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HOW POLICY CAN INFLUENCE HUMAN CAPITAL ACCUMULATION AND ENVIRONMENT QUALITY

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[PRELIMINARY DRAFT, DO NOT QUOTE WITHOUT PERMISSION OF THE AUTHORS]

Abstract

This paper considers the implications of education and environment policy for growth in a model where the interactions between health, education, and the environment are taken into account. With respect to previous works, in which one of these three dimensions is omitted, we consider their combined effects, arriving to novel results in the literature. According to our model, higher taxes and environment spending share in total public spending do not affect welfare significantly, but they have an important positive impact on human capital and environment quality. Here, a positive relationship between public education spending and environment quality emerges as well as between environment maintenance expenditure and human capital. At the same time, countries with a high environmental quality should spend less on environment maintenance compared to heavily polluted countries. Finally, for countries with advanced abatement technologies, the relationship between human capital and environment is positive, which is compatible with the environmental Kuznets curve.

JEL codes: E60, I12, I28, Q58
Keywords: Fiscal policy, Health production, Human capital, Environment quality.

1. Introduction

The interplay between environment quality and growth has attracted increasing attention on behalf of policy makers, economists and citizens alike recently in the advent of serious environmental problems facing the world, like climate change, ozone depletion and marine pollution (Tong et al., 2002).

There are several papers dealing with the relationship between environment quality and economic dynamics. One of the first papers similar in spirit with our work is by Gradus-Smulders (1993) who study an economy where human capital drives growth and pollution is a side-product of physical capital. They show that when environmental care is higher, production is less physical capital intensive and optimal growth is constant or higher, depending on whether pollution influences agents' learning ability. Subsequently, Hartman-Kwon (2005) in a growth model where human capital is produced cleanly and physical capital may be used for pollution control, prove that: a) growth is sustainable; b) in the long run it is optimal for human capital to grow more rapidly than physical capital, output and consumption, while pollution declines; c) an environmental Kuznets curve emerges; d) a pollution tax or a voucher system can implement Pareto efficiency. In a later work, Grimaud-Tournemaine (2007) find that tighter environmental policy can promote growth in a model where growth is driven by human capital, firms invest in emission abatement and education enhances productivity and enters in preferences. In a review paper, Ricci (2007) mentions that environmental regulation can enhance growth if higher environmental quality increases TFP or the efficiency of education. Furthermore, expectations of a better environment may enhance savings and growth if consumption and environmental quality are complements. Recently, Pautrel in a series of papers (2008, 2009a, 2009b, 2009c, 2009d, 2009e) shows that environmental policy is either growth- enhancing or has an inverse U-shaped relationship with growth taking into account the detrimental impact of pollution on health

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and utility. More recently, Varvarigos (2010), in a model where longevity is positively affected by public health spending and negatively by pollution, proves that emissions and pollution abatement may affect economic dynamics, the likelihood of multiple equilibria and poverty traps. Finally, Mariani et al. (2010) show the existence of a positive correlation between longevity and environmental quality and the possibility of multiple equilibria in models where growth is driven by physical and human capital.

Our paper examines the environment-growth relationship in an economy populated by two-period lived agents, where human capital is the engine of growth. Regarding the structure of our economy, first, we assume that environment and human capital stocks affect health (e.g. WHO, 2002, Valent et. al., 2004), which in turn influences the probability of survival from the first to the second period of life. The survival probability is a continuous function, unlike Mariani et al (2010) who use a two-step function and other papers, which do not incorporate uncertainty (e.g. Hartman-Kwon, 2005, Gradus-Smulders, 1993). Second, health affects human capital accumulation, as Van Zon-Muysken (2001), Gradus-Smulders (1993), Weil (2007), Aghion et al (2009/2010) suggest. Third, public environment maintenance expenditure boosts environment stock accumulation, as e.g. in Varvarigos (2010). Fourth, government education spending enhances human capital accumulation similarly to e.g. Glomm-Ravikumar (1992), Osang-Sarkar (2008). Fifth, our paper is one of very few papers in the relevant literature, where leisure affects utility directly, agents make a leisure-schooling choice and time devoted to education affects human capital accumulation unlike e.g. Varvarigos (2010), Pautrel (2009 Ecological Economics). So, our human capital accumulation equation is richer than most related papers (e.g. Pautrel, 2008, Grimaud-Tournemaine, 2007**)**. Sixth, production causes pollution, which lowers future environment quality, like most related work (e.g. Brock-Taylor, 2005, Handbook of Economic Growth, Hartman-Kwon, 2005, Mariani et al., 2010, Varvarigos, 2010). Finally, government taxes income of the old generation every period, since this is the only generation which earns income. We investigate the steady-state and solve for the optimal policy under the assumption of a benevolent dictator who cares only about the old generation. We do this, because we believe governments serve current generations, because the latter are the voters.

We arrive at interesting conclusions. First, higher taxes and environment spending share in total public spending do not affect welfare significantly, but they have an important positive impact on human capital and environment quality. Second, there is a positive relationship between public education spending and environment quality as well as human capital. Third, there is a positive relationship between environment maintenance expenditure and human capital, but a negative relation between environment maintenance expenditure and environment stock; that is countries with a high environmental quality should spend less on environment maintenance compared to heavily polluted countries. These are novel results in the literature. Fourth, for countries with advanced abatement technologies, the relationship between human capital and environment is positive, which is compatible with the environmental Kuznets curve. Fifth, taxation depends on current levels of environment and human capital stocks.

Since governments tend to apply myopic policies, i.e. serve just current generations, a way to influence such policies, therefore the stocks of human and environmental capital, is through stronger preferences for future environment quality. That is, a cultural change could influence the next "Copenhagen meeting". Additionally, "cleaner" production technologies and/or more effective abatement will make it optimal for governments to increase environment maintenance expenditure.

The rest of the paper is as follows. In section 2, we describe the structure of the economy, while in section 3 we analyze the general equilibrium. In section 4 we perform the numerical analysis of the model and in section 5 we solve for the optimal policy. Finally, in section 6 we conclude the paper and present directions for future research.

2. The structure of the economy

Time is discrete and the economy has an infinite-horizon. Every period t = 0, 1,… a new generation of individuals is born and they live for two periods. Every generation consists of a [0, 1] continuum of homogeneous agents with perfect foresight regarding future variables. The "initial old generation" is endowed with a positive stock of human capital and environment quality.[1]

[1] This assumption refers to the idea that human beings own a minimum stock of natural knowledge that gives them a certain probability to survive from one period to the other even when education is absent.

As in John and Pecchenino (1994), we assume that individuals born at time t have preferences defined over consumption in old age (c_{t+1}) and an index of environmental quality (hereafter, environment) which they provide as a bequest to their children (e_{t+1}). Additionally, in the first period of life, the agents allocate their time between leisure and formal education. The leisure time spent in young age (n_t) enters the utility function and its marginal utility represents the welfare cost of studying. Agents work only in the second period of life. They supply inelastically one unit of labour and consume all their income before they die. Formally, individuals born in t maximize the following intertemporal utility:

$$U_t = a\ln(n_t) + \rho\pi_{t+1}(\ln c_{t+1} + b\ln e_{t+1}) \quad (1)$$

where π_{t+1} is the probability of survival from the first to the second period of life; ρ is the discount factor; α and b are the weights of n_t , e_{t+1} relative to c_{t+1} respectively in the utility function. So, individuals face a certain probability to die before reaching adulthood and this affects the allocation of their time between leisure and schooling. The probability to survive through the next period depends on the health level of individuals when they are young:

$$\pi_{t+1} = \frac{q_t}{B + q_t} \quad (2)$$

where q_t is the health level of an individual born at time t when she is young and B>0 reflects factors affecting survival probability except health. From (2) we have that marginal returns to health in terms of the probability to survive are decreasing in health, that is, increasing the health level contributes more to the survival of people who have low levels of health. So, health enters the utility function, since it allows for future consumption. The level of health depends on environmental quality and parental human capital according to a standard Cobb-Douglas production function:

$$q_t = h_t^z e_t^\kappa \quad (3)$$

where h_t and e_t are the stocks of human capital and environment already accumulated at time t, while z and κ are the corresponding factor shares. Equation (3) captures the idea that the higher the environment quality as well as the education of parents (through child care), the better the health status of agents and the higher the individual probability of survival till adulthood.

We assume that the *initial old generation* is endowed with a positive stock of human capital and environment, so this probability will be always positive and less than 1.

For simplicity, we assume that output is produced with a one-to-one technology where human capital is the only input: $y_t = h_t$. This means that the human capital accumulation function also describes the way in which output is produced.

The quality of environment at time t+1, e_{t+1}, is a function of the previous stock, e_t, environment maintenance expenditure at t, m_t, and production, h_t, which causes pollution. Environment evolves according to the following law of motion:

$$e_{t+1} = (1-\delta)e_t + \sigma m_t - \beta h_t \quad (4)$$

where, σ represents the productivity of maintenance expenditure in the environment accumulation function, while δ and β capture the environmental depreciation due to natural and human activities respectively.

The stock of human capital at time t+1 depends on human capital at t, health at t, q_t, public education spending at t, g_t, and time devoted to education at t, 1- n_t:

$$h_{t+1} = Ah_t^\chi q_t^\varphi g_t^\lambda (1-n_t)^\mu = Ah_t^\theta e_t^\gamma g_t^\lambda (1-n_t)^\mu \quad (5)$$

Parameter A is an index of exogenous technological progress, while parameters χ, φ, λ and μ are the factor shares of our Cobb-Douglas production function. Given (3), we have that γ= κφ and θ= zχ.

Since we assumed that individuals consume all their income during the second period of life, the only bequest from parents to children is environmental quality. After-tax income (human capital) equals consumption as follows:

$$(1-\tau)h_{t+1} = c_{t+1} \tag{6}$$

where τ is the tax rate, which is exogenous for the moment.

Government taxes human capital (income) of the old generation in period t. Assuming that all public spending is devoted to environment and education and the budget is balanced, we can write the government's budget constraints and complete the model as follows:

$$m_t = \nu\tau h_t \tag{7}$$

Equation (7) states that environment maintenance expenditure at t is a fraction, ν, of total government revenues at the same date, τh_t. Accordingly, education expenditure will be a fraction, 1- ν, of government revenues:

$$g_t = (1-\nu)\tau h_t \tag{8}$$

Using this framework, in the next sections we study the steady-state equilibrium of the model by, initially, considering the government policy as exogenous and then endogenizing government decisions.[2]

3. General equilibrium

Events take place in two stages. First, government chooses the tax rate and the allocation of the associated revenues among the two types of policy. Second, private agents choose consumption, environment bequests for their children and leisure (therefore time devoted to education) taking economic policy as given. Since individuals are rational, have perfect foresight, we can solve the maximization problem by backward induction, that is, we substitute c_{t+1} and e_{t+1} using (6) and (4) respectively in the objective function (1) to get:

$$U_t = a\ln(n_t) + \rho\pi_{t+1}\{\ln[(1-\tau)h_{t+1}] + b\ln[(1-\delta)e_t + \sigma m_t - \beta h_t]\} \tag{9}$$

From (2), (3), (5), (7) and (8), we have:

$$U_t = a\ln(n_t) + \rho\frac{h_t^z e_t^\kappa}{B + h_t^z e_t^\kappa}\{\ln[(1-\tau)Ah_t^\theta e_t^\gamma(1-\nu)^\lambda\tau^\lambda h_t^\lambda(1-n_t)^\mu] + b\ln[(1-\delta)e_t + \sigma\nu\tau h_t - \beta h_t]\} \tag{10}$$

Taking the derivative of (10) w.r.t. n_t we can get the following first-order condition:

$$\frac{a}{n_t} - \frac{\mu\rho h_t^z e_t^\kappa}{(B + h_t^z e_t^\kappa)(1-n_t)} = 0 \tag{11}$$

that is,

$$n_t^* = \frac{(B + h_t^z e_t^\kappa)a}{Ba + (a+\mu\rho)h_t^z e_t^\kappa} \tag{12}$$

---

[2] We are aware that taxation is not exogenous, but we believe that this temporary assumption will be useful to better understand the mechanics of the model.

When $\mu\rho h_t^z e_t^\kappa > 0$, we have that $n_t^* < 1$. This means that - given our initial, positive values of *h* and *e* - if *μ* and *ρ* are positive, we always get an interior solution for optimal leisure time.

Since the probability to survive is positively related to q_t, the optimal leisure time, when an individual is young, negatively depends on her health level. In fact, an individual with a low probability to survive will not invest much time to accumulate human capital in order to increase her future consumption; she will instead prefer to enjoy leisure. Moreover, Equation (12) shows the intergenerational link: the decision to invest in education strongly depends on the stocks of human capital and environment already accumulated by previous generations.

Given (7), (12), we can rewrite the laws of motion of environment and human capital as follows:

$$e_{t+1} = (1-\delta)e_t + \sigma\nu\tau h_t - \beta h_t \tag{13}$$

$$h_{t+1} = A h_t^\theta e_t^\gamma (1-\nu)^\lambda \tau^\lambda h_t^\lambda \left(1 - \frac{(B + h_t^z e_t^\kappa)a}{Ba + (a+\mu\rho)h_t^z e_t^\kappa}\right)^\mu \tag{14}$$

The steady-state levels of environment quality and human capital will be

$$\bar{e} = \frac{(\nu\sigma\tau - \beta)}{\delta}\bar{h} \tag{15}$$

$$\bar{h} = A\bar{h}^{\theta+\lambda+\gamma}\frac{(\nu\sigma\tau-\beta)^\gamma}{\delta^\gamma}(1-\nu)^\lambda\tau^\lambda\left(1 - \frac{(B+\bar{h}^z\bar{e}^\kappa)a}{Ba+(a+\mu\rho)\bar{h}^z\bar{e}^\kappa}\right)^\mu \tag{16}$$

For the rest of the paper, we will assume $\nu\sigma\tau > \beta$, that is, the marginal effect of government expenditure on environmental policy overcomes the pollution effect, which we call the "we can clean" hypothesis. Consequently, the steady-state level of environmental quality is increasing in the steady-state level of human capital. By looking at the EKC (Environmental Kuznets Curve) literature, this conclusion seems to be consistent only with some developed countries that experienced a positive relationship between income and environmental quality. However, this literature is far from being exhaustive and considers only some specific indicators of pollution. What is new, here, compared with most literature on human capital, is that the latter is affected by health; this implies that a comprehensive set of pollution indicators, which influence learning through health, should be used in order to test this result. In light of that, empirical work should correct output measures incorporating health and schooling indicators.

Since Equation (16) cannot be solved in an algebraic way, we reformulate it as follows:

$$F(\bar{h}) = f(\bar{h}) - g(\bar{h}) = 0 \tag{17}$$

with $f(\bar{h}) \equiv \dfrac{\mu\rho\bar{h}^{z+\kappa}\dfrac{(\nu\sigma\tau-\beta)^\kappa}{\delta^\kappa}}{Ba+(a+\mu\rho)\bar{h}^{z+\kappa}\dfrac{(\nu\sigma\tau-\beta)^\kappa}{\delta^\kappa}}$ and $g(\bar{h}) \equiv \left(\dfrac{\delta^\gamma\bar{h}^{1-\theta-\lambda-\gamma}}{A(\nu\sigma\tau-\beta)^\gamma[(1-\nu)\tau]^\lambda}\right)^{\frac{1}{\mu}}$

Function *f*(.) represents the fraction of time devoted to education by individuals. At least one equilibrium always exists in our model: *F*(0) = 0. Since both functions are continuous and *f*(.) converges to a finite value as h goes to infinity whereas function *g*(.) goes to infinity, in order to have a non trivial solution, function *F*(.) must be positive for some positive values of h. It is easy to see that the behavior of the *f*(.) and *g*(.) functions depends on the nature of returns to scale in the production of health and human capital. By assuming $\nu\sigma\tau > \beta$, if $1-\theta-\gamma-\lambda > 0$ we will have $f'(\bar{h}) > 0$ and $g'(\bar{h}) > 0$. Concerning the concavity of these two functions we have:

$$
\begin{cases}
f''(\bar{h}) < 0 \quad if \quad z+\kappa < 1 \\
f''(\bar{h}) < 0 \quad if \quad z+\kappa > 1 \quad and \quad h > \left(\dfrac{Ba(z+\kappa-1)\delta^{\kappa}}{(1+z+\kappa)(a+\mu\rho)(\nu\sigma\tau-\beta)^{\kappa}} \right)^{\frac{1}{z+\kappa}} \\
f''(\bar{h}) \geq 0 \quad if \quad z+\kappa > 1 \quad and \quad h \leq \left(\dfrac{Ba(z+\kappa-1)\delta^{\kappa}}{(1+z+\kappa)(a+\mu\rho)(\nu\sigma\tau-\beta)^{\kappa}} \right)^{\frac{1}{z+\kappa}}
\end{cases}
$$

$$
\begin{cases}
g''(\bar{h}) \geq 0 \quad if \quad \theta+\gamma+\lambda+\mu \leq 1 \\
g''(\bar{h}) \geq 0 \quad if \quad \theta+\gamma+\lambda \geq 1 \\
g''(\bar{h}) < 0 \quad if \quad \theta+\gamma+\lambda < 1 \; and \; \mu > 1-\theta-\gamma-\lambda
\end{cases}
$$

Proposition 1: If returns to scale in both health and education are decreasing: i) a positive steady-state level of human capital always exists and it is unique; ii) the steady-state equilibrium is stable.

Proof:

i) Since $F(0) = 0$ and $F(\infty) = -\infty$, for continuity is sufficient to show that F(h) is positive for some values of h. This can be done by taking the first derivative of F(.): $F'(h) = f'(h) - g'(h)$. It is easy to see that, given our assumptions on the returns to scale, f'(h) goes to infinity as h goes to zero, whereas g'(h) goes to zero. This means that, for values of h small enough function F(.) assumes positive values.

Moreover, given the previous results on the shape of $f(h)$ and g(h), we know that the equilibrium is unique.

ii) For stability we must rewrite (16) as follows:

$$
\bar{h} - h_t = A\bar{h}^{\theta+\lambda+\gamma} \frac{(\nu\sigma\tau-\beta)^{\gamma}}{\delta^{\gamma}} (1-\nu)^{\lambda} \tau^{\lambda} \left(1 - \frac{(B+\bar{h}^{z}\bar{e}^{\kappa})a}{Ba+(a+\mu\rho)\bar{h}^{z}\bar{e}^{\kappa}} \right)^{\mu} - h_t
$$

For $h_t \in (\bar{h}-\varepsilon, \bar{h})$ and $\varepsilon > 0$ small enough, the stability requires

$$
\bar{h}A\bar{h}^{\theta+\lambda+\gamma} \frac{(\nu\sigma\tau-\beta)^{\gamma}}{\delta^{\gamma}} (1-\nu)^{\lambda} \tau^{\lambda} \left(1 - \frac{(B+\bar{h}^{z}\bar{e}^{\kappa})a}{Ba+(a+\mu\rho)\bar{h}^{z}\bar{e}^{\kappa}} \right)^{\mu} - h_t > 0
$$

That is

$$
1 - \frac{(B+\bar{h}^{z}\bar{e}^{\kappa})a}{Ba+(a+\mu\rho)\bar{h}^{z}\bar{e}^{\kappa}} > \left(\frac{h_t}{\bar{h}A\bar{h}^{\theta+\lambda+\gamma} \dfrac{(\nu\sigma\tau-\beta)^{\gamma}}{\delta^{\gamma}} (1-\nu)^{\lambda} \tau^{\lambda}} \right)^{\frac{1}{\mu}}
$$

In a left neighborhood of the steady-state equilibrium the following condition must hold:

$$
f(\bar{h}) > g(\bar{h})
$$

From (i) we know that this is true for our non trivial equilibrium. (Q.E.D.)

Corollary 1: Proposition 1, together with Equation (15), implies that the quality of environment will be positive in the stationary equilibrium.

Figure 1 shows the case in which returns to scale are decreasing in both health and human capital sectors. In particular, if returns to scale in the health sector are decreasing, the *f*(.) function is concave, while decreasing returns to scale in the education sector lead to a convex g(.) function. The steady-state level of human capital $\left(\bar{h}\right)$ will be unique.

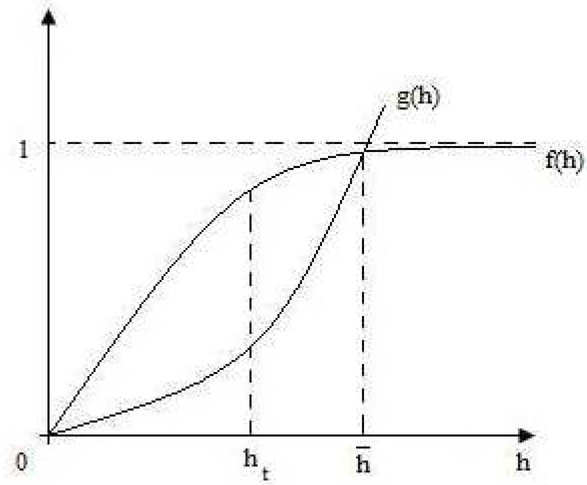


Figure 1: Unique steady-state equilibrium

Concerning the stability of the steady-state, assume to start from an initial point such as h_t: $f(h_t)>g(h_t)$, then we will have $F(h_t)>0$ and the human capital stock will move towards the steady-state value. When h_t is smaller than the steady-state value, agents devote a larger fraction of time to human capital accumulation than the fraction would be necessary in order to have the steady-state value at h_t. This leads to an increase in the levels of human capital and environment quality that improves individuals' health. On the other hand, since the probability to survive is a concave function of the health level, the incentives to accumulate further human capital will decrease till the steady-state level.

Proposition 2: If returns to scale in the health sector are increasing, equilibrium multiplicity can arise.
Proof: Since function g(.) is always convex or concave according to parameter values, multiple equilibria are possible only if function *f*(.) changes its concavity after a certain value of h. From the study of its second derivative we have seen that this is true, since:

$$\begin{cases} f''(\bar{h}) < 0 \quad if \quad z+\kappa > 1 \quad and \quad h > \left(\dfrac{Ba(z+\kappa-1)\delta^{\kappa}}{(1+z+\kappa)(a+\mu\rho)(\nu\sigma\tau-\beta)^{\kappa}} \right)^{\frac{1}{z+\kappa}} \\ f''(\bar{h}) \geq 0 \quad if \quad z+\kappa > 1 \quad and \quad h \leq \left(\dfrac{Ba(z+\kappa-1)\delta^{\kappa}}{(1+z+\kappa)(a+\mu\rho)(\nu\sigma\tau-\beta)^{\kappa}} \right)^{\frac{1}{z+\kappa}} \end{cases}$$

So, multiple equilibria arise. In other words, a necessary (but not sufficient) condition to have multiple equilibria is the presence of increasing returns to scale in the health sector. (Q.E.D.)

Figure 2 shows the case in which returns to scale are increasing in the health sector. Here three equilibria arise and two of them (0 and h_H) are stable because of the values of $f(h)$ with respect to $g(h)$ in a neighborhood of the steady-state equilibria.

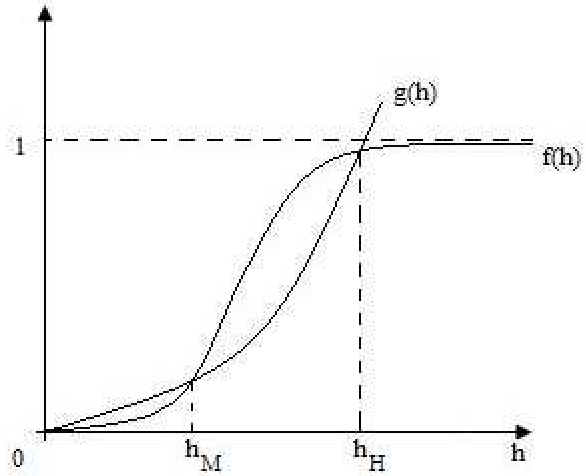


Figure 2: The case of multiple equilibria

In the next section, we will see that Proposition 1 is verified under plausible values of our parameters. However, before performing the numerical analysis, in Table 1 we report the effects of parameters' changes on the steady-state level of human capital. These results are obtained by studying the behavior of $g(h)$ and $f(h)$ when $\nu\sigma\tau > \beta$. Through Equation (15), we can also infer the effects on environment.

Table 1: The impact of parameters on human capital

Parameter (p)	Sign of f_p	Condition	Sign of g_p	Condition	If p increases
b	-				h decreases
a	-				h decreases
δ	-		+		h decreases
z	-	$if\ h<1$			h decreases
β	-		+		h decreases
ρ	+				h increases
κ	+	$if\ \frac{(\nu\sigma\tau-\beta)}{\delta}h>$			h increases
ν	+		-	$if\ \gamma\sigma\tau(1-\nu)>\lambda(\nu\sigma\tau-\beta)$	h increases
τ	+		-	$if\ \nu\sigma\tau(\gamma+\lambda)>\lambda\beta$	h increases
σ	+		-		h increases
μ	+		-	$if\ A^{-1}h^{1-\theta-\gamma-\lambda}(1-\nu)^{-\lambda}\tau^{-\lambda}\left(\frac{\nu\sigma\tau-\beta}{\delta}\right)^{-\gamma}>1$	h increases
A			-		h increases
γ			-	$if\ \frac{(\nu\sigma\tau-\beta)}{\delta}h>1$	h increases
θ			+	$if\ h<1$	h decreases
λ			+	$if\ h(1-\nu)\tau<1$	h decreases

For example, higher B implies lower probability of survival for any health level. For this reason B has a negative effect on human capital accumulation. Parameter α captures the relative preference for leisure time in young age, thus a higher α lowers human capital stock. The opposite happens for ρ; individuals with stronger preferences for future consumption and environment will invest more in human capital accumulation. Environmental depreciation parameters, δ and β, negatively affect the environmental stock and consequently the accumulation of human capital. On the contrary, σ positively influences the environmental stock and therefore human capital. Finally, technological progress A directly affects the accumulation of h, by increasing the productivity of all factors.

Under the "we can clean" hypothesis, the relationship between τ and steady-state human capital is always positive. Finally, factor shares and government variables have an ambiguous impact on the steady-state level of human capital. For this reason, we will study their effects through a numerical analysis.

4. Numerical Analysis

4.1 Parameter choices

Here, we want to check if for reasonable parameter values, a stable steady-state exists. The parameter values were chosen based among others on Pautrel (2009), Gutierez (2008), Jouvet et al. (2007), Antoci-Sodini (2009), Finlay (2006), Benos (2010).

Table 2: Parameters used in the numerical analysis

PARAMETERS	BENCHMARK VALUES	RANGE
B	1	1-3
ρ	0.24	0.2-0.3
β	0.01	0.003-0.015
δ	0.004	0.002-0.006
z	0.25	0.1-0.5
κ	0.1*	0.1-0.5
A	1	Free range
a	0.42	0.08-0.58
b	0.25	0.08-0.58
θ	0.45	0.3-0.7
μ	0.1	≤ 0.1 (CRS or DRS)
σ	0.5	0.25-0.75
λ	0.2	0.02-0.4
ν	0.5	-
τ	0.3	-

* corrected for the specification of π_{t+1}

4.2 Steady-state

By using the benchmark values in Table 2, Figures 3, 4 and 5 show that positive steady-state values of human capital, environment quality and leisure time exist under plausible values of parameters. The steady-state levels are $\bar{h}=0$, $\bar{e}=0$, $\bar{q}=0$ and $\bar{h}=0.717679$, $\bar{e}=11.6623$, $\bar{q}=1.17669$. In particular, the highest equilibrium is the non trivial equilibrium considered in Proposition 1.

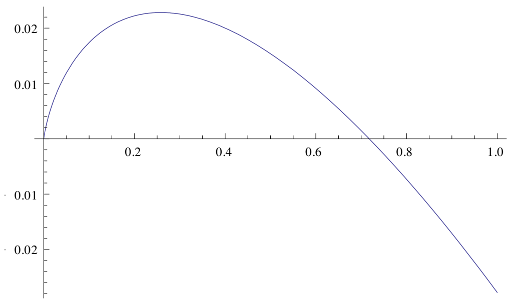


Figure 3: h(t+1)-h(t)

Figure 3 implies that the steady-state level of human capital is stable.[3]

[3] The eigenvalues of the Jacobian matrix confirm the stability result proved in Proposition 1.

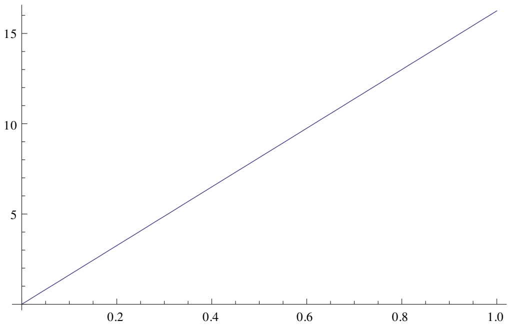


Figure 4: Environment quality as a function of $\overline{h}$

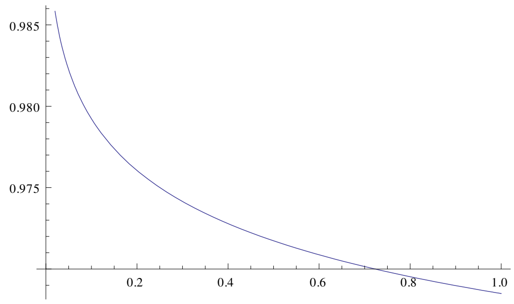


Figure 5: Optimal leisure time in the steady-state equilibrium

Finally, Figure 6 represents the health function.

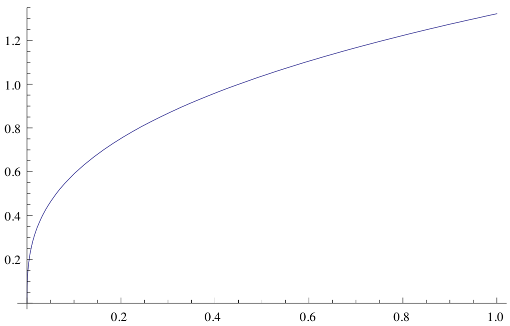


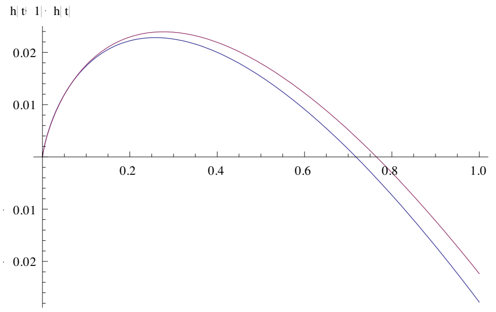
Figure 6: q(h)

By construction, the health function is concave with respect to human capital, which means that human capital investments increase health status, but marginal returns are decreasing.

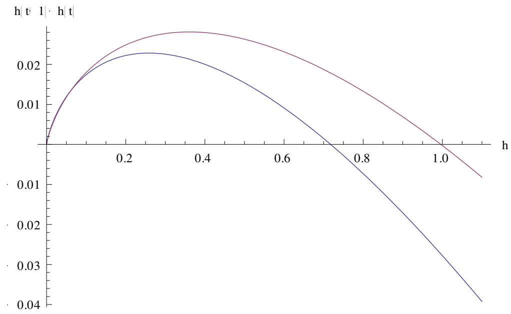
4.3 Ambiguous parameters

Now, we want to see how ambiguous parameters $\{\kappa, \gamma, \nu, z, \mu, \theta, \lambda, \tau\}$ influence the steady-state level of human capital. Below, blue functions correspond to the benchmark case (see Figure 3), while red functions correspond to the augmented parameter case.[4]

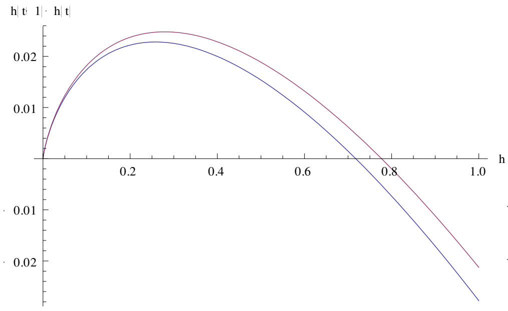
[4] Here, each parameter has been increased by a fraction that allows for a clear graphical presentation.



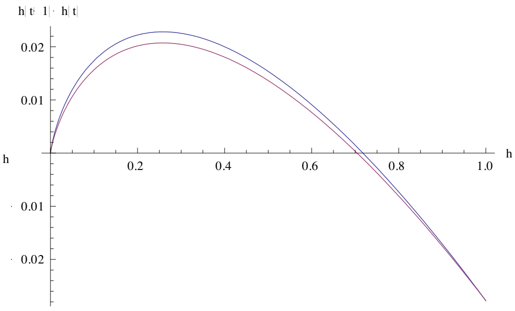
$\Delta\kappa$=+0.05



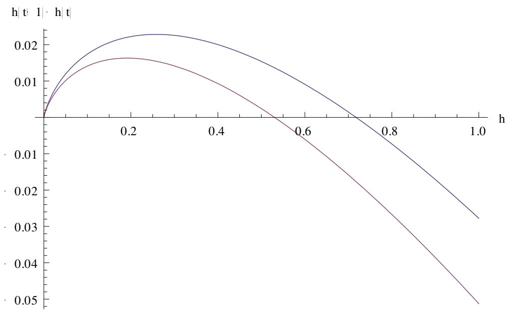
$\Delta\gamma$=+0.01



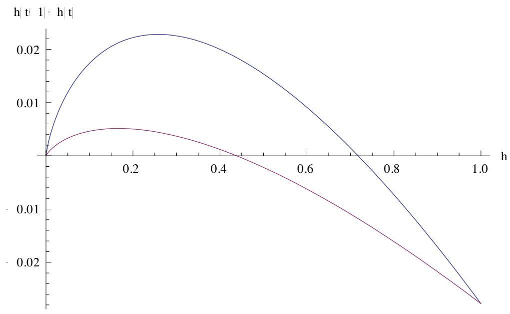
$\Delta\nu$=+0.05



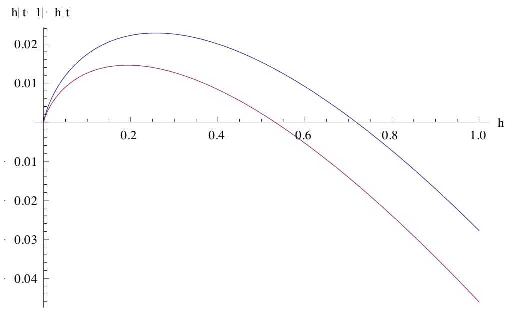
Δz=+0.10



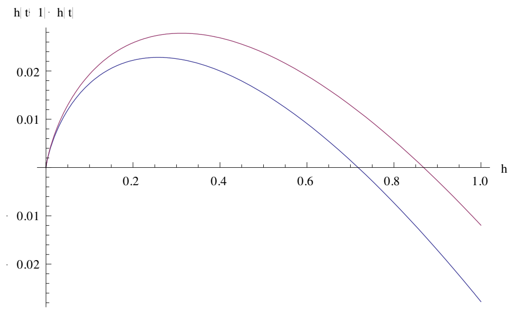
$\Delta\mu$=+0.01



$\Delta\theta$=+0.05



$\Delta\lambda$ =+0.01



$\Delta\tau$ =+0.01

As we can see, parameters linked to environment accumulation, κ, γ and ν, have positive effects on the steady state level of human capital, while parameters linked to human capital accumulation, z, μ, θ and λ, have negative effects on steady-state human capital. These parameters enter the human capital accumulation function as factor shares other than the environment share and their negative effects essentially depend on the fact that the steady-state level of human capital is less than 1.

In order to better understand this fact, we take a variation of the tax rate such that the new steady-state level of human capital is higher than 1 and, at the same time, we assume for instance a positive variation of z. The figure below shows that, now, z increases $\bar{h}$.

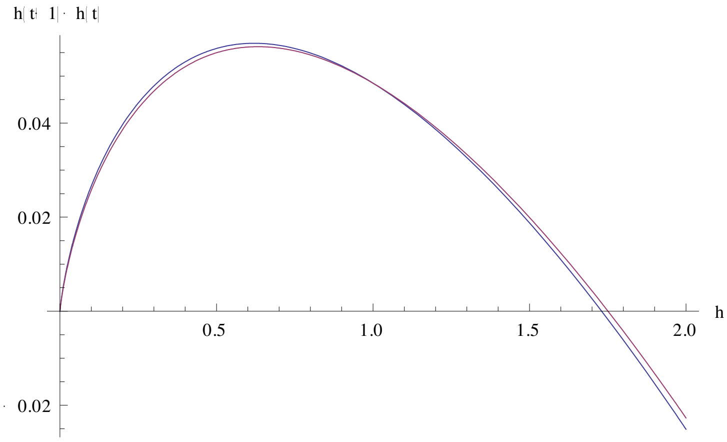


Figure 7:Δτ =+0.05 and Δz=+0.05

The above implies that taxes generate revenues enhancing human capital and environmental quality accumulation, and, through this channel, imply a positive role for factor shares. In the next section, we remove the hypothesis of exogenous policy in order to see if and when a positive role for government exists.

5. Optimal Policy

5.1 Necessary conditions

We believe that the best way to study the behavior of policy makers when we consider environmental and educational policies is to take into account the fact that the time horizon of governments is not infinite as often assumed in standard OLG models. On the contrary, governments aim to serve current generations, because the latter are the voters. The simplest way to model this consideration is by analyzing the case of a benevolent dictator that pleases the current generations.[5] That is, government acts as a benevolent Stackelberg leader *vis-à-vis* the private sector. So, the optimal policy a government implements maximizes the utility function (10) given agents' behaviour. In general, we can define a policy as a set of independent policy instruments {τ, ν}.

The F.O.C.s w.r.t. n, τ and ν for the government's problem are:

$$\frac{a}{n_t} = \frac{\pi_{t+1}\mu\rho}{1-n_t} \tag{18}$$

$$\frac{\pi_{t+1}\lambda\rho}{\tau} + \frac{b\pi_{t+1}\nu\rho\sigma}{e_t(1-\delta)+h_t(\nu\sigma\tau-\beta)}h_t = \frac{\pi_{t+1}\rho}{1-\tau} \tag{19}$$

$$\frac{b\pi_{t+1}\rho\sigma\tau}{e_t(1-\delta)+h_t(\nu\sigma\tau-\beta)}h_t = \frac{\pi_{t+1}\lambda\rho}{1-\nu} \tag{20}$$

This leads to the following relations:

$$n_t^* = \frac{a}{a+\pi_{t+1}\mu\rho} \tag{21}$$

$$\tau_t^* = \frac{b\sigma h_t + (h_t(\lambda\sigma+\beta)-e_t(1-\delta))}{h_t(\lambda+1+b)\sigma} \tag{22}$$

$$\nu_t^* = \frac{(\beta h_t - e_t(1-\delta))(1+\lambda)+b\sigma h_t}{b\sigma h_t + h_t(\lambda\sigma+\beta)-e_t(1-\delta)} \tag{23}$$

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[5] In a representative agent approach, our agent can be thought as the median voter.

We have an interior solution for τ and ν if $e_t(1-\delta)+h_t(\sigma-\beta)>0$, that is, if $\sigma>\beta$ or if $\sigma<\beta$ *but* $\dfrac{1-\delta}{\beta-\sigma}>\dfrac{h_t}{e_t}$.

Notice that Equation (21) coincides with Equation (12) once we substitute π_{t+1} with its expression, while Equations (22) and (23) define the optimal policy $\{\tau_t^*,\nu_t^*\}$ at time t. These equations show an important property of optimal taxation: it depends on the current stocks of environment and human capital. Therefore, only in the steady-state equilibrium taxes as well as government spending on environment and education remain constant. Along the convergence path, we can study the dynamics of the optimal policy $\{\tau_t^*,\nu_t^*\}$. A convenient way to perform this analysis is reducing the order of the dynamic system by considering the optimal environment maintenance expenditure instead of the two instruments separately. After having briefly examined the role of *h* and *e* on τ and ν, in the last section we will see that the optimal environment maintenance expenditure is increasing in h. In the next section, before examining the effects of parameters' changes on the optimal policy, we repeat our numerical example for the endogenous policy case in order to see how the steady-state is affected by public policies.

5.2 Steady-state

By implementing the numerical analysis using the same parameter values as before (see Table 2), we obtain the following results:

Benchmark case	**Optimal policy**
τ=0.3	τ=0.184013
ν=0.5	ν=0.113122
n=0.970035	n=0.999944
h= 0.717679	h=4.99903 10^{-9}
e=11.6623	e=5.09893 10^{-10}
Exponent U=0.932186	Exponent U=0.932863

If we compare the optimal policy with a non-optimal policy (characterized by higher levels of τ and ν) we can see that utility is 99.93% of the maximum utility, while the stocks of human capital and environment are notably higher with non-optimal policy.[6] Moreover, even leisure time does not change dramatically.

Public investments in education and environment can notably increase the stocks of human capital, environment and health by slightly reducing individuals' utility.

5.3 Parameters and optimal policy

In this section, we study how parameters influence the optimal policy. In order to investigate this question we must consider that τ influences our utility function through two channels:

1) *Direct channel*: τ directly reduces disposable income and consumption.
2) *Indirect channel*: τ has a positive effect on environment and human capital through government spending.

Even if the direct effect of ν on human capital is negative, since the share of government spending in environment directly reduces human capital accumulation, this relation is not simple. This is so, because ν increases environment stock which enters the utility function and the production of future human capital through environment spending.

The parameters that influence τ and ν are five and they can be divided into three groups:

i) Preference parameter (b)

[6] The optimal policy configuration leads to a stable node with oscillatory convergence, since one eigenvalue is positive (0.952764) and the other is negative (-0.140411), but both are less than 1.

When pollution is not too strong, $e_t(1-\delta)+h_t(\sigma-\beta)>0$, a higher b, increases τ and ν.[7] In other words, societies with a strong preference for environmental quality relative to consumption will be characterized by higher taxes and expenditure on environment.

ii) Elasticity of human capital w.r.t. schooling expenditure (λ)

At the same time, if $e_t(1-\delta)+h_t(\sigma-\beta)>0$, λ increases τ. When public expenditure is more effective in the educational sector, the society will invest more in schooling in order to enjoy higher levels of income, consumption and environment.

The impact of λ on ν will depend on the magnitude of b. If b is large enough, higher λ, lowers ν. That is, a society with strong preferences for environment, when investment in schooling becomes more efficient, will prefer improve environment quality through human capital accumulation (reducing ν) instead of investing directly in environment.

iii) Environmental parameters (σ, δ, β)

When the remaining environment stock after natural depreciation is greater than human pollution, $e_t(1-\delta)>h_t\beta$, the more effective is environment maintenance expenditure, the higher τ and ν will be. This is the same mechanism behind the role of λ with respect to schooling.

Finally, δ and β are always positively related to τ and ν. That is, higher environmental depreciation will require higher levels of public intervention in order to avoid environment destruction.

5.4 Government spending

From Table 1, we know that an increase in the policy instruments {τ, ν} leads to an increase in *h* and *e*. The latter effect implies a higher natural depreciation rate for environment and this causes a counterbalancing mechanism on optimal policy. That is, there is a positive relationship between *h* and the policy instruments and a negative relationship between *e* and the same instruments. Although, this analysis is relevant, in terms of empirical investigation it is more suitable to study the effects of human capital and environment quality variations on government spending.

Therefore, here, we discuss how parameters influence the optimal public spending in environment and education. Formally, the public spending on environment is $m_t=v_t\tau_t h_t$:

$$m_t=\frac{[h_t\beta+e_t(\delta-1)](1+\lambda)+b\sigma h_t}{(1+b+\lambda)\sigma}$$

Whereas, public spending on education is $g_t=(1-v_t)\tau_t h_t$:

$$g_t=\frac{\lambda[e_t(1-\delta)-h_t(\sigma-\beta)]}{(1+b+\lambda)\sigma}$$

The optimal environment maintenance expenditure is increasing in h and decreasing in e. The second effect comes from the fact that both τ and ν decrease when environmental quality increase.

When the productivity of maintenance expenditure overcomes the pollution effect, the higher the stock of human capital, the higher the educational spending. So, if economic growth is not too polluting, government must invest in the education sector.

Finally, since environment maintenance expenditure is decreasing in the environmental stock, when this stock increases, a government will substitute part of the environmental spending with educational spending.

The role of other parameters is summarized in Table 3, and they simply involve the combined effects of parameters' changes already discussed in the previous section.

[7] Notice that this condition also implies an interior solution for τ and ν.

Table 3: Qualitative effects of parameters' changes on public spending			
Parameter	Effect on m_t	Effect on g_t	Condition
b	+	-	$e_t(1-\delta)+h_t(\sigma-\beta)>0$
λ	-	+	$e_t(1-\delta)+h_t(\sigma-\beta)>0$
σ	+	-	$e_t(1-\delta)-\beta h_t>0$
δ	+	-	Always
β	+	-	Always

Briefly, we can say that the relative preference for future environmental quality, b, has a positive impact on environmental spending and consequently a negative impact on educational spending. The optimal spending in schooling increases when λ increases. This is due to the fact that the higher λ, the higher the productivity of public expenditure on education. Finally, concerning environmental parameters, when depreciation parameters (δ and β) are higher, government spending on environment maintenance must be higher; the role of σ, i.e. government productivity in environment maintenance, depends on the size of pollution (if pollution is not too high, it is optimal to increase the environmental spending when σ is higher).

6. Conclusions

This paper examines the implications of education and environment policies for the dynamics of the economy when the interactions between health, education, and the environment are taken into account in a two-period overlapping generations model. The first characteristic of the model concerns environment and human capital stocks, which affect health. Heath status influences the probability of survival from the first to the second period of life and human capital accumulation, therefore future consumption. The second feature is production, which causes pollution reducing future environment quality. The third attribute is public environment maintenance expenditure that boosts environment stock accumulation. Finally, there is government education spending, which enhances human capital accumulation and future consumption. The above constitute different channels through which agents' welfare is affected. Additionally, government revenues come from income taxation of the old generation every period. We study the steady-state and solve for the optimal policy under the assumption of a benevolent dictator who cares about the old generation every period.

We derive several interesting conclusions. First, for countries with advanced abatement technologies, the relationship between human capital and environment is positive. Second, variations in fiscal policy do not affect welfare significantly, but they have an important impact on the stocks of human capital and environment quality. Third, taxation depends on the levels of environment and human capital stocks. Fourth, there is a positive relationship between environment maintenance expenditure and human capital, but a negative relationship between environment maintenance expenditure and environment stock; that is countries with a high environmental quality should spend less on environment maintenance compared to heavily polluted countries. Fifth, there is a positive relationship between public education spending and environment quality as well as human capital.

Since governments tend to apply myopic policies, i.e. serve just current generations, the best way to influence such policies, therefore the stocks of human and environmental capital, is through an increase in b. That is, a cultural change, reflected greener preferences for future environment, could influence the next "Copenhagen meeting". Additionally, "cleaner" production technologies and/or more effective abatement will make it optimal for governments to increase environment maintenance expenditure.

There are various extensions of this work. First, we could endogenize the preference parameters, e.g. assuming that preferences for future environmental quality depend on current environment stock. Second, we might introduce public health spending in the health production function. Third, agent heterogeneity might be introduced, so that an mechanism of fiscal policy determination in a political economy setting is necessary. These are left for future work.

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