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TECHNOLOGICAL DIFFUSION 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. Furthermore, subsidies, by promoting technological knowledge progress, lead to a permanent increase in the world steady-state growth rate.

INTRODUCTION

This paper aims to understand how international trade in intermediate goods affects the structure and diffusion of technological knowledge (TK) between Ecological and Dirty countries. In most literature, TK diffusion has been studied for one country alone. Very few papers have analysed the interaction between two or more countries (e.g., Di Maria and Smulders, 2004; Acemoglu and Zilibotti, 2001).

For a long time, developed countries have emitted the large majority of anthropogenic Greenhouse Gases (GHG). However, more recently, shares of developing countries are rising very quickly and are expected to grow continuously. Between 1990 and 2011, China has strongly increased its *per capita* emissions by three times, while the United States have reduced by 13% (IEA, 2013), see Figures 1-2.

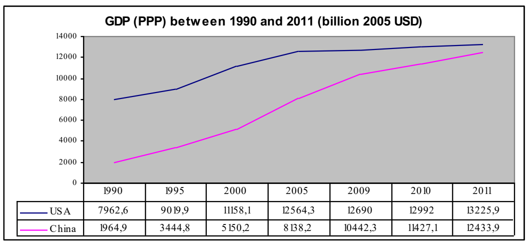

Figure 1: GDP (PPP) 1990-2011

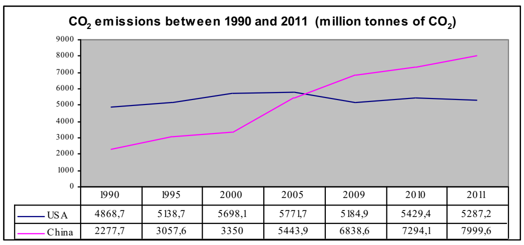

Figure 2: CO_2 Emissions 1990-2011

Since "eco-friendly" technologies enhance the environmental sustainability by inducing more ecological goods production, attention should be addressed to TK to reduce these emissions.

Thus, we present an endogenous growth model where TK diffusion between developed (ecological) and developing (dirty) countries is analysed to ascertain how it affects ecological goods production. Also, a tax on dirty intensive resources and a subsidy on ecological intensive resources are introduced to analyse how they can affect the development of better environmental quality inputs. Both countries produce final goods (FG) using labour 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 labour. 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.
The remainder of the paper is organised as follows. Section 2 presents the Ecological and Dirty countries' economies. Section 3 introduces the international trade. Section 4 analyses the steady-state equilibrium and section 5 concludes.

THE DOMESTIC 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-labour contributing to reduce pollution. Those producing with dirty technology can only use polluting IGs and unskilled-labour contributing to raise pollution. Also, the skilled-labour has an absolute productivity advantage over unskilled-labour 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 $0 \le n \le \bar{n}$ ($\bar{n} < n \le 1$):

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

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

Aggregate quality indexes in (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. 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:

$$p = q(1+\varphi_x), \text{ where } (1+\varphi_x) < q(1+\varphi_x) \le [(1+\varphi_x)/(1-\alpha)] \tag{3}$$

In turn, the price indexes ratio of ecological and dirty FGs is:

$$p(t) = p_E(t)/p_D(t) = [\bar{n}(t)/(1-\bar{n}(t))]^{\alpha}, \text{ where } \begin{cases} p_D = p_n (1-n)^{\alpha} = \exp(-\alpha)\bar{n}^{-\alpha} \\ p_E = p_n n^{\alpha} = \exp(-\alpha)(1-\bar{n})^{-\alpha} \end{cases} \tag{4}$$

Small $\bar{n}$ implies more FGs produced with ecological technology and hence, a small relative price of these goods. Thus, the demand for *E*-IGs is low, discouraging their R&D (Acemoglu, 2002).
The instantaneous probability of a successful innovation is given by:

$$pb(k,j,t) = rs(k,j,t)\, \beta q^{k(j,t)} \xi^{-1} q^{-(1/\alpha)k(j,t)} M^{-1} \tag{5}$$

(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 $0 \le j \le J$ and $M=E$ if $J<j\le 1$, 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:

$$pb(j,k,t)\, V(k+1,j,t) = (1-s_r)\, rs(k,j,t) \tag{6}$$

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:

$$E(\Delta Q_M / Q_M) = \dot{Q}_M / Q_M = \underbrace{\left[\frac{\beta_L}{\xi_L} \frac{(1+\varphi_{x,M})}{(1-s_{r,M})} \frac{(q-1)}{q} \left(\frac{p_{M,L}\, A_{M,L}\,(1-\alpha)}{(1+\varphi_{x,M})} \right)^{1/\alpha} m_L - r(t) \right]}_{pb_{M,L}} \left[q^{(1-\alpha)/\alpha} - 1 \right] \tag{7}$$

From (7), 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 *E*- and *D*-country is given, respectively by:

$$U_F(a,t) = \int_0^\infty \left[\frac{c(a,t)^{1-\theta} - 1}{1-\theta} \right] \exp(-\rho t)\, dt \tag{8.a}$$

$$U_L(a,t) = \int_0^\infty \left[\frac{\left[\frac{1}{\overline{n}} c(a,t) \right]^{1-\theta} - 1}{1-\theta} \right] \exp(-\rho t)\, dt \tag{8.b}$$

$c(a,t)$ is the consumption of *Y* by $a \in [0, 1]$ individuals, where ($a \leq \overline{a}$) $a > \overline{a}$ 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:

$$\dot{c}(a,t)/c(a,t) = \dot{c}(t)/c(t) = \dot{C}(t)/C(t) = (1/\theta)\, [(1-\tau_k)\, r(t) - \rho\,] \tag{9}$$

TECHNOLOGICAL DIFFUSION BETWEEN DIRTY AND CLEAN COUNTRIES

With 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 under-price them. Thus, IGs can be produced by either 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.
The structure of FGs production in the *F*-country, is now, affected by the ratio $Q_{E,L}/Q_{D,L}$:

$$\overline{n}_F = \left\{ \left[\left(\frac{A_{E,F}}{A_{D,F}} \right)^{1/\alpha} \frac{e}{d} \frac{E_F}{D_F} \frac{Q_{E,L}}{Q_{D,L}} \right]^{1/2} + 1 \right\}^{-1} \tag{10}$$

Since TK gap is always favourable to the *L*-country in either specific knowledge – $Q_{M,L} > Q_{M,F}$, 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 determined only by differences in national technological environment, A_M, and national labour levels, *M*, see (10).
The prices of both *E*-FGs and *D*-FGs are given by:

$$p(t) = p_E(t)/p_D(t) = [\overline{n}(t)/(1-\overline{n}(t))]^{\alpha}, \text{ where } \begin{cases} p_{D,L} = p_n\,(1-n)^{\alpha} = p_{D,F} \\ p_{E,L} = p_n\, n^{\alpha} = p_{E,F} \end{cases} \tag{11}$$

The instantaneous probability of the successful imitation of the IG top environmental quality that transfers its production to the *F*-country, is given by:

$$pb_F(k,j,t) = rs_F(k,j,t) \cdot \beta_F\, q^{k_F(j,t)} \cdot \xi_F^{-1} q^{-(1/\alpha)\,k_F(j,t)} \cdot (M_F + M_L)^{-\zeta_F} \cdot H_N(j,t) \cdot H_T(j,t) \cdot f\big(\tilde{Q}_M(t), h\big)^{-\overline{\sigma} + \tilde{Q}_M(t)} \tag{12}$$

(i) $\beta_L > \beta_F > 0$, i.e., learning by past innovations should have greater effects than learning by past imitations; (ii) $k = k_L \geq k_F$, 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) $H_N(j,t) \cdot H_T(j,t) \cdot f\left(\widetilde{Q}_M(t), h\right)^{-\bar{\sigma} + \widetilde{Q}_M(t)}$, with $0 < \widetilde{Q}_M(t) < 1$ and $\bar{\sigma} > 0$, 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). $f\left(\widetilde{Q}_M(t), h\right)$ is a quadratic imitation function capturing the backwardness advantage (Papageorgiou, 2002):

$$f\left(\widetilde{Q}_M(t), h\right) = \begin{cases} 0 & , 0 < \widetilde{Q}_M(t) \leq h \\ -\widetilde{Q}_M(t)^2 + (1+h)\,\widetilde{Q}_M(t) - h & , h < \widetilde{Q}_M(t) < 1 \end{cases} \tag{13}$$

$\widetilde{Q}_M(t) \equiv \left(Q_{M,F}(t)/Q_{M,L}(t)\right)$ is the relative TK level of the Dirty-country and $h \in (0,1)$ is the TK threshold that dictates whether the *F*-country can imitate or not. If the gap is smaller than the threshold, i.e., $\widetilde{Q}_M(t)$ is above *h*, *F*-countries can benefit from the backwardness advantage as in Barro and Sala-i-Martin (1997). Otherwise, backwardness is no longer an advantage. Once affected by the exponent function $\sigma\left(\widetilde{Q}_M, t\right) = -\bar{\sigma} + \widetilde{Q}_M(t)$ in (12-v), $f(\cdot)$ yields an increasing advantage of backwardness.
Under R&D equilibrium, expected revenues must equal spent resources:

$$pb_F(k,j,t)\, V_F(k,j,t) = \left(1 - s_{r,F}\right) rs_F(k,j,t) \tag{14a}$$

$$pb_L(k,j,t)\, V_L(k+1,j,t) = \left(1 - s_{r,L}\right) rs_L(k,j,t) \tag{14b}$$

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

$$pb_L(j,k,t) = \frac{\beta_F}{\xi_F} H_D\, H_T\, f\left(\widetilde{Q}_M(t), h\right)^{-\bar{\sigma} + \widetilde{Q}_M(t)} \widetilde{Q}_M(t) (1-\alpha)^{1/\alpha} \frac{\left(1 - MC_F\right)}{\left(1 - s_{r,M,F}\right)} m\, Z_M(t) - r(t) \tag{15}$$

Where, $$Z_M(t) = \frac{M_F}{M_F + M_L}\left(\frac{p_{M,F}\, A_{M,F}}{\left(1 + \varphi_{x,M,F}\right)}\right)^{1/\alpha} + \frac{M_L}{M_F + M_L}\left(\frac{p_{M,L}\, A_{M,L}}{\left(1 + \varphi_{x,M,F}\right)}\right)^{1/\alpha} \tag{16}$$

Equation (15) 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 (15)-(16), 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:

$$\dot{Q}_{M,L}/Q_{M,L} = pb_{M,L}\left[q^{(1-\alpha)/\alpha} - 1\right] \tag{17}$$

From (17), we can conclude that like under no IT (7), 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 labour 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:

$$g^* = \left(\frac{F\dot{G}}{FG}\right)^* = \left(\frac{I\dot{G}}{IG}\right)^* = \left(\frac{R\,\dot{\&}\,D}{R\,\&\,S}\right)^* = \left(\frac{\dot{Q}_D}{Q_D}\right)^* = \left(\frac{\dot{Q}_E}{Q_E}\right)^* = \left(\frac{\dot{C}}{C}\right)^* = \left(\frac{\dot{c}}{c}\right)^* = \frac{1}{\theta}\left[(1-\tau_K)r^* - \rho\right] \Rightarrow \left(\frac{\dot{p}_E}{p_E}\right)^* = \left(\frac{\dot{p}_D}{p_D}\right)^* = \left(\frac{\dot{\bar{n}}}{\bar{n}}\right)^* = 0 \qquad (18)$$

By setting (18) equal to (17), we get a constant steady-state $r^*\left(\equiv r_D^* \equiv r_E^*\right)$ and g^* arises from plugging r^* into (18). 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 (18) 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 labour 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, (19), and the one that would prevail in the *F*-country without IT, (20), shows the increase in the steady-state growth rate associated to the IT in IG (21).

$$r^* = \left\{\left[q^{(1-\alpha)/\alpha} - 1\right]\theta + (1-\tau_k)\right\}^{-1} \left\{\frac{\beta_F}{\xi_F} H_N H_T f\left(\tilde{Q}^*{}_M(t), h\right)^{-\sigma+\tilde{Q}^*{}_M(t)} \tilde{Q}^*{}_M(t)\,(1-\alpha)^{1/\alpha} \frac{(1-MC_F)}{\left(1-s_{r,M,F}\right)}\left(1+\varphi_{x,M,F}\right) m\, Z^*{}_M(t)\left[q^{(1-\alpha)/\alpha}-1\right]\theta + \rho\right\} \qquad (19)$$

$$r^* = \left\{\left[q^{(1-\alpha)/\alpha} - 1\right]\theta + (1-\tau_k)\right\}^{-1} \left\{\frac{\beta}{\xi}(1-\alpha)^{1/\alpha} \frac{\left(1+\varphi_{x,M,F}\right)}{\left(1-s_{r,M,F}\right)} \frac{q-1}{q}\left(\frac{p_M A_M}{1+\varphi_{x,M}}\right)^{1/\alpha} m\left[q^{(1-\alpha)/\alpha}-1\right]\theta + \rho\right\} \qquad (20)$$

$$\left[H_N H_T f\left(\tilde{Q}^*{}_M(t), h\right)^{-\sigma+\tilde{Q}^*{}_M(t)} \tilde{Q}^*{}_M(t)(1-MC_F)\left(1+\varphi_{x,M,F}\right) Z_M^*(t)\right]\Bigg|_{IT\ of\ IG} - \left[\left(MC_F + \varphi_{x,M,F}\right)^{(\alpha-1)/\alpha}\left(\frac{q-1}{q}\right)\left(p^*_{M,F} A_{M,F}\right)^{1/\alpha}\right]\Bigg|_{pre-trade} \qquad (21)$$

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, (16). 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.

CONCLUSIONS

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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