Q_E}\right)^*=\left(\frac{\dot{C}}{C}\right)^*=\left(\frac{\dot{c}}{c}\right)^*=\frac{1}{\theta}\left[\left(1-\tau_K\right)r^*-\rho\right]\Rightarrow\left(\frac{\dot{p}_E}{p_E}\right)^*=\left(\frac{\dot{p}_D}{p_D}\right)^*=\left(\frac{\dot{\bar{n}}}{\bar{n}}\right)^*=0 \tag{12}$$

By setting Equation (6) equal to Equation (11), we get a constant steady state $r^*\left(\equiv r_D^*\equiv r_E^*\right)$ and $g*$ arises from plugging $r*$ into (6). Equalizing $\left(\dot{Q}_D/Q_D\right)^*=\left(\dot{Q}_E/Q_E\right)^*$, it can also be found p_M^* and $\bar{n}^*$. Equation (12) shows that steady-state growth is driven by the *L*-country TK growth rate, although it is affected by *F*-country imitation and demand for IGs, which depends on its labor levels. By $s_{x,E}$ and $s_{r,M}$ government affects positively $r*$ and thus $g*$. Conversely, $\tau_{x,D}$ and τ_K affect negatively $r*$ and thus $g*$. As τ_w is absent in equilibrium, it does not directly affect $g*$. Thus, a higher steady-state interest rate, $r*$, induces a stronger R&D activity that shortens the duration of monopoly, resulting in a strong process of creative destruction. Since in steady state the world growth rate is common to both countries, the difference between the world steady-state interest rate with IT, Equation (13), and the one that would prevail in the *F*-country without IT, Equation (14), shows the increase in the steady-state growth rate associated to the IT in IG (15):

$$r^* = \left\{\left[q^{(1-\alpha)/\alpha} - 1\right]\theta + (1-\tau_k)\right\}^{-1} \left\{\frac{\beta_F}{\xi_F} H_N\, H_T\, f\left(\tilde{Q}^*{}_M(t), h\right)^{-\sigma + \tilde{Q}^*{}_M(t)} \tilde{Q}^*{}_M(t)\,(1-\alpha)^{1/\alpha} \frac{(1-MC_F)}{(1-s_{r,M,F})}\left(1+\varphi_{x,M,F}\right) m\, Z^*{}_M(t)\left[q^{(1-\alpha)/\alpha} - 1\right]\theta + \rho\right\} \tag{13}$$

$$r^* = \left\{\left[q^{(1-\alpha)/\alpha} - 1\right]\theta + (1-\tau_k)\right\}^{-1} \left\{\frac{\beta}{\xi}(1-\alpha)^{1/\alpha} \frac{\left(1+\varphi_{x,M,F}\right)}{\left(1-s_{r,M,F}\right)} \frac{q-1}{q}\left(\frac{p_M A_M}{1+\varphi_{x,M}}\right)^{1/\alpha} m \left[q^{(1-\alpha)/\alpha} - 1\right]\theta + \rho\right\} \tag{14}$$

$$\left[H_N H_T\, f\left(\tilde{Q}^*{}_M(t), h\right)^{-\sigma + \tilde{Q}^*{}_M(t)} \tilde{Q}^*{}_M(t)(1-MC_F)\left(1+\varphi_{x,M,F}\right) Z_M^*(t)\right]\Bigg|_{IT\ of\ IG} - \left[\left(MC_F + \varphi_{x,M,F}\right)^{(\alpha-1)/\alpha}\left(\frac{q-1}{q}\right)\left(p^*_{M,F} A_{M,F}\right)^{1/\alpha}\right]\Bigg|_{pre-trade} \tag{15}$$

If the impact of openness, H_T, is strong and if MC_F is low, the steady-state growth tends to be higher under IT in IGs than without IT. This world growth rate is affected by the exogenous variables and parameters levels, as expected in an endogenous growth model. In particular, in both countries the levels of technological environment ($A_{M,L}$ and $A_{M,F}$) and of R&D technology parameters (β, H_N and H_T) improve the common growth rate through their positive effect on R&D, (10). Indeed, β, H_N and H_T enhance imitation which allows increasing the probability of successful innovation. Additionally, each innovation lowers the cost of imitation leading to positive spillovers from innovation to imitation. A higher MC_L provides an incentive to imitation activity, affecting positively the equilibrium probability of successful innovation and world growth, while the inverse holds when MC_F is higher.

CONCLUSION

Developed countries emit far larger amounts of CO_2 *per capita* than the world average. However, some growing economies are significantly increasing their emissions *per capita*, while developed countries are decreasing. The future slow-down in the growth of CO_2 emissions will, then, depend strongly on the technology and its diffusion.

Therefore, this study assesses the impact of international trade in intermediate goods on technological diffusion between Ecological and Dirty countries. The Ecological country devotes innovative R&D activities while the Dirty country mimics the Ecological country's current best qualities. IGs can flow from the Ecological to the Dirty country and *vice-versa*.

This paper concludes that if the probability of successful imitation is sufficiently strong, both countries grow more quickly under IT. Indeed, a higher probability of successful imitation allows the Dirty-country to benefit from Ecological-country innovations inducing an efficient allocation of production in the Dirty-country where *MC* is lower. However, once the innovations are imitated, Ecological-country IGs firms can only capture the world market by supporting the next innovation. Moreover, when government introduces R&D subsidies they lead to a permanent increase in the long-run world steady-state as they foster TK progress.

Thus, this study shows that with IT in IGs the probability of successful imitation is strong, resulting in an increase in ecological goods production, crucial to decrease GHG emissions.

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