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CLEAN AND DIRTY TECHNOLOGIES UNDER ENVIRONMENTAL POLICY

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ABSTRACT

This paper aims is to study the contributions of environmental policies to the production of ecological goods, when consumers are indifferent between ecological and dirty goods. It develops a Schumpeterian R&D growth model with endogenous directed technological change. By solving the transitional dynamics numerically and by removing the scale effects, it is shown that, through the price channel, when green firms and green research are supported by policy and/or dirty activities are taxed, technological progress leads to relatively more production of ecological goods and environmental quality improvements. Furthermore, if there is a positive change in the green technological environment, it strongly fosters R&D towards quality improvement of ecological goods, increasing their production.

Keywords: Endogenous growth, Technological change, Environmental Policy, Environment.

JEL codes: C61; O13; Q55; Q58.

1. INTRODUCTION

The Intergovernmental Panel on Climate Change has stated that carbon dioxide (CO_2) concentrations in the atmosphere have been increasing significantly over the past century, compared to the rather steady level of the pre-industrial era. Among the many human activities that produce Greenhouse Gases (GHGs), the use of energy represents by far the largest source of emissions (IEA, 2014). Since “eco-friendly” technologies enhance the environmental sustainability by inducing more ecological goods production, through low-carbon technologies, attention should be addressed to TK to reduce these emissions.

In line with this thought, this paper develops a dynamic general equilibrium growth model with endogenous skill-biased technological change to study the contributions of environmental policies to produce relatively more ecological goods, with fewer 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. In recent years, the economic and financial crises have changed consumers' behavior. Some studies (e.g., McKenzie et al, 2011 and Kaytaz et al, 2014) have found that during recession periods consumers switch a significant amount of expenditures towards essential goods and lower priced goods. As a result, we will assume that consumers are indifferent between dirty and ecological goods, as their main interest is surviving to uncertain future conditions rather than taking into account social or ecological concerns. This work relates to papers that analyze the environmental policy using endogenous growth models focused on the direction of technological change (e.g., Acemoglu et al. 2011; Grimaud et al., 2008; Hart, 2008; Ricci, 2007). However, in contrast to these works, our study stresses the price channel role in directing R&D towards the higher priced good. Three productive sectors are considered: the final goods (FGs), the intermediate goods (IGs) and the research and development (R&D). FGs can be produced by ecological or dirty technology, i.e., FGs can be produced either by more advanced and quality improved renewable technologies or by less advanced and less quality improved technologies. 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 increase it. The quality of the IGs is raised by (vertical) innovations resulted from R&D.

The remainder of the paper is organised as it follows. Section 2 presents the model. Section 3 analyses the steady-state equilibrium. Section 4 studies the transitional dynamics and proceeds to some sensitive analysis. Section 5 concludes.

2. THE MODEL

Following Acemoglu et al. (2001), Barro et al. (2004) and Meireles et al. (2012), each perfectly competitive FG $n \in [0,1]$ production is given by:

$$Y_n(t) = \left\{ A_D \left[\int_0^J \left(q^{k(j,t)} x_n(k,j,t) \right)^{1-\alpha} dj \right] \left[(1-n)\, d D_n \right]^{\alpha} + A_E \left[\int_J^1 q^{k(j,t)} x_n(k,j,t)^{1-\alpha} dj \right] \left[n\, e E_n \right]^{\alpha} \right\} \quad (1)$$

(i) A is the exogenous productivity level reflecting the dirty technological environment (A_D) or the ecological technological environment (A_E); (ii) $x_n(k,j,t)$ are IGs adjusted by the highest environmental quality, $q^{k(j,t)}$ with q>1, obtained by each successful R&D; (iii) $j \in [0,J]$ is for dirty IGs (D-IGs) and $j \in]J,1]$ is for ecological IGs (E-IGs); (iv) E and D are the skilled and the unskilled labour; (v) $\alpha \in]0,1[$ and (1-α) indicate the labour and the IG shares; (vi) $e>d\geq 1$ guarantees an absolute productivity advantage of E over D; (vii) n and (1-n) assure that E is relatively more productive in producing FGs indexed by larger n, while D is relatively more productive in producing FGs indexed by smaller 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 $0 \leq n \leq \bar{n}$ ($\bar{n} < n \leq 1$):

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

$$Q_D(t) \equiv \int_0^J q^{k(j,t)(1-\alpha)/\alpha} \, dj$$

and $$Q_E(t) \equiv \int_J^1 q^{k(j,t)(1-\alpha)/\alpha} \, dj \tag{3}$$

The aggregate quality indexes in (3) evaluate the technological knowledge (TK) and the ratio $Q_E/Q_D=B$ measures the (ecological) TK bias. Equation (2) represents a "proxy" for the environmental quality. Small $\bar{n}$ means a relatively higher level of ecological goods production and thus, a better environmental quality and vice-versa.

All resources, Y, can be consumed, C, used in the IGs production, X, or directed to R&D, RS:

$$Y(t) = X(t) + RS(t) + C(t) \tag{4}$$

Unlike FGs, IGs are provided by a monopolistic firm whose production requires a start-up cost of R&D that is recovered by a patent law. Since IGs employ FGs, the marginal costs (MC) of both IGs and FGs are equal (MC=1). Since consumers are assumed to be indifferent between ecological or dirty goods, firms will not have the incentive to produce relatively more ecological goods. Hence, they will produce according to their maximum profits and the environmental quality may fall below a critical threshold. In this context, government needs to encourage ecological goods production to decrease GHGs emissions. In the literature, there is a conventional wisdom that, from an efficiency perspective, market-based instruments are preferred over command-and-control instruments (Baumol et al., 1994). Furthermore, they are believed to be more effective in inducing technological change as they offer a permanent incentive to use lesser environmental commodities.

Assuming that government can subsidise the E-IG and tax the D-IG, 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 the IG firms yields:

$$p = (1+\varphi_X)/(1-\alpha) \tag{5}$$

and the limit pricing used to capture the whole market is:

$$p = q(1+\varphi_X), \text{ where } (1+\varphi_X) < q(1+\varphi_X) \leq [(1+\varphi_x)/(1-\alpha)] \tag{6}$$

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

$$p(t) = p_E(t)/p_D(t) = [\bar{n}(t)/(1-\bar{n}(t))]^{\alpha}, \quad \begin{cases} p_D = p_n(1-n)^{\alpha} = \exp(-\alpha)\bar{n}^{-\alpha} \\ p_E = p_n n^{\alpha} = \exp(-\alpha)(1-\bar{n})^{-\alpha} \end{cases} \tag{7}$$

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 R&D that improves their environmental quality. Thus, labour and environmental quality levels affect the R&D direction through the FG price channel (e.g. Acemoglu et al., 2002).

The incentive to support R&D relies on the expected present value of profits flow:

$$V(k,j,t) = \Pi(k,j,t) / [r(t) + pb(j,k,t)] \tag{8}$$

The denominator is the interest rate plus the Schumpeter's creative destruction rate. R&D improves IGs and, hence, the quality indexes (3), while creatively destroying the previous profits.

Following Aghion et al. (1992), the instantaneous probability – or the Poisson probability distribution - of a successful innovation is given by:

$$pb(k,j,t) = rs(k,j,t)\,\beta\,q^{k(j,t)}\,\xi^{-1} q^{-(1/\alpha)\,k(j,t)} M^{-1}\,h(j) \tag{9}$$

(i) $rs(k,j,t)$ is the flow of FGs devoted to R&D; (ii) $\beta q^{k(j,t)}$, *β>0*, is the positive learning effect of accumulated TK from past successful R&D; (iii) $\xi^{-1} q^{-(1/\alpha)\,k(j,t)}$, *ξ>0*, is the adverse effect caused by the increasing complexity of quality improvements; (iv) M^{-1}, with *M=D* if 0≤*j*≤*J* and *M=E* if *J*<*j*≤1, is the adverse effect of market size; (v) *h*(*j*) is the TK absorption effect that captures the absolute advantage of less over more polluted environment in implementing advanced TK (cleaner air improves health and workers productivity, and thus their capacity to adapt to new TK). Its proposed specification is:

$$h(j) = \begin{cases} 1 & , \textit{ if } \; 0 \le j \le J \\ [1 + A_E/(A_E + A_D)]^{\sigma} & , \textit{ if } \; J < j \le 1 \end{cases} \qquad \text{where: } \sigma = 1 + A_E/A_D \tag{10}$$

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:

$$pb(j,k,t)\,V(k+1,j,t) = (1-s_r)\,rs(k,j,t) \tag{11}$$

s_r is an ad-valorem subsidy to R&D that decreases R&D costs, which can be specific to *E*- or *D*-R&D.

Re-arranging the terms, the instantaneous probability can be written by:

$$pb_M = \frac{\beta}{\xi}\frac{(1+\tau_{x,M})}{(1-s_{r,M})}\frac{(q-1)}{q}\left(\frac{p_M A_M (1-\alpha)}{(1+\tau_{x,M})}\right)^{1/\alpha} \mu\, h(j) - r(t) \tag{12}$$

Therefore, the TK growth rate equilibrium, Q_M, is given by the following TK path:

$$E(\Delta Q_M/Q_M) = \dot{Q}_M/Q_M = pb_M\left[q^{(1-\alpha)/\alpha} - 1\right] \tag{13}$$

[$q^{((1-\alpha)/\alpha)}$-1] is the R&D effect on TK and pb_M is the probability of successful R&D.

From (13), it is clear that R&D equilibrium rates reply negatively to the interest rate, *r*, and to a raise in $\tau_{x,D}$ and positively to an increase in $s_{r,M}$ and $s_{x,E}$. Thus, the direction of the TK is driven by the price channel and can be affected by government.

The government budget is assumed to be balanced at each time:

$$\tau_k r(t)\int_0^1 K(a,t)da + \tau_M w_M(t)\int_0^1 [u_w(a,t)M(a,t)]da + \tau_{x,D} X(t) = s_{x,E} X(t) + s_{r,M} RS(t) \qquad (14)$$

The left-hand side of (14) is government tax revenue from assets income, $\tau_k r(t)K(t)$, from labour income, $\tau_M\,[w_E(t)E(t)+w_D(t)D(t)]$, and from an environmental tax on IGs that use *D*-technology, $\tau_{x,D}X(t)$. The right-hand side is government expenditures on environmental subsidies for *E*-IGs that use *E*-technology, $s_{x,E}X(t)$, and for R&D that enhance the environmental quality of both *E*- and *D*-specific IGs, $s_{r,M}RS(t)$.

Regarding the consumption, it is assumed a time invariant number of heterogeneous individuals, $a \in [0,1]$, that decide between consuming the aggregate FG and saving. For simplicity, $a \leq \bar{a}$ are unskilled-workers assumed to perform better using *D*-technology, while $a > \bar{a}$ are skilled-workers assumed to perform better using *E*-technology. The utility function for the individual is given by:

$$U(a,t) = \int_0^\infty \left[\frac{c(a,t)^{1-\theta} - 1}{1-\theta}\right] \exp(-\rho t)\,dt \qquad (15)$$

where $c(a,t)$ is the consumption of *Y* by a, at *t*; $\rho > 0$ is the homogeneous subjective discount rate and $\theta > 0$ is the inverse of the intertemporal elasticity of substitution.

The solution for the individual's consumption path is the standard Euler equation:

$$\dot{c}(a,t)/c(a,t) = \dot{c}(t)/c(t) = \dot{C}(t)/C(t) = (1/\theta)\,[(1-\tau_k)\,r(t) - \rho\,] \qquad (16)$$

where $\dot{c}(t)/c(t)$ yields the growth rate of consumption.

3. THE STEADY-STATE EQUILIBRIUM

In steady-state agents can maximize utility or profits and all markets clear. The dynamic equilibrium can be described by Q_E and Q_D paths. Therefore, the stable and unique steady-state endogenous growth rate, $g^*(\equiv g_D^* \equiv g_E^*)$, is:

$$g^* = \left(\frac{\dot{Y}}{Y}\right)^* = \left(\frac{\dot{X}}{X}\right)^* = \left(\frac{R\dot{S}}{RS}\right)^* = \left(\frac{\dot{Q}_D}{Q_D}\right)^* = \left(\frac{\dot{Q}_E}{Q_E}\right)^* = \left(\frac{\dot{C}}{C}\right)^* = \left(\frac{\dot{c}}{c}\right)^* = \frac{1}{\theta}\left[(1-\tau_K)r^* - \rho\right] \Rightarrow \left(\frac{\dot{p}_E}{p_E}\right)^* = \left(\frac{\dot{p}_D}{p_D}\right)^* = \left(\frac{\dot{\bar{n}}}{\bar{n}}\right)^* = 0 \qquad (17)$$

By setting (16) equal to (13) we get the constant steady-state interest rate, $r^*(\equiv r_D^* \equiv r_E^*)$. By plugging *r** into (16) we get *g**. Equalizing the steady-state TK paths, $(\dot{Q}_D/Q_D)^* = (\dot{Q}_E/Q_E)^*$, it can also be found p_M* and $\bar{n}^*$.

By $s_{x,E}$ and $s_{r,M}$, government intervention affects positively *r** and thus *g**. Indeed, $s_{x,E}$ and $s_{r,M}$ stimulate R&D by increasing monopolistic profits and by reducing R&D costs, respectively. Conversely, $\tau_{x,D}$ and τ_K affect negatively *r** and thus *g**. In fact, $\tau_{x,D}$ and τ_K discourage R&D. The former because it reduces monopolistic profits and the latter due to the smaller expected marginal benefit. As τ_W is absent in equilibrium, it does not directly affect g^*.

4. TRANSITIONAL DYNAMICS AND SENSITIVITY ANALYSIS

From (13) and since r is unique, the stability of B is:

$$\frac{\dot{B}}{B}=\frac{\dot{Q}_E}{Q_E}-\frac{\dot{Q}_D}{Q_D}=\frac{\beta}{\xi}\left(\frac{q-1}{q}\right)(1-\alpha)^{1/\alpha}\exp(-\alpha)\left\{e\left(1+\frac{A_E}{A_E+A_D}\right)^{\sigma}\left(\frac{1-s_{x,E}}{1-s_{r,E}}\right)\left(\frac{A_E}{1-s_{x.E}}\right)^{1/\alpha}\left[1+\left(\frac{Q_E}{Q_D}\frac{e\ E}{d\ D}\right)^{-1/2}\right]^{\alpha}-d\left(\frac{1+\tau_{x,D}}{1-s_{r,D}}\right)\left(\frac{A_D}{1+\tau_{x.D}}\right)^{1/\alpha}\left[1+\left(\frac{Q_E}{Q_D}\frac{e\ E}{d\ D}\right)^{1/2}\right]^{\alpha}\right\} \tag{18}$$

We solve the model numerically to illustrate the effect of government intervention on both TK bias, B, and FG bias, $\bar{n}$, using the parameter values in Table 1. The parameter calibration is based on empirical literature and on theoretical specifications. The mark-up ratio, q=(1/(1-α)), is set in line with the mark-up estimates of Kwan et al. (2003). θ is in accordance with previous calibrations of growth models, assumed to exceed one (e.g., Jones et al., 1993) and ρ follows from previous works on growth (e.g., Dinopoulos, 1999). The remaining parameters have been calibrated taking into account our theoretical assumptions and considering a steady-state growth rate of 2%, the average *per capita* growth rate of the USA in the post-war period.

Table 1. Baseline parameter values

Parameter	Value	Parameter	Value
A_E	1.50	α	0.70
A_D	1.00	β	1.60
e	1.20	θ	1.50
d	1.00	ρ	0.02
E	0.70	σ	2.00
D	1.00	ξ	4.00
q	3.33	$s_{X,E}$, $s_{r,E}$, $s_{r,D}$ $\tau_{X,D}$	0.00

Source: Authors' assumptions based on theoretical framework and on the literature.

Considering the baseline values in Table 1, the paths of B and $\bar{n}$ with and without government intervention are displayed in Fig.1 and Fig. 2, respectively.

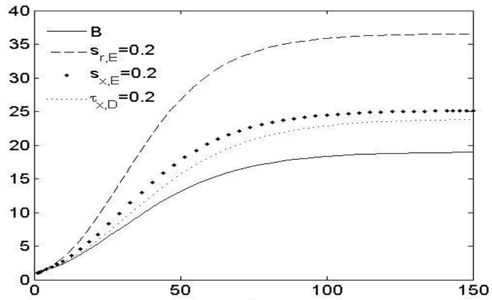

Fig. 1 Transitional dynamics of TK bias (B) under government intervention

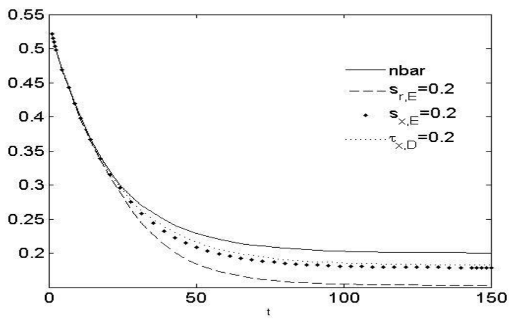

Fig. 2 Transitional dynamics of FGs bias ($\bar{n}$) under government intervention

Fig. 1 and Fig. 2 compare the baseline steady-state values of, respectively, B and $\bar{n}$, under no government intervention to the ones with government intervention.

With a raise of each type of subsidies and tax, it is clear that $s_{r,E}$ is the most contributor to heighten both the TK bias and the final good sector bias while $\tau_{x,D}$ is the least contributor. Indeed, $s_{r,E}$ reduces *E*-R&D costs, stimulating *E*-R&D and increasing the *E*-TK growth rate. Conversely, $\tau_{x,D}$ decreases the profits of *D*-IG producers discouraging *D*-R&D in favour of *E*-R&D. Thus, the production of *E*-IG rises, increasing the number of *E*-FGs, whose relative prices decrease continuously towards the new steady-state. Therefore, $\bar{n}$ decreases, showing an improvement of the environmental quality, see (2). Hence, as a result of the price channel, B is increasing, but at a falling rate until it reaches its new higher steady-state and $\bar{n}$ is decreasing, but at a falling rate until it reaches its new lower steady-state.

Table 2 presents the steady-state values of both the TK bias, B, and the environmental quality bias, $\bar{n}$ under no government intervention. Table 3 depicts the steady-state values of both the TK bias and the environmental quality bias under government intervention.

Table 2. Steady-State Values of B and $\bar{n}$ under No Government Intervention

Variables	Initial Values	Steady-state values under no government intervention
B	1	18.96
$\bar{n}$	0.52	0.20

Table 3. Steady-State Values of B and $\bar{n}$ under Government Intervention

Variables	Steady-state values under government intervention		
	$s_{r,E}$=0.2	$s_{x,E}$=0.2	$\tau_{x,D}$=0.2
B	36.53	25.13	23.82
$\bar{n}$	0.15	0.178	0.18

Considering, now, an improvement in the exogenous environmental quality, the paths of B and $\bar{n}$ with and without government intervention are displayed in Fig.3 and Fig. 4, respectively.

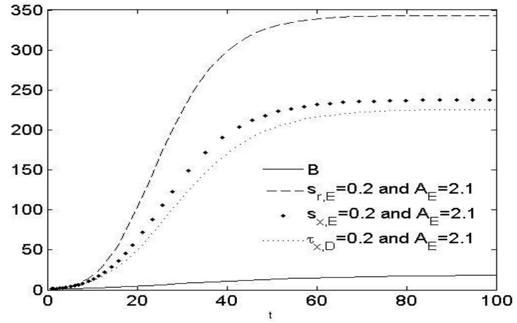

Fig. 3 Transitional dynamics of TK bias (*B*) under both government intervention and an improvement in the exogenous environmental quality

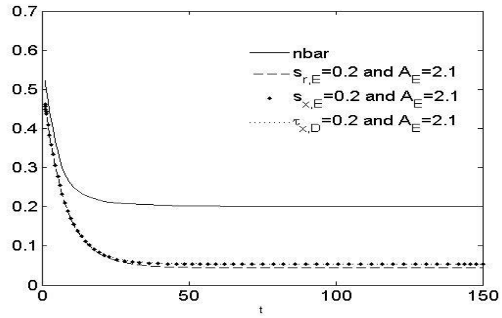

Fig. 4 Transitional dynamics of FGs bias ($\bar{n}$) under both government intervention and an improvement in the exogenous environmental quality

Fig. 3 shows that an increase in A_E, clearly heightens *B* in favour of *E*-IGs, the least polluting goods. That increase re-directs R&D towards improvement of ecological IGs and increases the TK absorption effect. In (10), *h*(*j*) jumps immediately as a result of a move from A_E=1.50 to A_E=2.10. Hence, as with government intervention only, though now with stronger magnitude, the production of *E*-IGs raises, increasing the number of *E*-FGs whose relative prices decrease continuously towards the stable new steady-state, Thus, *B* is growing, but at a falling rate until it reaches its new higher steady-state.

In turn, Fig. 4 shows that an increase in A_E heightens $\bar{n}$ in favour of *E*-FGs. Notwithstanding, at *t*=0, it also causes an instantly drop in $\bar{n}$, due to the rise in A_E without change in *B*. The increase in *E*-FGs (a decrease in $\bar{n}$) diminishes their relative prices, discouraging ecological TK, which implies that $\bar{n}$ is decreasing, but at a falling rate until its new lower steady-state. Once in steady-state, with a constant *B*, $\bar{n}^*$ remains constant. With a sufficiently TK absorption effect, $\bar{n}^*$ is smaller than under the baseline scenario, with no increase in A_E.

As a result of the price channel, the paths of *B* and $\bar{n}$ in Fig. 1 and Fig. 2, respectively, are strongly smoothed compared to the path of *B* and $\bar{n}$ in Fig. 3 and Fig. 4. In fact, *ceteris paribus*, the increase of A_E immediately increases the profits of the monopolistic producers of ecological IGs and, thus, the demand for *E*-R&D.

5. CONCLUSION

This paper presents a dynamic general equilibrium growth model with endogenous skill-biased technological change. It analyses the contributions of both environmental policies and technological environment to the ecological goods production, when consumers are indifferent between ecological and dirty goods. A measure of the environmental quality is also provided, expressed by the FGs sector bias, $\bar{n}$.

We found that technological progress leads to relatively more production of ecological goods and environmental quality improvements when green firms and green research are supported by policy and/or dirty activities are taxed. This result is in line with, for instance, Ricci (2007). In the same way, a positive change in the green technological environment strongly fosters R&D towards quality improvement of green IGs, increasing their production. Notwithstanding, the raise in the number of ecological FG reduces their relative prices, discouraging ecological TK and ecological production. Consequently, through the price channel, ecological TK bias and ecological FG sector bias increases at a falling rate until they reach their new steady-state.

For future research, it would be interesting to develop an endogenous multi-country growth model with different environmental endowments to discuss issues of global policy coordination and to verify whether, with international trade, environmental regulation would be sufficient to encourage both the development of clean technologies and the production of ecological goods.

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