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Environmental Health and Education: Towards Sustainable Growth*

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Résumé

Cet article analyse les interactions entre qualité de l'environnement, santé et éducation. Nous considérons une structure à générations imbriquées, où l'accumulation de capital humain dépend des conditions environnementales à travers leur impact sur le niveau d'absentéisme des enfants à l'école. Par ailleurs, la dynamique de l'environnement est directement affectée par les flux de pollution générés par la production mais aussi par les efforts de maintenance engagés par les agents économiques. Cette double causalité génère une évolution jointe du capital humain et de la qualité de l'environnement et peux induire l'émergence d'une trappe, caractérisée à la fois par un faible niveau de développement et une environnement dégradé. De plus, ces résultats illustrent les débats empiriques qui ont trait à l'existence d'une courbe de Kuznets environnementale. Enfin, le modèle propose un cadre permettant d'analyser les conséquences d'une politique environnementale sur l'existence de la trappe.
Mots-clef : Education, Qualité environnementale, Croissance, Santé.
Codes JEL : D90, H51, I20, Q01.

Abstract

This article aims at investigating the interplay between environmental quality, health and development. We consider an OLG model, where human capital dynamics depend on the current environment, through its impact on children's school attendance. In turn, environmental quality dynamics depend on human capital, through maintenance and pollution. This two-way causality generates a co-evolution of human capital and environmental quality and may induce the emergence of an environmental poverty trap characterized by a low level of human capital and deteriorated environmental quality. Our results are consistent with empirical observation about the existence of the Environmental Kuznets Curve. Finally, the model allows for the assessment of an environmental policy that would allow to escape the trap.
JEL Codes: D90, H51, I20, Q01.
Keywords: Education, Environmental Quality, Growth, Health.

1 Introduction

This article emphasizes the negative effects of a damaged environment on the growth process, through human health. In particular, the model highlights a two-way causality between human capital accumulation and the environment: on the one hand, human capital depends on the environment, since the educational choices vary with the level of school attendance, which is affected by environmental conditions; on the other hand, environmental quality dynamics is affected by human capital, through pollution flows and environmental maintenance. Indeed, we consider that pollution is a by-product of production, so that a higher level of human capital implies more production and, in turn, more pollution. Similarly, we show that maintenance is positively related to income, and thus to human capital. These interplays allow for a multiplicity of development paths, and the existence of an *environmental poverty trap*, characterized both by a low level of human capital and deteriorated environmental conditions. Thus, the model matches empirical evidence suggesting that higher levels of human capital are associated with a good environment and that health risks exacerbate poverty. In addition, it provides a framework for public intervention assessment, in the fields of both environment and education.

As underlined by the World Bank (2001) in its strategic report and by the United Nations Development Program (UNDP (2008)), the environment considerably affects health outcomes, due to traditional environmental hazards (lack of safe sanitation, indoor pollution, exposure to disease vector) but also through more modern environmental risks (transports, industry, agro-chemicals...). Moreover, the World Bank report points out that poor countries are more sensitive to both kind of environmental issues and gives a "*... new dimension to environmental health as a principal indicator of development...*". According to this report of facts and as a starting point of the motivation, our paper relies on a wide empirical literature which highlights the damages imposed on agents' health status due to a low quality of the environment. It has been shown that acute, as well as chronic levels of pollution significantly impact health outcomes especially that of children and elderly people (Fitzgerald *et al.* (1998), Pope (2000), Evans & Smith (2005), Chay & Greenstone (2003), (WHO, 2004, 2006)). In most cases, the deterioration of the environment is associated with atmospheric pollution (Pope (2000)), water quality degradation (Dasgupta (2004)), soils occupations (Lessenger *et al.* (1995)), natural resources depletion etc. All these phenomena may translate into health risks and diseases going from cardiopulmonary to respiratory symptoms (asthma, cough....), epidemiologic diseases, blood lead level, acute poisoning or even cancers among others (Murray & Lopez (1996), World Bank (2001)). Of course, all those effects differ in their magnitude, depending on the level of income, the health care system, the medicine technology...

When focusing on development issues, the impact of the environment on children's health is particularly interesting, since the latter induces strong effects on human capital accumulation. Some existing papers like Hansen & Selte (2000), Bloom *et al.* (2001), Schultz (2003), Chakraborty (2004), Weil (2008), show that health outcomes contribute to human capital-led growth, since healthier agents are more productive, present lower levels of absenteeism, and more cognitive capacities of learning. In turn, as emphasized by the World Health Report in 2002, school attendance is crucially affected by the environment. In fact, some studies conclude for a significant effect of pollution on children's school attendance, after controlling for many variables[1] (see Romieu *et al.* (1992), Park *et al.* (2002), Mendell & Heath (2004), Currie *et al.* (2007), Ikefuji & Horii (2007)). Hence, environmental quality plays a key role in the growth process through this channel on children's school attendance.

The major novelty of the present article is to propose a theoretical model in which the harmful effect of pollution on human capital accumulation is introduced: it is assumed that the productivity of education expenditure is directly affected by the environment, through the level of school attendance.

We consider an overlapping generations model where parents invest in education for their offspring, but the effectiveness of this investment depends on the current state of the environment. In fact, we assume that school attendance depends on environmental quality: the level of school attendance can be lower, due to illness, or because parents prefer children to stay at home as a precaution, during acute period of pollution, etc (Romieu *et al.* (1992), Currie *et al.* (2007)). In this framework, school attendance embodies the productivity of education expenditure. Hence, human capital dynamics is linked to the current state of the environment but it is also affected by the level of human capital inherited from the previous generation. In turn, the environment is influenced by human capital through pollution flows (generated by the production process) and environmental maintenance (positively related to agent's income). Thus, in our model human capital and environmental quality dynamics are jointly determined. This leads to multiple equilibria and an environmental poverty trap may occur if returns to education are too low. From a theoretical point of view, growth-induced environmental risks decrease health outcomes, thus diminishing the return to education, because the environment deteriorates: human capital accumulation is slackened and income becomes too low to trigger further investment in the environment preservation. Environmental conditions are still deteriorating and the economy may fall into a vicious cycle which drives it into the trap.

The results of our model are also consistent with empirical observations about the existence of an Environmental Kuznets Curve (Grossman & Krueger (1995), Shafik (1994), Panayotou (1993)), hereafter EKC. In most cases, it turns out that only developed economies have experienced over time this inverted U-shape relationship between pollution and income: during first stages of development, the economy develops while environmental quality decreases (*i.e.*, pollution increases); Once the economy reaches a high enough level of development, it cares about environmental conditions and may start to invest in the environment preservation: the second stage of development is characterized by a simultaneous improvement of environmental quality. On the contrary, developing countries seldom display this kind of dynamics, and the negative effects of a damaged environment on agents health could be a major justification for this phenomena (see Gangadharan & Valenzuela (2001)). Our model can account for non-ergodic dynamics that allows to replicate these two different trajectories and may explain why some economies can be caught into a trap.

Our model also provides a framework for an environmental policy assessment, as in the article of Ono (2002). In fact, it considers the implementation of an exogenous tax rate on polluting emissions and evaluates the opportunities of driving one economy out of the environmental poverty trap. The main results of the benchmark model still hold. However, it is shown that the effect of an increased tax rate on the possibilities of escaping the trap are ambiguous and follow an inverted U-shaped pattern: only when the positive effect (of the tax) on environmental quality overcomes the negative one on the income, then a rise in the tax rate enhances the situation. Hence, there exists a range of tax rates that may improve the overall situation, by reducing pollution flows while stimulating educational spending.

Finally, this article is related to two fields of the economic literature. First, it considers an OLG structure, where agents value the future environmental quality, both for self-interested and purely altruistic motives[2], and may invest in maintenance in order to improve it. This basic framework is in line with the seminal works of John & Pecchenino (1994), Ono (2002). However, in our set up, intergenerational externalities do not come from physical capital accumulation, but human capital dynamics. Here, the growth process is driven by human capital accumulation and private choices of education affect the future state of the environment. Investing in education raises income, and generates more pollution but simultaneously, allows for expenditure in environmental maintenance: the environmental quality dynamics evolves thereby. Second, our contribution is related to many papers dealing with educational choices and economic development (see for instance de La Croix & Doepke (2003), Chakraborty (2004), Galor & Moav (2002)). In those theoretical models, altruistic parents invest in their children's education. Then, the key mechanisms lie in the utility associated with these educational choices compared to the cost and the expected private returns to the investment itself. However, the educational choices are not related with a prospect of sustainable growth, from an environmental point of view. This literature also deals with multiple equilibria and poverty traps, associated with income, technology, fertility or even human capital (see Azariadis (1996), Blackburn & Cipriani (2002)). Here, the trap will be characterized in addition by environmental quality.

The article is organized as follows: after this Introduction, Section 2 presents the basic framework and the structure of the model; Section 3 analyses microeconomic behaviours; Section 4 proposes the main dynamical results and Section 5 assesses the consequences of environmental policy. Finally, Section 6 concludes.

2 The Model

In this section, we present the setup of the model and discuss the main assumptions.

2.1 Basic Framework

Agents live for three periods: childhood, adulthood, where all decisions are taken, and the old age. They maximize their lifetime utility, defined over consumption when adult (c_t), environmental quality when old (E_{t+1}) and the level of human capital attained by their children (h_{t+1}):

$$U_t = \ln c_t + \mu(\ln E_{t+1} + \ln h_{t+1}), \tag{1}$$

where $\mu > 0$ represents the weight given to both the future level of human capital and environmental quality[3]. It is assumed that children are endowed with one unit of time, dedicated to education that is privately funded. In line with de La Croix & Doepke (2003), human capital evolves according to:

$$h_{t+1} = [\beta + v_t\theta_t]^{\eta} h_t^{1-\eta}, \tag{2}$$

The stock of human capital depends on two main elements: human capital inherited from of parents (h_t) and v_t being the education expenditure. Notice that $0 < \eta < 1$ measures the productivity of education in the production of human capital[4]. In this framework, education expenditure could be regarded as the potential quantity of education provided by parents to their offspring while $v_t\theta_t$ is the effective quantity of education received by a child. Then, $(1 - \theta_t) \in [0, 1]$ represents the fraction of education lost, due to illness, or the time spent at home instead of school etc. Here, θ_t can be considered as education expenditure effectiveness which depends on the current state of the environment. Yet, the determinants of this variable will be deeply discussed later on (see section 2.2). Moreover, notice that agents are also endowed with "basic skills" ($\beta > 0$) that allow their human capital to be positive, even if parents do not invest in education. Expression (2) highlights the existence of an intergenerational externality in human capital accumulation.

Following John & Pecchenino (1994), the law of motion of environmental quality writes as:

$$E_{t+1} = (1 - b)E_t - P_t + \gamma m_t, \tag{3}$$

where $0 < b < 1$ is the natural depreciation rate, P_t is pollution flow, m_t is environmental maintenance, while $\gamma > 0$ accounts for its effectiveness. Let us notice that maintenance represents all actions engaged by agents in order to preserve or improve the environment. Adults supply inelastically h_t units of human capital and earn $w_t h_t$, with w_t being the wage rate. Income can be used for three alternative purposes: consumption, education expenditure and environmental maintenance. Hence, the budget constraint can be written as:

$$w_t h_t = c_t + m_t + v_t \tag{4}$$

One good is produced in the economy and the production technology requires only one input, human capital. The production function can be expressed as: $Y_t = \omega h_t$, where ω is an index of productivity. As the production function exhibits constant returns to scale, it follows directly that the wage rate is given by the average productivity of human capital: $w_t = \omega$. In addition, pollution flows arise from production process[5] so that (see Stockey (1998) for instance):

$$P_t = z^{\alpha} \omega h_t, \tag{5}$$

where $\alpha \in [0,1]$, and $z \in]0,1]$, the cleanness degree of production. Here, a high value of z induces that production is more pollution intensive. Similarly, α high implies more pollution flows, given the final output. For the time being we make this simplifying assumption that $\alpha = 1$[6].

2.2 Environmental Quality and School Attendance

Let us now consider θ_t, the time spent at school, as a function of environmental quality, such that: $\theta_t \equiv \theta(E_t)$, where $\theta(\cdot)$ is increasing and takes it values on the interval $[0, \lambda]$, with $\lambda \leq 1$. This assumption derives from the empirically established effect of health on human capital accumulation: healthier agents display better cognitive capacities, more willingness to learn, less absenteeism etc. (Weil (2008), Grossman & Kaestner (1997)). Besides, as already mentioned in Introduction, children are more vulnerable to much kind of environmental damages, such that their level of school attendance is crucially affected by the environmental quality (see for instance Currie *et al.* (2007), Pope (2000), Romieu *et al.* (1992)). Thus, everything goes as if the environment affects education expenditure productivity, through its impacts on children's health. Then, the time spent at school (or conversely the level of absenteeism) is related to the environmental quality, and the latter becomes a key factor in human capital accumulation. In order to obtain closed-form solutions, we assume that the effect of the environment on school attendance is described by:

$$\theta(E_t) = \frac{\lambda E_t}{(1 + E_t)} \tag{6}$$

The function $\theta(\cdot)$ is thus increasing and concave in the environmental quality and $\lim_{E_t \to \infty} \theta(E_t) \to \lambda$. As environmental quality improves, children spend more and more time at school; nevertheless, it is supposed that this level of school attendance is strictly bounded and smaller than 1. Despite the environment, children may not go to school for many reasons. Here, λ may be regarded as the health care effectiveness or the medicine technology, meaning that if it is low, an improvement in the environmental quality translates into a small enhancement of school attendance. This two-way relationship will be established in the following section which presents the optimal microeconomic choices of agents. Notice that through this variable θ_t, a two-way causality between human capital and environmental quality is established: on the one hand, the environment affects the productivity of education; on the other hand, human capital influences the evolution of environmental quality.

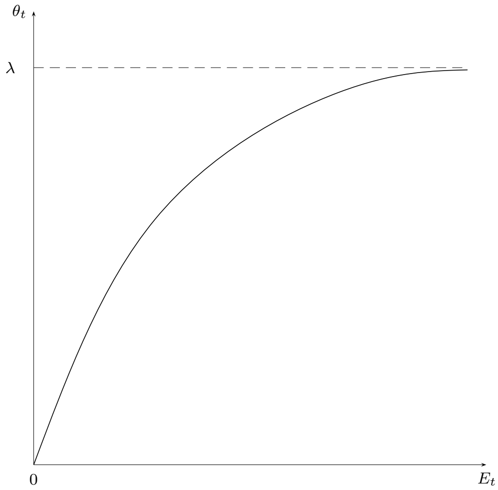


Figure 1. *School attendance as a function of environmental quality*

3 Microeconomic Choices

In this section, we derive and discuss the optimal microeconomic choices, from the maximisation of U_t under (2), (3), (4) and (5). As we will see, the optimisation problem may induce the existence of corner solutions both in terms of educational spending and environmental maintenance. Then, superscripts $i = \{S, U\}$, $j = \{C, D\}$ denote respectively the *Schooled* solution when children are educated ($v_t > 0$) or the *Unschooled* one ($v_t = 0$), and the *Clean* solution ($m_t > 0$) when agents do invest in environmental preservation or the *Dirty* one ($m_t = 0$).

Solving the maximization program yields the following FOC on education expenditure:

$$\mu\eta\theta_t c_t \leq [\beta + v_t\theta_t], \text{ an equality holds if } v_t > 0. \tag{7}$$

We also obtain the FOC on maintenance:

$$\mu\gamma c_t \leq E_{t+1}, \text{ an equality holds if } m_t > 0. \tag{8}$$

These two equations might lead to four distinct configurations: a Schooled and Clean (S, C) region in which parents invest in both education and maintenance; a Schooled and Dirty (S, D) region where parents only educate their offspring; a Unschooled and Clean (U, C) region, where agents do invest only in maintenance; and finally, a Unschooled and Dirty (U, D) region, where parents only consume. Then, in the following subsections, optimal choices are derived in each of these four configurations. In particular, $v_t^{i,j}$ and $m_t^{i,j}$ denote the level of education and maintenance provided in a configuration (i, j).

3.1 Education Expenditure

Taking into account (7) and (8), when $v_t > 0$ and $m_t > 0$, the optimal choice of education expenditure is given by:

$$v_t^{S,C} = \frac{1}{\gamma(1+\mu+\mu\eta)} \left[\mu\eta\omega h_t(\gamma - z) + \mu\eta(1-b)E_t - \frac{\gamma\beta(1+\mu)}{\theta(E_t)} \right] \tag{9}$$

Environment has two effects on human capital investment. First, it fosters education through a substitution effect: if less maintenance is needed, parents will be able to educate more their offspring. Second, it increases $\theta(E_t)$, the productivity of education expenditure and thus triggers more investment; otherwise said, if children spend more time at school, parents are likely to invest more in education.

Moreover, education is a normal good only if the following condition is satisfied:

Condition 1 *Let suppose that:*

$$\gamma - z > 0$$

If Condition 1 does not hold, it implies that effectiveness of maintenance is very low. Then, it induces a substitution effect: increasing the agent's income would involve that the share of this income devoted to maintenance becomes larger than one at the expense of education expenditure. When effectiveness of environmental investment is low, there is more need of maintenance to compensate for pollution and so education expenditure reduce. Moreover, in case this condition does not hold, environmental quality would decrease over time in the income despite the efforts engaged by agents: this would reduce the level of school attendance and finally prevent agents to invest in education.

One have also to consider the case where agents do not invest anymore in maintenance, for instance, for high environmental quality values (see equation 8). Thus, the budget constraint becomes:

$$\omega h_t = c_t + v_t \tag{10}$$

When only equation (7) holds with equality, the implied optimal level of education expenditure is:

$$v_t^{S,D} = \frac{1}{(1+\mu\eta)} \left[\mu\eta\omega h_t - \frac{\beta}{\theta(E_t)} \right] \tag{11}$$

The difference between z and γ does not play a role anymore and we get a positive link between income and education.

3.2 Maintenance

Similarly, substituting (9) into (8) yields the expression for optimal maintenance, in the case of an interior solution, *i.e.* $m_t > 0$ and $v_t > 0$:

$$m_t^{S,C} = \frac{1}{\gamma(1+\mu+\mu\eta)} \left[\frac{\mu\gamma\beta}{\theta(E_t)} + \omega h_t(\mu\gamma + z(1+\mu\eta)) - (1-b)(1+\mu\eta)E_t \right] \tag{12}$$

The above expression reproduces the standard result found in the literature (see for instance John & Pecchenino (1994); Ono (2002)), according to which both pollution flows and income (the second term in the numerator) have a positive impact on environmental actions, while improved environmental conditions tend to reduce maintenance (represented by the third term in the numerator). However, introducing human capital accumulation in this framework reinforces the second effect: for a clean environmental quality, agents are likely to invest in education and then may substitute maintenance with education expenditure. This happens all the more so as basic skills are high.

However, agents may not invest in education, but only in maintenance, if the level of basic skills is high or if current environmental conditions are too deteriorated (see equation 8). This would imply that the budget constraint becomes:

$$\omega h_t = c_t + m_t \tag{13}$$

Therefore, when $v_t = 0$, the optimal maintenance choice can be rewritten as:

$$m_t^{U,C} = \frac{\omega h_t(\mu\gamma + z) - (1-b)E_t}{\gamma(1+\mu)} \tag{14}$$

It is worth noticing that in this case school attendance has no impact on maintenance. In fact, considering that $v_t = 0$ implies that the additional effect induced by human capital accumulation vanishes.

3.3 Graphical Analysis

In order to describe clearly the dynamics of our model, the plan (E_t, h_t) has been divided into four regions (see Figure 2). Moreover, from now on, we substitute $\theta(E_t)$ by its expression (6).

As a result of utility maximization, the corner solution for education occurs if (equation (7)):

$$h_t < \frac{\gamma\beta(1+\mu)(1+E_t) - \mu\eta\lambda(1-b)E_t^2}{\mu\eta\omega\lambda(\gamma - z)E_t} \equiv \Phi(E_t), \tag{15}$$

This function separates the plan into two regions, a Schooled one and Unschooled one. $\Phi(E_t)$ being a downward sloping curve, it implies that the level of human capital required to invest in education reduces with the environmental quality. Moreover, equation (8) provides conditions for a corner solution for maintenance to occur:

$$h_t < \frac{\lambda E_t^2(1+\mu\eta)(1-b) - \mu\gamma\beta(1+E_t)}{\lambda\omega E_t[\mu\gamma + z(1+\mu\eta)]} \equiv \Psi(E_t), \tag{16}$$

where $\Psi(E_t)$ is an increasing and concave function, that separates the plan into two regions, the Clean one and the Dirty one: It follows obviously that income is increasing in the environmental quality. It could also be the case that agents do not invest neither in education nor in maintenance: according to both FOCs, this would happen if both the following inequalities hold:

$$h_t < \frac{\beta(1+E_t)}{\mu\eta\omega\lambda E_t} \equiv \phi(E_t) \tag{17}$$

and

$$h_t < \frac{(1-b)E_t}{\omega(\mu\gamma+z)} \equiv \psi(E_t), \tag{18}$$

where $\phi(E_t)$ is downward sloping while $\psi(E_t)$ is increasing and linear. These functions (15-18) divide the state space into four sets[7], $\mathcal{S}^{i,j}$:

$$\begin{aligned} \mathcal{S}^{S,C} &= \left\{ (h_t, E_t) \in \mathbb{R}^2_+ : h_t > \Phi(E_t) \text{ and } h_t > \Psi(E_t) \right\}, \\ \mathcal{S}^{U,C} &= \left\{ (h_t, E_t) \in \mathbb{R}^2_+ : \psi(E_t) < h_t < \Phi(E_t) \right\}, \\ \mathcal{S}^{S,D} &= \left\{ (h_t, E_t) \in \mathbb{R}^2_+ : \phi(E_t < h_t < \Psi(E_t)) \right\}, \\ \mathcal{S}^{U,D} &= \left\{ (h_t, E_t) \in \mathbb{R}^2_+ : (E_t, h_t) \notin \mathcal{S}^{S,C} \cup \mathcal{S}^{U,C} \cup \mathcal{S}^{S,D} \right\}. \end{aligned} \tag{19}$$

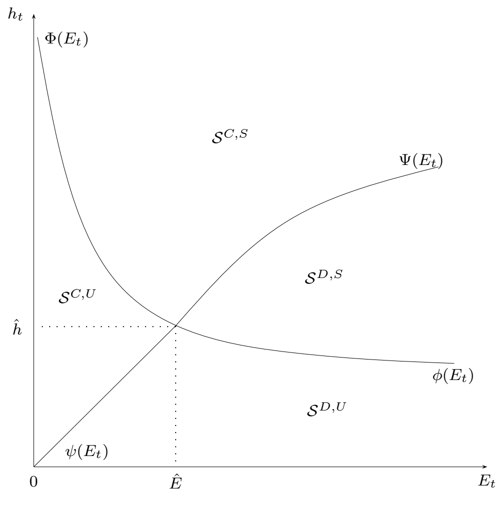


Figure 2. *Plan*

To summarize, for very low levels of development (human capital) agents will not invest neither in education, nor in maintenance, because income is too low. If income increases but the environment is still damaged, agents do not educate their children, as the return to education is depleted, but might invest in maintenance. Then, for intermediate values of human capital while environmental conditions improve, parents will start educating their children. Finally, an interior solution appears for high enough levels of human capital and as soon as environmental quality reaches intermediate values. The following section deals with the dynamic analysis of this model, considering these four distinct regions.

4 Dynamics

Substituting optimal choices into the equations describing the evolution of human capital (2) and environmental quality (3) yields a bi-dimensional dynamical system that illustrate the co-evolution of E_t and h_t:

$$\begin{cases} h_{t+1} = [\beta + v(E_t, h_t)\theta(E_t)]^{\eta} h_t^{1-\eta} \\ E_{t+1} = (1-b)E_t - P(h_t) + \gamma m(E_t, h_t), \end{cases} \tag{20}$$

with given initial conditions (E_0, h_0). Here the functions $v(E_t, h_t)$, $m(E_t, h_t)$ and $P(h_t)$ describe respectively the optimal choices of education and maintenance, and the level of pollution. We will draw a phase diagram that depicts the overall dynamics, however we start by presenting separately the human capital stationarity condition (*hh* locus) and that of the environment (*EE* locus).

4.1 The *hh* Locus

Let us consider the stationarity condition for human capital, $hh \equiv \{(E_t, h_t) : h_{t+1} = h_t\}$. The level of human capital in the steady state is crucially affected by the region it belongs to so that many cases may occur depending on the value of parameters. However, the analysis proposed here is restricted to a case where ω is sufficiently high. Then, it is possible to state that, as shown in Figure 3:

Lemma 1 *For a high enough value of ω, the human capital is constant when it equals:*

$$h_{hh}(E_t) = \begin{cases} \beta & \text{for } (E_t, h_t) \in \mathcal{S}^{U,C} \\ \frac{\mu\eta\gamma\beta(1+E_t)+\mu\eta\lambda(1-b)E_t^2}{\gamma(1+\mu+\mu\eta)(1+E_t)-\mu\eta\lambda\omega(\gamma-z)E_t} & \text{for } (E_t, h_t) \in \mathcal{S}^{S,C} \end{cases} \tag{21}$$

Moreover, for any given value of the environmental quality, human capital converges towards this stationary locus, hh.

Proof. See Appendix A ■

As it is shown in Appendix A, a higher value of ω, the productivity of workers, induces an upward shift of the stationary locus of human capital. Indeed, a larger income triggers more expenditure in education, so that the stationary level reached by the economy is higher. In addition, this configuration of the parameters implies that the

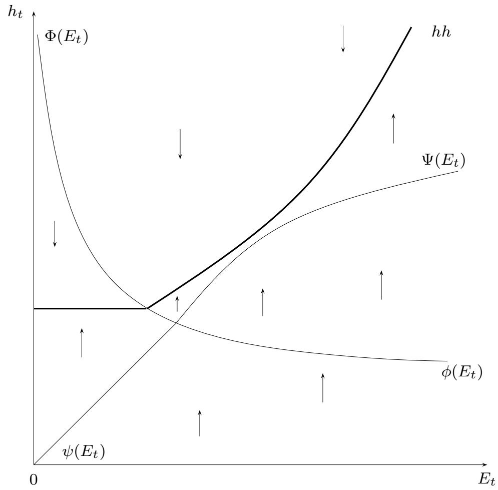


Figure 3. *The hh locus*

hh locus cannot belong to any area characterized by zero maintenance[8]. In this set up, the *hh* locus is split into two distinct parts. For a too low environmental quality, agents do not invest in education and therefore the stock of human capital does not increase over time: it is pinned down to the exogenous level of basic skills. Further increases in environment quality push agents to invest in education. The *hh* locus enters the interior regime and becomes convex. This result stems from the positive relationship between environment and returns to education, reinforced by the substitution effect between maintenance and education expenditure, when environmental conditions improve.

Finally, human capital attains a stationary value since its production function exhibits decreasing returns to education.

4.2 The EE Locus

Let us now consider the stationarity locus for environmental quality defined as $EE \equiv \{(E_t, h_t) : E_{t+1} = E_t\}$ as depicted in Figure 4. Environmental quality is at the steady state when the positive effect of maintenance is fully offset by the negative effect of pollution flows, and the natural depreciation of the environment: above (below) the EE locus, environmental maintenance counter-balances (is more than compensated by) pollution flows. Therefore, it is possible to claim that:

Lemma 2 *Environmental quality is constant when:*

$$h_{EE}(E_t) = \begin{cases} \frac{E_t(1+\mu b)}{\mu\omega(\gamma-z)} & \textit{for } (E_t, h_t) \in \mathcal{S}^{U,C} \\ \frac{\lambda E_t^2(1+\mu(b+\eta))-\mu\beta\gamma(1+E_t)}{\mu\lambda E_t\omega(\gamma-z)} & \textit{for } (E_t, h_t) \in \mathcal{S}^{S,C} \end{cases} \tag{22}$$

Moreover, for any given level of human capital, environmental quality converges towards this stationary locus, EE.

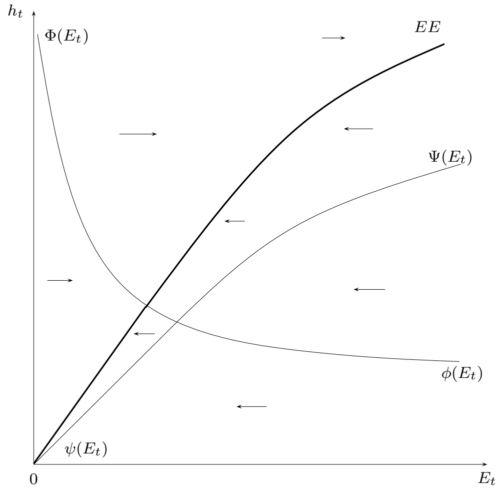


Figure 4. *The EE locus*

Proof. See Appendix B ■

As illustrated by Figure 4, and provided the properties of the *EE* locus (see Appendix B), the stationary locus of the environment is globally increasing in h_t. This means that a higher level of human capital implies a higher stationary environmental quality. This property comes from Condition 1, according to which the positive effect of maintenance dominates the effect of pollution flows. A growing level of human capital induces directly a stronger pressure on the environment that is more than compensated by more investment in maintenance. Then, environmental quality improves. More precisely, this relationship is first linear (within the clean but unschooled regime) and becomes concave (in the interior regime, since the level of school attendance is also concave in the environment). Environmental quality dynamics takes into account the effect of the environment on the productivity of education. Yet, as environmental quality enhances, human capital increases but at lower rates so that improvements in the environment become smaller.

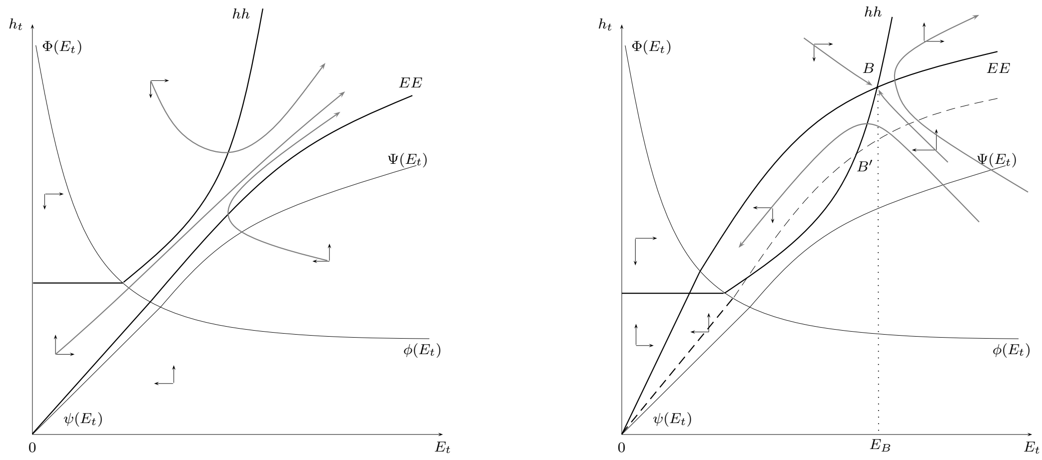
4.3 Global Dynamics

This section presents the main dynamical results of the model. We study long-run implications of our model, that is to say the loci where *EE* and *hh* loci intersect. It is possible to claim that:

Proposition 1 *The dynamic system described by (20) exhibits the following properties:*
(i) when ω is sufficiently high, the dynamics is characterized by a continuous growth path.
(ii) when ω is not large, the dynamics exhibits two steady states, the first one, namely the environmental trap being stable, the second is not. Hence, depending on initial conditions, the economy converges towards the low equilibrium or engages in a continuous and sustainable growth path.

Proof. See Appendix C ■

These situations are depicted in Figure 5. It is worth noticing that the low equilibrium (provided that it exists) may belong either to the clean but unschooled area or to the clean and schooled one. In particular, a higher wage rate ω or a cleaner technology z would, at least, move to the right the low equilibrium (see the dashed line in Figure 5b). This implies that the low equilibrium exhibits higher human capital and better environmental conditions. In presence of multiple development paths, this low equilibrium defines an environmental development trap, displaying both deteriorated environmental conditions and low level of human capital.



(a) sustainable growth path (b) environmental trap

Figure 5. *Global Dynamics*

In fact, in this setup initial conditions do matter (see Figure 5b). For low initial environmental quality (below the saddle path), the economy will end up in the low equilibrium. When the environmental quality is strongly damaged, agents invest less in education (or do not invest at all), because returns to this investment reduce. Then the dynamics of human capital is slackened and the level of production is low, just as the total income perceived by agents. Thus, even with low pollution flows, households are not able to invest enough in maintenance, and the environment does not improve enough to trigger future additional education expenditure. In turn, relatively clean initial environmental conditions (above the saddle path) allow reaching a situation characterized by a self-sustained increase both of human capital and environmental quality. Above the EE locus, environmental investment dominates harmful pollution flows all the more so as human capital is rising. Thus, as human capital accumulates the environmental quality improves which reciprocally stimulate the investment in education: this virtuous cycle drives the economy to develop in a green and sustainable way. Similarly but whatever initial conditions, for a high enough level of workers productivity, the economy will follow a monotonous sustainable dynamics trajectory as soon as it attains the area located between the two loci (see figure 5a).

The mechanisms presented above is consistent with empirical evidence, and in particular with the existence of low human development traps (see UNDP (2008)). As in our model, this kind of trap can be induced by environmental shocks and low levels of income: the negative effects of climate change could harm economic development, through their interactions with health, unemployment, conflict etc.

4.4 Environmental Kuznets Curve

Moreover, this article contributes to the debate on the existence of an Environmental Kuznets Curve. As described by Grossman & Krueger (1995), during early stages of development process, as long as the economy develops, it might simultaneously deteriorates its environmental conditions; then, the economy attains a sufficiently high level of income and starts to care about the environment, thus allowing to grow and improve environmental conditions. However, some papers argue that developing countries do not experience this U-shaped pattern[9]. For instance, Gangadharan & Valenzuela (2001) underline the negative impact of a degraded environment on health, during early stages of development: the benefit from the growth process might be thus offset by the harmful effect of bad environmental conditions on health, and the economy might not be able to reach a sufficient level of income which would then induce a growth take-off.

Our theoretical framework allows us to replicate these results. If initial conditions are bad (the system stands below the saddle path, see figure 5b), the economy will be caught in a poverty trap. At first, income grows while environment deteriorates. However, this fall in environmental quality affects negatively children's health and school attendance sharply diminishes. Thus, education expenditure becomes less productive and human capital accumulation might be slackened. It can be the case that some economies do not reach the "threshold" value of income that would enable them to develop and improve environmental conditions. On the contrary, if the economy starts above the saddle path, it will experience a U-shaped dynamical pattern and then follow a sustainable growth path. In the "dirty" regimes, environmental conditions deteriorate while human capital rises, since parents still educate their offspring. The economy goes through the interior regime: parents start investing in environmental quality and harmful pollution flows are offset by maintenance. Then, the economy follows a continuous and sustainable growth path.

4.5 Escaping the Environmental Poverty Trap

Let us now focus on the two parameters "in favour" of human capital accumulation, *i.e.*: the "adjusted" elasticity of the human capital to education expenditure (η) and the medical technology λ. A positive variation of these parameters involves ambiguous effects on global dynamics, so that the equilibria are characterized by a higher level of human capital but lower environmental quality. Indeed, on the one hand, this positive shock triggers more educational spending, through microeconomic choices, since it raises the productivity of the investment. Therefore, the hh locus shifts upward. Moreover, it implies that any increase in environmental quality would have a stronger effect on the education. On the other hand, the same shock generates a substitution effect between education expenditure and environmental maintenance, as it rises the private rate of return to schooling investment. Moreover, as human capital accumulates, pollution flows get larger. It follows that, in order to keep environmental quality constant, the level of human capital must be higher: the EE locus is also shift upward.

Second, let us consider a positive productivity shock on unskilled agents, implying that the level of basic skills (β) would increase. This would allow for higher value of the equilibria. Not surprisingly, such a shock increases the overall level of human capital, regardless of agents'microeconomic choices, and shifts up the hh locus. The same shock produces different consequences on the stationary value of the environment: as aggregate human capital stock is higher, pressure on the environment is stronger and pollution flows are consequently larger. This shock bears upon the environment quality and moves down the EE locus. Finally, there may exist a value of β that would drive one economy out of the trap, so that the hh and EE loci do not intersect anymore. The productivity shock raises income and, in turn, enables to spend more in maintenance: whatever initial conditions are, the economy follows a sustainable growth trajectory.

Finally, let us consider the use of a cleaner technology as a mean to escape the trap. A smaller value of the parameter z may, at least, increase the value of the low equilibrium, when this latter belongs to the clean but unschooled regime. In addition, it could be the case that the trap shifts from the clean but unschooled regime to the clean and schooled area, if z becomes small enough. Indeed, the EE locus which rules out the dynamics of environmental quality is positively affected by a clean technology. If production is less pollution intensive, then, the harmful pressure of human capital on the environment reduces. In particular, it depends crucially on the difference between the efficiency of maintenance (γ) and the cleanness of the production process (z): if z

decreases, the stationary level of the environment will be reached for lower levels of human capital. This implies that the effect of maintenance offsets the harmful effects of pollution and natural depreciation. Moreover, technology also affects the stationary locus of human capital: a dirty production reduces incentives to invest in education through a substitution effect with maintenance. Consequently human capital accumulation is slackened and its stationary value is lower. Then, the *hh* locus moves up when z falls. Finally, a sufficiently clean technology makes a higher equilibrium attainable and may eliminate the environmental development trap. This solution is even more interesting as it opens the way for environmental policies, which could improve the overall situation. An initially trapped economy may step out of the trap by implementing a more environmentally friendly policy (see Section 5).

5 Environmental Policy

This section proposes a modified version of the benchmark model, in order to assess the potential consequences of environmental policies on the global dynamics of the economy.

5.1 Endogenous Pollution Technology and Environmental Concern

Let us suppose that there exists a government that cares about the environment: it implements an exogenous environmental tax on polluting emissions, $\tau \in [0, 1]$. The major difference with the basic model is to consider that pollution flows are, from now on, endogenous. However, the issue here is not to assess an optimal environmental policy, but only to discuss the implied possibilities of coming out the environmental trap. The government does not maximise any objective function. The production function can be rewritten, similar to Stockey (1998), as:

$$Y_t = \omega h_t z_t, \tag{23}$$

so that the technology (z_t) is endogenous. As previously, pollution flows are expressed as a by-product:

$$P_t = z_t^{\alpha} Y_t, \tag{24}$$

with $0 < \alpha \leq 1$. Substituting this expression into production function (23) yields:

$$Y_t = (\omega h_t)^{\frac{\alpha}{1+\alpha}} P_t^{\frac{1}{1+\alpha}} \tag{25}$$

Pollution is an essential input in the production function, which exhibits in addition constant returns to scale. From now on, the firm, which produces the manufactured good, behaves in order to maximize its profit (Π_t), choosing both the level of harmful pollution flows and employment:

$$\max_{h_t, P_t} \Pi_t = Y_t - w_t h_t - \tau P_t \tag{26}$$

All factors are paid to their marginal productivity, and from the FOCs we obtain optimal wage rate and pollution flows:

$$w_t = \frac{\alpha\omega\tau}{g(\tau)} \tag{27}$$

and

$$P_t = \frac{\omega h_t}{g(\tau)}, \tag{28}$$

with $[\tau(1+\alpha)]^{\frac{1+\alpha}{\alpha}} \equiv g(\tau)$, $g(0) = 0$, $g'(\tau) > 0$ and $g''(\tau) > 0$. An increased environmental tax reduces pollution flows as well as the wage rate. In fact, it raises the cost of pollution, thus lowering the demand of pollution and then the productivity of human capital.

Moreover, we suppose that this tax is used to finance public expenditure (G_t), which is redistributed to households as form of lump-sum transfer[10]: $G_t = \tau P_t$. Hence, the budget constraint for adult agents becomes:

$$\frac{\omega\tau h_t(1+\alpha)}{g(\tau)} = c_t + m_t + v_t \tag{29}$$

The tax rate has two opposite effects on the global income: larger transfers are distributed while human capital productivity falls. Finally, the revenue perceived by agents depends negatively on the tax rate, meaning that the negative effect on the wage rate dominates the positive effect of public expenditure.

Agents maximize their lifetime utility under (2), (3) and (29). As they receive a lump sum transfer, their behavior is unaffected and equations (7) and (8) still hold. It follows straightforward that the optimal choice of education can be expressed as:

$$v_t = \begin{cases} \frac{\mu\eta(1-b)E_t}{\gamma(1+\mu+\mu\eta)} - \frac{\gamma\beta(1+\mu)(1+E_t)}{\gamma(1+\mu+\mu\eta)\lambda E_t} - \frac{\mu\eta(1-(1+\alpha)\gamma\tau)\omega h_t}{\gamma(1+\mu+\mu\eta)g(\tau)} & \text{for } (E_t, h_t) \in \mathcal{S}^{S,C} \\ \frac{\mu\eta\omega h_t\tau(1+\alpha)g^{-1}(\tau) - \frac{\beta(1+E_t)}{\lambda E_t}}{(1+\mu\eta)} & \text{for } (E_t, h_t) \in \mathcal{S}^{S,D} \end{cases} \tag{30}$$

Once again, to ensure that education is a normal good we suppose the following condition:

Condition 2

$$\tau > \frac{1}{(1+\alpha)\gamma}$$

Condition 2 is similar to Condition 1 expressed in the case of endogenous pollution. If the tax rate is too low, pollution will be too large so that an increase in the income translates into a rise in maintenance, which is more than proportional. Hence, education expenditure reduces through a substitution effect. To ensure that education is still a normal good, τ has to be high enough.

We can observe that the effect of the tax is negative in the dirty area but ambiguous in the interior regime. In particular, it depends on the sign of $(\gamma\tau - 1)$. Here, the tax rate reduces the harmful pressure of pollution on the environment while it decreases the total income of agents. Thus, only when $\tau < 1/\gamma$, an increase in the tax rate might trigger education expenditure, through a substitution effect: if τ increases, pollution decreases, there is less need of maintenance, so that agents spend more in education. Otherwise, the negative effect of the tax rate on the income dominates and prevent agents to invest (this negative effect prevails for any level of the tax in the dirty but schooled area). In a similar way, the optimal choice of maintenance can be derived:

$$m_t = \begin{cases} \frac{(1+\mu\eta+(1+\alpha)\gamma\mu\tau)\omega h_t g^{-1}(\tau)\lambda E_t + \mu\beta\gamma(1+E_t) - (1-b)(1+\mu\eta)\lambda E_t^2}{\gamma(1+\mu+\mu\eta)\lambda E_t} & \text{for } (E_t, h_t) \in \mathcal{S}^{S,C} \\ \frac{(1+(1+\alpha)\gamma\mu\tau)\omega h_t g^{-1}(\tau) - (1-b)E_t}{\gamma(1+\mu)} & \text{for } (E_t, h_t) \in \mathcal{S}^{U,C} \end{cases} \quad (31)$$

Optimal environmental maintenance exhibits the same properties as before, concerning the effects of the environment, pollution flows or income. However, notice that the tax rate affects negatively the optimal level of maintenance, as a crowding effect, through two channels: first, a higher tax rate reduces pollution flows, so that environmental quality is better and agents engage more in education; second, the income is negatively affected, so that the investment in maintenance is reduced.

5.2 Global Dynamics

Substituting these choices into dynamic equations (2) and (3) allows us to obtain a new bi-dimensional dynamic system, depending on the tax rate τ:

$$\begin{cases} h_{t+1} = [\beta + v(E_t, h_t; \tau)\theta(E_t)]^\eta h_t^{1-\eta} \\ E_{t+1} = (1-b)E_t - P(h_t; \tau) + \gamma m(E_t, h_t; \tau) \end{cases} \quad (32)$$

The stationary loci of both the human capital (hh) and environmental quality (EE) can be consequently derived:

$$h_{hh}(E_t; \tau) = \begin{cases} \beta & \text{for } (E_t, h_t) \in \mathcal{S}^{U,C} \\ \frac{\mu\eta g(\tau)[\beta\gamma(1+E_t) + (1-b)\lambda E_t^2]}{\gamma(1+\mu+\mu\eta)g(\tau)(1+E_t) - \mu\eta\lambda((1+\alpha)\gamma\tau - 1)\omega E_t} & \text{for } (E_t, h_t) \in \mathcal{S}^{S,C} \end{cases} \quad (33)$$

and

$$h_{EE}(E_t; \tau) = \begin{cases} \frac{g(\tau)E_t(1+\mu b)}{\mu\omega((1+\alpha)\gamma\tau - 1)} & \text{for } (E_t, h_t) \in \mathcal{S}^{U,C} \\ \frac{\lambda E_t^2(1+\mu(b+\eta))g(\tau) - \mu\beta\gamma g(\tau)(1+E_t)}{\mu\lambda E_t\omega((1+\alpha)\gamma\tau - 1)} & \text{for } (E_t, h_t) \in \mathcal{S}^{S,C} \end{cases} \quad (34)$$

Once again, the consequences of an increased tax rate on human capital stationary locus depend crucially on the sign of $(\gamma\tau - 1)$. If the latter is negative, we will have an upward shift of the hh locus: the positive effect of the tax on environmental quality (as it reduces sharply pollution) stimulates the investment in education, while incentives to engage in maintenance diminish. Thus, the stationary level of human capital is reached but for lower levels of the environmental quality. On the contrary, a rise in the tax rate if $(\gamma\tau - 1) > 0$ reduces incentives for parents to educate their children through the income effect. Nevertheless, as pollution falls, an identical stationary level of human capital is attained with a cleaner environment.

In the clean but unschooled area, *i.e.* when $(E_t, h_t) \in \mathcal{S}^{U,C}$, an increase in τ implies a downward movement of the environmental quality stationary locus only if $(\gamma\tau - 1) < 0$. This holds also inside the interior regime. In fact, if *tau* increases, pollution falls, but also maintenance (crowding effect). However, when the effects of a reduction of pollution dominate those of the diminishing maintenance, the *EE* locus shifts down: the same level of human capital is attained with a cleaner environment.

Finally, the global effect of a rise in the tax rate follows an inverted U-shaped pattern, with a maximum reached for $\tau = \frac{1}{\gamma}$. In particular, when $\gamma\tau - 1 < 0$, an increase in the tax rate fosters investment in education, while reducing sharply pollution: the total effect is positive and the economy may be dragged out from the trap. However, if the tax rate is already high, the negative income effect dominates, thus lowering both investment in education expenditure and maintenance. The total effect is negative, human capital accumulation is slackened as well as environmental quality. Then, we can claim:

Proposition 2 *If Condition 2 holds, the relationship between the tax rate and the environmental quality at the low equilibrium is ambiguous.*

Proof. See Appendix D ■

For a sufficiently low tax rate, a stricter environmental policy may enhance the low equilibrium, meaning that the trap exhibits better environmental quality, while similar level of human capital (compared with the basic model), when it belongs to clean but unschooled regime; in the interior regime, the rise in the tax rate involve an upward shift of the *hh* locus and a downward movement of the *EE* locus. Consequently, the unstable equilibrium shifts to the down left. Compared to the situation without any environmental policy, initial conditions that enable to experience a sustainable growth are less constrained: economies that displays initially lower environmental quality or lower human capital might escape from being trapped and instead will follow a continuous growth.

Corollary 1 *There exists a range of tax rates, for which a tighter environmental policy might allow the economy to step out from the environmental poverty trap. This range is defined by:*

$$\frac{1}{(1+\alpha)\gamma} < \tau < \frac{1}{\gamma}$$

If the above restriction holds, a higher tax rate discourages firms to pollute and a greener technology will be adopted. This is consistent with what we have said (see Section 4.5) about an exogenous shock on the parameter z. Despite the possible negative effects of the tax increase on the total income, the reduction of pollution is an incentive to invest in education: more human capital is accumulated and may allow

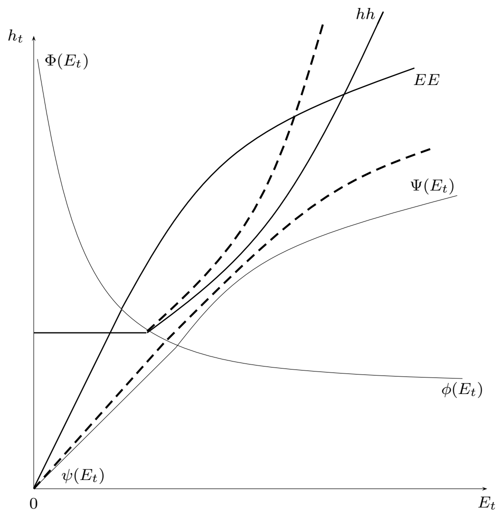


Figure 6. *Environmental Policy*

for an investment in environmental maintenance. Hence, if z becomes lower while educational spending grows, then the stationary locus of human capital moves upward. Similarly, less pollution enables the economy to attain a constant environmental quality for lower levels of human capital: the EE locus shifts downward.

6 Conclusion

In this paper we have analyse the interplay between health, human capital and the environment, as well as the resulting dynamic implications. The model is built upon a simple mechanism which highlights a trade off between human capital accumulation and sustainable development. Human capital dynamics depends crucially on current environmental conditions, through school attendance, while the dynamics of the environment is, in turn, affected by human capital, through pollution and maintenance. The joint dynamics of these variables is determined and may imply the existence of multiple development regimes. In particular, our results are consistent with the empirical evidences on the existence of the EKC. In addition, non-ergodicity allows us to identify an environmental poverty trap, characterized by a low level of development and bad environmental conditions.

Possible strategies to escape the trap, as well as factors affecting the risk to be caught in such a trap, have been discussed. Moreover, the model proposes an assessment of environmental policy, providing a range of tax rates on polluting emissions, which may drive the economy out of the trap.

Finally, our model can be extended along the following directions: (i) investigating the implementation of an optimal environmental policy in this framework; (ii) introducing some demographic issues; (iii) providing a deeper discussion on the relationship between education and environmental investment.

Notes

[1]The consequences of specific environmental issues could also be measured through a lot of indicators like for instance hospital admissions, medicine visits, or even DALY's data (which measure the Disability-Adjusted Life Year across various causes of illness or environmental risks).

[2]See, for instance, Popp (2001) for further discussion on the various motives that may trigger environmental expenditure.

[3]It could be regarded as a discount factor.

[4]Notice that η is, in fact, an "adjusted" elasticity of human capital to education expenditure, since it includes not only education but innate ability (β).

[5]Usually pollution is associated with physical capital rather than human capital. However, it could be the case that human capital pollutes through emissions of wastes for instance.

[6]This assumption does not affect qualitatively the main results. However, for a deeper analysis, this will be relaxed in Section 5.

[7]Notice that $\Phi(E_t)$ and $\phi(E_t)$ are continuous, as well as $\Psi(E_t)$ and $\psi(E_t)$. Moreover, those frontiers cross in a unique point $(\hat{E}, \hat{h})$, that is also the continuity point.

[8]If this case occurs, then this would reconsider the property of multiplicity of equilibria presented later on.

[9]The existing debate around the existence of the EKC is even wider, as conclusions often differ according the nature of pollution. However, here we restrict our discussion to global comparisons.

[10]This way of redistributing public funds could be discussed. Indeed, we could have transferred these receipts as a form of education subsidy. However, in this set up, the effects would have been identical.

Appendices

A Proof of Lemma 1

First, let us characterize the stationarity locus of human capital $h_{hh}^{i,j}(E_t)$ for $i \in \{S, U\}$ and $j \in \{C, D\}$. In the case of the interior solution, and substituting (9) into (2), it comes that:

$$h_{hh}^{S,C}(E_t) = \frac{\mu\eta\gamma\beta(1+E_t) + \mu\eta\lambda(1-b)E_t^2}{\gamma(1+\mu+\mu\eta) - \mu\eta\lambda\omega(\gamma - z)E_t} \tag{A1}$$

This locus exhibits the following properties: $h_{hh}^{S,C}(0) > 0$, $\partial h_{hh}^{S,C}/\partial E > 0$ and $\partial^2 h_{hh}^{S,C}/\partial E^2 > 0$. In the case of a corner solution on environmental maintenance ($m_t = 0$), equation (11) is substituted into (2) and the hh locus becomes:

$$h_{hh}^{S,D}(E_t) = \frac{\mu\eta\beta(1+E_t)}{(1+\mu\eta)(1+E_t) - \mu\eta\omega\lambda E_t}, \tag{A2}$$

with $h_{hh}^{S,D}(0) > 0$, $\partial h_{hh}^{S,D}/\partial E > 0$ and $\partial^2 h_{hh}^{S,D}/\partial E^2 < 0$. When $v_t = 0$, the hh locus becomes a constant and equals the level of basic skills, hence:

$$h_{hh}^{U,C} = h_{hh}^{U,D} = \beta \tag{A3}$$

We can easily show that the hh locus is continuous, in each case: there exists a unique point $\hat{E}$ such that when $E_t = \overline{E}$: $h_{hh}^{U,C}(\overline{E}) = \Phi(\overline{E}) = h_{hh}^{S,C}(\hat{E})$. Similarly, it can also easily be checked that there exists a unique $\check{E} > 0$ so that $h_{hh}^{U,C}(\check{E}) = \Phi(\check{E}) = h_{hh}^{S,D}(\check{E})$.
We now show that a high enough ω ensures that the hh locus only belongs either to $\mathcal{S}^{S,C}$ and $\mathcal{S}^{U,C}$. First of all, notice that ω always increases the value of the stationary locus hh, whatever the regime. Moreover, it displays a negative impact on the frontiers, such that $\Phi(E_t)$, $\phi(E_t)$, $\Psi(E_t)$ and $\psi(E_t)$ are shifted downward. Thus, for a high enough value of ω, $h_{hh}^{i,j}(E)$ is always superior to $\psi(E_t)$ and $\Psi(E_t)$, for all i, j. Hence, the hh locus is finally characterized by $h^{U,C}$ and $h^{S,C}$
Finally, we prove the stability of the hh locus. Let define $\triangle h_t = h_{t+1} - h_t$. For $\mathcal{S}^{S,C}$, $\triangle h_t = h_t^{1-\eta}\left\{\frac{\mu\eta[\beta\gamma(1+E_t)+\omega h_t(\gamma-z)\lambda E_t+\lambda E_t^2(1-b)]}{\gamma(1+\mu+\mu\eta)(1+E_t)}\right\}^{\eta} - h_t$, with $h_{hh}^{S,C}$ the value of h_t such that $\triangle h_t = 0$. Consequently, we can verify that for $h_{hh}^{S,C}(E_t) > (<) h_t$, $\triangle h_t > (<) 0$. Hence,for $(E_t, h_t) \in \mathcal{S}^{S,C}$, the value of h_t converges towards $h_{hh}^{S,C}(E_t)$. For $(E_t, h_t) \in \mathcal{S}^{U,C}$, $h_{t+1} = \beta$, human capital instantaneously adjusts to the stationary value, β.

Finally, for $(E_t, h_t) \in \mathcal{S}^{S,D}$, $\triangle h_t = h_t^{1-\eta}\left\{\frac{\mu\eta[\beta(1+E_t)+\omega h_t(\gamma-z)\lambda E_t]}{(1+\mu\eta)(1+E_t)}\right\}^{\eta} - h_t$ and $h_{hh}^{S,D}(E_t)$ is the value of h_t such that $\triangle h_t = 0$. It is straightforward that, if $h_t < h_{hh}^{S,D}(E_t)$, $\triangle h_t > 0$. Since for a ω high enough $h_{hh}^{S,D}(E_t)$ is always higher than $\psi(E_t)$ and $\Psi(E_t)$, for all $(E_t, h_t) \in \mathcal{S}^{S,D}$, h_t increases and the economy reaches the interior regime.

B Proof of Lemma 2

First of all, let us characterize the stationarity locus of human capital $h_{hh}^{i,j}(E_t)$ for $i \in \{S, U\}$ and $j \in \{C, D\}$. In the case of the interior solution, the optimal choice of maintenance (12) is substituted into (3) and yields:

$$h_{EE}^{S,C}(E_t) = \frac{\lambda E_t^2(1+\mu(b+\eta)) - \mu\beta\gamma(1+E_t)}{\mu\lambda E_t\omega(\gamma-z)}, \tag{B1}$$

the stationary locus of environment. Let notice that $\lim_{E\to 0} h_{EE}^{S,C}(E) \to -\infty$, $\partial h_{EE}^{S,C}/\partial E > 0$ and $\partial^2 h_{EE}^{S,C}/\partial E^2 < 0$. In the clean but unschooled area and substituting (14) into (3), the EE locus becomes:

$$h_{EE}^{U,C}(E_t) = \frac{E_t(1+\mu b)}{\mu\omega(\gamma-z)} \tag{B2}$$

The clean but unschooled regime is characterized by the fact that $h_{EE}^{U,C}(E)$ is increasing and linear, with $h_{EE}^{U,C}(0) = 0$. Finally, notice that when agents do not invest in maintenance (this is the case for both regimes (S, D) and (U, D)), then, the EE locus can be expressed as:

$$h_{EE}^{D,S}(E) = h_{EE}^{D,U}(E) = \frac{-bE_t}{z\omega} \tag{B3}$$

Let have a quick look at the stability properties of this locus and let define $\triangle E_t = E_{t+1} - E_t$. For $(E_t, h_t) \in \mathcal{S}^{S,C}$, $\triangle E_t = \left\{ \frac{\mu[\gamma\beta(1+E_t)+\omega h_t(\gamma-z)\lambda E_t+(1-b)\lambda E_t^2]}{(1+\mu+\mu\eta)\lambda E_t} \right\} - E_t$, with $h_{EE}^{S,C}(E_t)$ the value of E_t such that $\triangle E_t = 0$. We can then show that for $h_{EE}^{S,C} < (>) h_t$, $\triangle E_t > (<) 0$. Then, for $(E_t, h_t) \in \mathcal{S}^{S,C}$ the value of E_t converges to $h_{EE}^{S,C}(E_t)$. Similarly, for $(E_t, h_t) \in \mathcal{S}^{U,C}$, $\triangle E_t = \left\{ \frac{\mu\omega h_t(\gamma-z)-(1-b)E_t}{(1+\mu)} \right\} - E_t$. It is easy to verify that for $h_{EE}^{C,U} < (>) h_t$, $\triangle E_t > (<) 0$. Finally, for $(E_t, h_t) \in \mathcal{S}^{S,D} \cup \mathcal{S}^{U,D}$, $\triangle E_t = -bE_t - P_t < 0$, hence E_t always decreases.

C Proof of Proposition 1

We have shown that, for ω high enough, the hh locus consists in an horizontal line in $\mathcal{S}^{U,C}$ and is increasing and convex in $\mathcal{S}^{S,C}$. The EE locus is linearly increasing in $\mathcal{S}^{U,C}$ while increasing and concave in $\mathcal{S}^{S,C}$. Moreover, an increase in ω induces an upward shift of the hh locus while it translates the EE locus ad all the frontiers downward. Hence, it is straightforward that: (i) when ω becomes high enough, the two loci do not cross while (ii) for relatively low values of ω, the two loci cross twice. In the situation *ii*, the economy displays two steady states. It directly comes from the analysis of the stability of the two loci (see proof Lemma 1 and Lemma 2), that the higher equilibrium is a saddle point while the lower is locally stable. Hence, the plan (h_t, E_t) is separated by a saddle path, below which the economy converges towards the low equilibrium. Above this path, both E_t and h_t grow continuously. Finally, in the case (i), it directly that for all initial condition, the economy reaches a development path characterized by a continuous increase of both E_t and h_t.

D Proof of Proposition 2

It directly comes from (A3) and (B2) that: $\partial h_{hh}^{U,C}/\partial\tau = 0$, $\partial h_{hh}^{S,C}/\partial\tau \geq 0 (< 0)$ and $\partial h_{EE}^{S,C}/\partial\tau \geq 0 (< 0)$ if $\tau \leq (>) 1/\gamma$. Hence, it is straightforward that the value of E associated to the low equilibrium (when it exists) is increasing with τ, for $\tau < 1/\gamma$.

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