Environmental policy, health and long-run economic growth

Xavier Pautrel[*†]

xavier.pautrel@univ-nantes.fr

Very preliminary

May 31, 2007

Abstract

This paper investigates how environmental policy affects long-run economic growth focusing on the detrimental impact of pollution on health. Marrying environmental economics, health economics and the theory of growth, it demonstrates that environmental policy improves long-run growth for low levels of pollution tax but becomes detrimental for high levels. It also shows that, the more important is the harmful effect of pollution on health and the greater is the influence of health on productivity parameters, the more likely environmental policy will affect positively growth. These results remain valid when we consider other channels through which health affects growth and when we assume that agents invest scarce resources in health promoting activities. They call for an active policy to improve environmental quality.

Keywords : Growth; Environment; Health; Overlapping generations.

[*]address: Université de Nantes, Nantes Atlantique Université, Laboratoire d'Économie de Nantes (LEN), Chemin de la Censive du Tertre, BP 81307, 44313 Nantes Cedex 3, France.

[†]I thank two anonymous referees for their comments on an earlier version of this paper. The usual disclaimer applies.

1 Introduction

Is environmental policy harmful to long-run economic growth? Does the reduction of pollution imply a cost for economic activities so heavy that the gains from a better environment quality are not able to offset it? At the theoretical level, the answers are not clear-cut. The aim of this article is to contribute to the debate focusing on one of the more striking features of pollution: its detrimental impact on health. Our analysis is based on the bulk of empirical evidence which emphasizes the negative influence of pollution on health and on the growing set of works which examines the effect of health on economic growth.

Since more than a decade, theorists study the effects of pollution and environmental policy on long-term economic growth without finding clear conclusions. By example, Gradus and Smulders (1993) demonstrate that in AK model environmental policy has a negative effect on growth by reducing the returns to investment, but in a model of human capital accumulation, environmental policy is positive for growth if pollution alters the ability of training. In a schumpeterian innovation model, Nakada (2004) finds two possible opposite effects of environmental policy on growth. On the one hand, taxation on pollution reduces profits of intermediate firms and final outputs but, on the other hand, it increases their mark-up and so enhances R&D activities which promote growth. He demonstrates that the second effect offsets the first one and that environmental policy is positive for growth. Ono (2003) in an overlapping generations model shows that two opposite forces link environmental policy and growth. Environmental policy reduces growth by limiting pollution which is a factor of production (for low level of tax-pollution) and enhances growth because it leads to a lower level of pollution, that is a higher quality of environment which is bequeathed to future generations.

Nevertheless, none of these analysis integrate explicitly what seems to be one of the more striking features of pollution: its detrimental effect on health.[1] However numerous empirical studies emphasize the dramatic negative influence of different types of pollution on health status, not only in developing countries but also in the more industrialized economies (see for example the report of the WHO (2002) and of the HEI International Scientific Oversight Committee (2004)). Investigating mainly the impact of air pollution in Europe and the United States, some of these studies highlight that pollution has detrimental effects on infant mortality [Chay and Greenstone (2003)], on heart attacks and angina [Dominici et al. (2000), Evans and Smith (2005)] or on lung cancers and cardiopulmonary mortality [Pope et al. (2002)], for example, both in the short and the long run.[2] The negative impact of water pollution [Paulu et al. (1999), Valent et al. (2004)] or industrial pollution [Nadal et al. (2004), Chen and Liao (2005), Schuhmacher and Domingo (2006)] on health is also well-documented.

This impact of pollution on health is crucial to understand the link between environmental policy and growth because health plays a great role on economic activities. As highlighted by Bloom et al. (2004), Bloom and Canning (2005), Howitt (2005), amongst others,[3] health influences positively economic growth in several ways: by increasing productive efficiency (healthier workers are more productive, creative) and life expectancy (which incites agents to save more), by promoting learning capacity and so accumulation

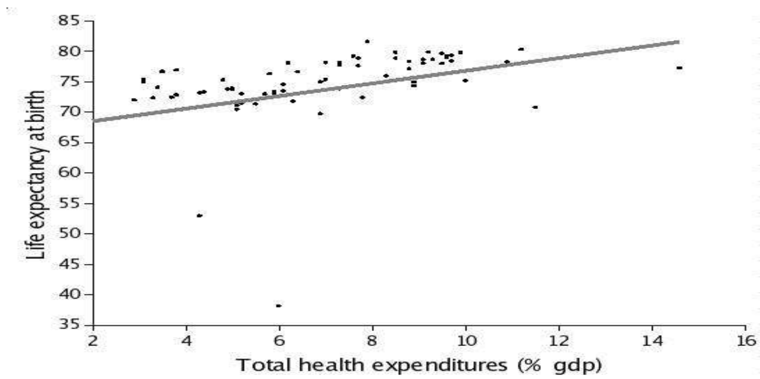
[1] Gradus and Smulders (1993) justify the negative impact of pollution on human capital accumulation by its effect on health. Nevertheless, their formalization seems too rough to enable to capture all the mechanisms at work.

[2] For a survey, see Brunekreef and Holgate (2002).

[3] For more details and more references, see theoretical and empirical contributions in López-Casanovas et al. (2005). For empirical evidences on the causal role of health conditions in growth, see the time-series analysis of Arora (2001).

of knowledge[4]... Therefore, the harmful impact of pollution on health may have several detrimental effects on economic growth through these channels.

Figure 1: Life expectancy and total health expenditures for middle- and high-income countries, 2002



Source: World Development Indicators 2005.

To study this point, we use a two-period overlapping generations model with environmental concerns and health. Assuming *(i)* that health is negatively influenced by pollution but is enhanced by public health expenditures (see Figure 1), *(ii)* that healthier workers are more productive but that firms pollute by producing, we emphasize two opposite effects of environmental policy on long-run growth. The negative one arises from the fact that pollution taxes reduce the rewards to factor, and so saving of young. The positive one relies on the reduction of pollution which makes workers healthier and so increases their productivity. We demonstrate that for low level of pollution tax, the second impact offsets the first one: environmental policy is good for growth. But, for high level of tax, environmental policy is detrimental to growth. We show that the greater is the harmful effect of pollution on

[4]See van Zon and Muysken (2001) to see a theoretical model which integrates such a positive effect of health on economic growth.

health and the higher is the influence of health on productivity parameters, the more likely environmental policy will affect positively growth.

We also investigate the impact of environmental policy when health affects growth through the lifetime of agents rather than workers productivity. We demonstrate that the impact of environmental policy on growth remains ambiguous when we account for both channels (productivity and lifetime), but that there is a larger range of environmental taxes which promote economic growth. The ambiguous impact of environmental policy remains valid if we only consider the channel of lifetime. Finally, when we account for the investment of agents in health promoting activities, qualitative results are not modified: pollution tax has an ambiguous effect on long-run growth.

The paper is set out as follows. Section 2 presents the economy's structure, section 3 studies the balanced growth path and section 4 investigates the impacts of environmental taxation when health affects the lifetime of agents. Section 5 introduces the choice of agents in terms of health expenditures. Section 6 concludes.

2 The Economy's structure

2.1 Consumers

Let's consider an overlapping generations model. A new generation is born at each date $t = 1, 2, ...$, and lives for two periods. Population is constant and the size of each generation is normalized to unity. Individuals are non-altruistic; the old do not care for the young and the young do not care for the old. A consumer, born at t, works during the first period of his life, consumes an amount c_{1t} and saves the remainder of his revenue. There is a probability $1 - \pi \in (0, 1)$ that the consumer dies at the end of his first period of life (after having his children).[5] For the moment, this probability is exogenous and constant over time. We will endogeneize it in section 5. If the consumer survives to the second period of life, he does not work and consumes an amount c_{2t+1}. Agents born at t have the following expected utility:

$$U_t = \ln\left(c_{1t}Q_t^{\eta}\right) + \pi\delta \ln\left(c_{2t+1}Q_{t+1}^{\eta}\right) \tag{1}$$

where $0 < \delta \leq 1$ is the inverse of one plus the rate of time preferences. Q_t and Q_{t+1} are the environmental respectively at t and $t+1$. $\eta > 0$ measures environmental care.

Each young agent is endowed with one unit of labor which he supplies to firms inelastically. He earns a wage income w_t and pays on this income a tax τ^h used by the government to finance health expenditures (see below). Following Blanchard (1985) and Yaari (1965), we assume that there exists a perfect annuities market whereby each individual deposits his saving with a mutual fund, at the end of her youth. The mutual fund invests their saving in capital and guarantees a gross return $\hat{R}_{t+1}$ to the surviving old. If the gross returns on investment in the economy is R_{t+1}, perfect competition ensures that in equilibrium $R_{t+1} = \pi\hat{R}_{t+1}$.

The budget constraint of a young is

$$c_{1t} + s_t = (1 - \tau^h)w_t$$

where s_t denotes saving in young. The budget constraint of an old is

$$c_{2t+1} = \hat{R}_{t+1}s_t$$

[5] Although individual consumers face uncertainty about their date of death, there is no aggregate uncertainty: a fraction π of the consumers in each generation dies at the end of the first period of life.

The program of a consumer is

$$\begin{array}{ll} \max_{c_{1t},s_t} & U_t \\ \text{s.t.} & c_{1t} \leq (1-\tau^h)w_t - s_t \\ & c_{2t+1} \leq \hat{R}_{t+1} s_t \end{array}$$

with w_t, Q_t, Q_{t+1}, $\hat{R}_{t+1}$ given.

It gives

$$s_t = \frac{\pi}{1+\pi}\,(1-\tau^h)w_t \tag{2}$$

2.2 Firms and pollution

Firms operate through perfect competition using physical capital and labor to produce a final good with a constant returns technology:

$$Y_t = \tilde{A}_t K_t^{\alpha} (h_t^{\varepsilon})^{1-\alpha}, \qquad \alpha \in]0,1[\tag{3}$$

where Y_t is the aggregate output, K_t is the aggregate productive capital and h_t^{ε} is labor measured in terms of efficiency units (recall that the size of each generation is normalized to unity). $\varepsilon \in [0,1]$ captures the influence of health on the productivity of workers in the final production. $\tilde{A}_t$ is a productive scalar. As discussed in Romer (1986), we assume that there exists external effects of aggregate capital on productivity: $\tilde{A}_t = AK_t^{1-\alpha}$, where $A > 0$ is a constant parameter. The aggregate capital stock K_t enters the technology as a constant parameter from the perspective of current producers.[6] Capital depreciates fully in the production process.[7]

Firms create environmental harmful emissions of pollutants as by-products of their use of physical capital. The emission of pollution at time t is therefore

[6] This assumption is made to obtain an endogenous growth in the steady-state. The choice of an AK source of endogenous growth is made by convenience.

[7] The production process is over the course of a generation. As noted by Pecchenino and Pollard (1997), "*[s]ince empirically the depreciation rate is about 10% per year, capital is all but fully depreciated over the course of a 25 year generation. We assume, therefore, that capital is fully used up in the production process.*" (p.28)

given by:

$$E_t = z_k K_t \tag{4}$$

where $z_k > 0$ measures the units of emissions produced by one unit of physical capital used in the final production. In order to control emissions, the government levies environmental taxes on firms. In period t, the firms must pay τ^p units of ressources for one unit of production and they choose the amount of factors they use maximizing their after-tax profit $(1-\tau^p)Y_t - w_t L_t - \rho_t K_t$, where ρ_t is the rental price of capital in period t. The following first-order conditions are obtained:

$$\alpha(1-\tau^p)A\left(h_t^{\varepsilon}\right)^{1-\alpha} = \rho_t \tag{5}$$

$$(1-\alpha)(1-\tau^p)AK_t\left(h_t^{\varepsilon}\right)^{1-\alpha} = w_t \tag{6}$$

The stock of pollution, P, increases with the emissions produced by firms, such that the motion of the stock of pollution is:

$$P_{t+1} = (1-\psi_t)P_t + E_t \tag{7}$$

where $0 \leq \psi_t \leq 1$ is the level of pollution absorption. This level is assumed to depend on the maintenance of environment provided by the government as a public good and financed by the environmental tax revenue $\tau^p Y$. Therefore, we pose:

$$\psi_t = z_\psi \tau^p Y_t \tag{8}$$

where $z_\psi > 0$ measures the efficiency of the environmental investment. Finally, the environmental quality, Q_t, is defined by the difference

$$Q_t = \bar{Q} - P_t \tag{9}$$

where $\bar{Q}$ represents the environmental quality without pollution.

2.3 Pollution and health

The health status, h, evolves according two opposite forces. On the one hand, biological processes involve a natural decay of health simply as time passes. On the other hand, health expenditures are used to fight against this deterioration. Following Grossman (1972) and Cropper (1981) we further assume that health depreciates over time with pollution, and more precisely at a rate which positively depends on the stock of pollution.[8] So, we pose that health evolves as the following:

$$h_{t+1} - h_t = \frac{G_t}{Y_t} - \xi P_t^{\gamma} h_t, \qquad \gamma \in [0, 1] \tag{10}$$

where G_t/Y_t represents the health expenditures per GDP and γ measures the influence of the stock of pollution on the natural decay. ξ is the natural rate of decay without pollution. Public health expenditures are financed through a proportional tax $\tau^h \in (0, 1)$ on the wage, then $G_t = \tau^h w_t$.

3 The general equilibrium and the balanced growth path (BGP)

The good market clearing yields:

$$s_t = K_{t+1}$$

and perfect competition in the final goods sector implies that (assuming complete capital depreciation)

$$R_t = \rho_t \tag{11}$$

[8]Grossman (1972) and Cropper (1981) consider that ambient air pollution affects the rate at which health depreciates. Several empirical studies emphasize that this is the cumulative process of air pollution which strongly affect health, espcially for young people. That is the reason why we take into account the stock of pollution rather than the flow of pollution.

with $R_t = \pi \hat{R}_t$.

In the balanced growth path, defined as a steady-state where all variables evolve at a common positive rate of growth, the quality of environment must remain constant. From (9), it implies that the stock of pollution must also be constant. From (7) and (8), the level of the stock of pollution in the steady-state is (the star refers to the steady-state):

$$P^\star = \frac{z_k}{z_\psi \tau^p} \left[A \left(h^{\star\varepsilon} \right)^{1-\alpha} \right]^{-1} \tag{12}$$

It is negatively influenced by the environmental policy and by the health-status through its impact on final ouput. Healthier workers generate a higher level of output and therefore a higher level of abatement activities.

Health status also remains constant in the steady-state. Therefore, from (10) and (6), its value in the steady-state is given by:

$$h^\star = \frac{(1-\alpha)\tau^h(1-\tau^p)}{\xi P^{\star\gamma}} \tag{13}$$

It is negatively influenced by the stock of pollution in the steady-state and by the level of pollution tax which reduces health expenditures per GDP.

Equations (12) and (13) together define both $P^\star$ and $h^\star$:

$$h^\star = \left[\left(\frac{z_\psi A}{\xi z_k} \right)^\gamma (1-\alpha)\tau^h(1-\tau^p)(\tau^p)^\gamma \right]^\phi \tag{14}$$

with $\phi \equiv \dfrac{1}{1-\varepsilon\gamma(1-\alpha)}$. The environmental tax has an ambiguous impact on health status. On the one hand, it reduces emissions of pollutants and therefore the stock of pollution, which lowers the depreciation rate of the health-status and is positive for health. On the other hand, it reduces the wage rate and therefore health-care expenditures which is detrimental for health.

Finally, the growth rate in the economy is $K_{t+1}/K_t = s_t/K_t = 1 + g_t$:

$$1 + g_1^\star = \left[\frac{(1-\tau^h)(1-\alpha)}{\pi^{-1}+1} \right] \Omega(\tau^p) \tag{15}$$

where $\Omega(\tau^p) \equiv \left[\left(\dfrac{z_\psi}{\xi z_k}\right)^\gamma (1-\alpha)\tau^h\right]^\varphi A^{1+\gamma\varphi}(1-\tau^p)^{1+\varphi}(\tau^p)^{\gamma\varphi}$, and $\varphi \equiv (1-\alpha)\varepsilon\phi = (1-\alpha)\varepsilon/(1-\varepsilon\gamma(1-\alpha))$.

The influence of τ^p is given by $\partial(1+g_1^\star)/\partial\tau^p = \frac{\partial(1+g_1^\star)}{\partial\Omega(\tau^p)} \times \frac{\partial\Omega(\tau^p)}{\partial\tau^p}$. Because $\dfrac{\partial(1+g_1^\star)}{\partial\Omega(\tau^p)} = \dfrac{(1+g_1^\star)^2}{(1-\tau^h)(1-\alpha)}\{\sigma\alpha^{1-\sigma}\Omega(\tau^p)^{-\sigma-1}\pi^{-\sigma} + \Omega(\tau^p)^{-2}\} > 0 \quad \forall\sigma$ and $\dfrac{\partial\Omega(\tau^p)}{\partial\tau^p} = \left(\dfrac{\gamma\varphi}{\tau^p} - \dfrac{1+\varphi}{1-\tau^p}\right)\Omega(\tau^p)$, environmental policy positively influences the rate of growth when the environmental tax τ^p is lower than a threshold value

$$\bar{\tau}^p \equiv \frac{\gamma(1-\alpha)\varepsilon}{1+(1-\alpha)\varepsilon} < 1$$

Consequently the influence of environmental policy on growth is a reversed-U shape function. On the one hand, by taxing production, environmental policy reduces the rewards to factor and so diminishes saving, which is detrimental to growth. On the other hand, by reducing pollution it increases health in the economy. Agents have a higher productivity which promotes factor rewards and so saving.

The threshold value of τ^p over which environmental policy is detrimental to growth, is positively influenced by ε, which measures the influence of health on the productivity of workers, and by γ, which measures the influence of pollution on public health. The more pollution hits health (higher γ) and the more health affects the productivity of workers (higher ε), the more government can tax pollution with a positive impact on growth. The higher the part of the physical capital in final production (α) the more likely is a detrimental impact of environmental taxation on growth.

This result calls for an active environmental policy. If ε or γ is null, health does not influence productivity or the stock of pollution does not affect health-status, the environmental policy is always detrimental for growth.

4 Health investment and environmental policy

Previously, we made simplified assumptions to capture the main mechanisms between environment, health and growth. Especially we abstracted from the fact that better health may be expected to affect positively utility[9] and that agents may invest scarce resources to increase health. This may modify the results found in the previous section.

Following van Zon and Muysken (2001), preferences (1) are modified to integrate health and become

$$U_t = \ln\left(c_{1t}^{1-\theta} h_t^{\theta}\right) - \eta \ln Q_t + \delta\pi\left[\ln\left(c_{2t+1}^{1-\theta} h_{t+1}^{\theta}\right) - \eta \ln Q_{t+1}\right] \tag{16}$$

with $0 \leq \theta \leq 1$ measures the relative contribution of health to intertemporal utility, compared to per capita consumption.

Furthermore, we assume that health is not promoted by the government but rather by a private health sector which provides health services H_t. To keep things simple, we consider that health sector only uses labor in a proportion $\nu \in]0,1[$:[10]

$$H_t = \tilde{A}_{H,t}\nu_t h_t$$

with $\tilde{A}_{H,t} > 0$ is a productivity parameter.[11] In our formulation, healthy workers produce more health services. To keep the model tractable we suppose that the external effects in the manufacturing sector spill over into health sector such that $\tilde{A}_{H,t} = A_H K_t$.

In the law of motion of h given by equation (10), G_t is now replaced by

[9] See van Zon and Muysken (2001) for some justifications.

[10] Assuming that physical capital is also used in the health sector would give the same qualitative results but also more complicated expressions. Proof upon request.

[11] We assume constant returns in health sector because it highly simplifies the model and enables to obtain an implicit expression of the growth rate.

H_t, so

$$h_{t+1} = h_t - \xi P_t^{\gamma} h_t + H_t / Y_t$$

The production function (3) becomes

$$Y_t = AK_t h^{\varepsilon(1-\alpha)} (1-\nu_t)^{1-\alpha}$$

and profit maximization gives

$$w_t = (1-\alpha)(1-\tau^p) AK_t h_t^{\varepsilon(1-\alpha)} (1-\nu_t)^{-\alpha}$$

$$\rho_t = \alpha(1-\tau^p) A h_t^{\varepsilon(1-\alpha)} (1-\nu_t)^{1-\alpha}$$

Now, the program of the consumer is

$$\begin{aligned} \max_{s_t, H_t} \quad & U_t \\ s.t. \qquad & c_t \leq w_t - s_t - m_t H_t \\ & d_{t+1} \leq \hat{R}_{t+1} s_t \\ & h_{t+1} = h_t - P_t^{\gamma} h_t + H_t / Y_t \end{aligned}$$

where m_t is the price of health services and $m_t H_t$ represents the value of health services expenditures made by an individual when he is young.

Free-allocation of labor between sectors implies that the remuneration of labor in final output equals the remuneration of labor in health sector: $m_t A_H K_t h = w_t$. So $w_t - m_t H_t = (1-\nu_t) w_t$ and saving is written as:

$$s_t = \frac{\delta\pi}{1+\delta\pi} \; (1-\nu_t)\, w_t \tag{17}$$

The maximization of utility also gives the expression of ν:

$$\nu_t = \left[\frac{(1-\theta)(1+\delta\pi)}{\theta\delta\pi} \frac{Y_t}{H_t} h_{t+1} + 1 \right]^{-1} \tag{18}$$

In the steady-state, the stock of pollution is constant at the level

$$P^{\star} = \frac{z_k}{z_\psi \tau^p} \left[A h^{\star\varepsilon(1-\alpha)} (1-\nu^{\star})^{1-\alpha} \right]^{-1} \tag{19}$$

The health-status is also constant at the level

$$h^\star = \left[\frac{A_H}{\xi A}\nu^\star(1-\nu^\star)^{\alpha-1}P^{\star-\gamma}\right]^\phi \equiv \mathcal{H}(\underset{+}{\nu^\star}, \underset{-}{P^\star}) \tag{20}$$

and the allocation of labor in the health-sector in the steady-state is constant at the level

$$\nu^\star = \left[\frac{(1-\theta)(1+\delta\pi)}{\theta\delta\pi}P^{\star-\gamma}+1\right]^{-1} \equiv \mathcal{V}(\underset{+}{P^\star}) \tag{21}$$

In the steady-state, young allocates more labor to health sector when the relative contribution of health to intertemporal utility (θ) is higher and when the probability of surviving (π) in the next period is higher because the probability to benefit from investment in health increases. They also invest more in health when the level of pollution is higher in order to compensate the deterioration of his health status.

Equations (19), (20) and (21) define both the stock of pollution, the health-status and the allocation of labor in health sector at the steady-state:

$$\left(\frac{A_H}{\xi}\right)P^{\star 1-\gamma} - \frac{z_k}{z_\psi \tau^p}\left[\frac{(1-\theta)(1+\delta\pi)}{\theta\delta\pi}P^{\star-\gamma}+1\right] = 0 \tag{22}$$

Because the left-hand side is increasing with $P^\star$ this equation defines a unique steady-state value for the stock of pollution $P^\star$. An increase in τ^p reduces the stock of pollution in the steady-state at an increasing rate:

$$P^{\star\prime} = \partial P^\star/\partial\tau^p = -P^\star\mathcal{D}(P^\star) < 0$$

with $\mathcal{D}(P^\star) \equiv \left[(1-\gamma)\tau^p + \gamma\frac{z_k}{z_\psi}\left(\frac{\xi}{A_H}\right)\frac{(1-\theta)(1+\delta\pi)}{\theta\delta\pi}P^{\star-1}\right]^{-1} > 0$, and

$$P^{\star\prime\prime} = -P^{\star\prime}\mathcal{D}(P^\star)+P^\star\mathcal{D}(P^\star)^2\left[(1-\gamma)-\gamma\frac{z_k}{z_\psi}\left(\frac{\xi}{A_H}\right)\frac{(1-\theta)(1+\delta\pi)}{\theta\delta\pi}P^{\star-2}P^{\star\prime}\right] > 0$$

From (21) it implies that the allocation of labor into the health sector is decreasing with τ^p. From the expression of saving, the growth rate in this economy is

$$1+g_2 = \frac{\delta\pi(1-\alpha)}{(1+\delta\pi)}\left(\frac{z_k}{z_\psi}\right)\left(\frac{1}{\tau^p}-1\right)P^{\star-1} \tag{23}$$

The influence of the environmental tax is given by:

$$\partial(1+g_2)/\partial\tau^p = -\frac{\delta\pi(1-\alpha)}{(1+\delta\pi)}\ \left(\frac{z_k}{z_\psi}\right)(P^\star\tau^p)^{-2}\left[P^\star+\tau^p(1-\tau^p)P^{\star\prime}\right]$$

Consequently $\partial(1+g_2)/\partial\tau^p > 0$ if

$$\gamma\tau^p > \tau^{p2} + \gamma\frac{z_k}{z_\psi}\left(\frac{\xi}{A_H}\right)\frac{(1-\theta)(1+\delta\pi)}{\theta\delta\pi}P^{\star-1} \tag{24}$$

Because the first term in the right-hand side of the equation is convex and the second term is concave, it is not easy to find the threshold value of τ^p for which both sides equate. Therefore, to investigate under what conditions this relation is verified, let us consider three values for γ.

When $\gamma = 0$, equation (22) defines an explicit expression for $P^\star$:

$$P^\star|_{\gamma=0} = \frac{z_k}{z_\psi\tau^p}\left[\frac{(1-\theta)(1+\delta\pi)}{\theta\delta\pi}+1\right]$$

and the growth rate in the economy becomes

$$1+g_2|_{\gamma=0} = \frac{\delta\pi(1-\alpha)}{(1+\delta\pi)}\ (1-\tau^p)\left[\frac{(1-\theta)(1+\delta\pi)}{\theta\delta\pi}+1\right]^{-1}$$

which is a decreasing function of τ^p. Therefore,when pollution does not influence the evolution of health status, environmental taxation has always a negative impact on the steady-state the growth rate.

When $\gamma = 1$, the steady-state stock of pollution is defined by

$$P^\star|_{\gamma=1} = \left[\frac{A_H z_\psi}{\xi z_k}\tau^p - 1\right]^{-1}\frac{(1-\theta)(1+\delta\pi)}{\theta\delta\pi}$$

To have $P^\star > 0$, it is required that $\tau^p > \dfrac{\xi z_k}{A_H z_\psi}$, and we have to impose that $\dfrac{\xi z_k}{A_H z_\psi} < 1$, otherwise no positive growth is possible. Condition (24) becomes

$$\tau^p < \left[\frac{\xi z_k}{A_H z_\psi}\right]^{1/2}$$

Therefore, when the impact of pollution on health-status is the highest, there exists a threshold value of the environmental tax under which environmental policy promotes growth. This threshold value is independent from the impact of health on workers' productivity (ε) but positively depends on the rate of depreciation of health-status (ξ) and the capacity of physical capital to generate pollution z_k. It negatively depends on the productivity parameter in the health sector (A_H) and on the efficiency of the abatement activities (z_ψ).

Finally, when $\gamma = 1/2$, equation (22) becomes a second-order equation with an explicit solution for $P^\star$:

$$P^\star|_{\gamma=1/2} = \left[\sqrt{\frac{4z_\psi A_H(1-\theta)(1+\delta\pi)}{\xi z_k \theta\delta\pi}\tau^p} + 1\right]^2 \left(\frac{\xi z_k}{A_H z_\psi \tau^p}\right)^2$$

Therefore, condition (24) becomes

$$1/2 > \tau^p + \frac{1}{8}\left[\sqrt{\frac{\xi z_k \theta\delta\pi}{4z_\psi A_H(1-\theta)(1+\delta\pi)\tau^p}} + 1\right]^{-2}$$

Because the right-hand side of this equation is an increasing function of τ^p and its limit equals 0 when τ^p tends towards 0, for low values of τ^p this condition is verified while for high values of τ^p this is not the case. The threshold value positively depends on the ratio $\frac{\xi z_k}{A_H z_\psi}$ and on $\theta\delta\pi$. It is lower than 1/2.

5 Endogenous probability of surviving and environmental policy

In this section we investigate the impact of environmental policy when health damage from air pollution comes in the form of premature mortality rather than a lower productivity of workers. This may modify the link between pollution and growth highlighted in the previous section because two opposite effects arise. On the one hand, healthier persons have a higher life expectancy and so a higher probability of surviving. So they save more and then it is positive for growth. On the other hand, if old agents contribute to the workforce, a higher probability of surviving leads to a increase in the labor force and tends to reduce the productivity of labor and therefore wages. Consequently, is the negative impact of environmental taxes always offseted by a healthier population?

To answer this question, we modify the model of section 2 in two ways. First, we choose $\varepsilon = 0$ and we endogeneize the probability of surviving π in the same line than Chakraborty (2005) assuming that the probability of surviving π is a non-decreasing function:

$$\pi_t = \pi(h_t) \tag{25}$$

that satisfies $\pi(0) = 0$, $\lim_{h\to\infty} \Pi(h) = \beta \leq 1$ and $\lim_{h\to 0} \Pi'(h) = \gamma < \infty$.

Second, we assume that old consumers (born at t) enter the labour force at $t+1$ and earn a wage w_{t+1}. Therefore, the program of the consumer born at t becomes:

$$\begin{array}{ll} \max_{c_{1t},s_t} & U_t \\ \text{s.t.} & c_{1t} \leq (1-\tau^h)w_t - s_t \\ & c_{2t+1} \leq \hat{R}_{t+1}s_t + w_{t+1} \end{array}$$

The first order condition gives saving

$$s_t = \frac{\pi_t\delta}{1+\pi_t\delta}(1-\tau^h)w_t - \frac{1}{1+\pi_t\delta}w_{t+1}/\hat{R}_{t+1} \tag{26}$$

with $\hat{R}_t = \rho_t/\pi_t$.

Because the old work, the labor in the manufacturing sector at date t is the sum of the overall young (with a size normalized to unity) and of the old still alive (with a size equal to π_{t-1}). Therefore, the production function becomes

$$Y_t = AK_t(1+\pi_{t-1})^{1-\alpha}$$

The wage rate and the interest rate are respectively:

$$w_t = (1-\alpha)(1-\tau^p)AK_t(1+\pi_{t-1})^{-\alpha}$$

$$\rho_t = \alpha(1-\tau^p)A(1+\pi_{t-1})^{1-\alpha}$$

Therefore, the discounted wage when old is

$$w_{t+1}/\hat{R}_{t+1} = \frac{\pi_{t+1}(1-\alpha)}{\alpha(1+\pi_t)}K_{t+1}$$

and saving may be written as:

$$s_t = \frac{(1-\alpha)\pi_t\delta(1-\tau^h)(1-\tau^p)A}{(1+\delta\pi_t)(1+\pi_{t-1})^{\alpha}}K_t - \frac{\pi_{t+1}(1-\alpha)}{\alpha(1+\delta\pi_t)(1+\pi_t)}K_{t+1}$$

The market clearing condition always equates the overall saving by young at t and the stock of physical capital at $t+1$. Using the previous equation, we obtain the expression of the ratio K_{t+1}/K_t and therefore the growth rate in the economy $g_{3,t}$:

$$\frac{K_{t+1}}{K_t} = \frac{(1-\alpha)\pi\delta(1-\tau^h)(1-\tau^p)A}{(1+\pi_{t-1})^{\alpha}\left[1+\delta\pi+\dfrac{\pi_{t+1}(1-\alpha)}{\alpha(1+\pi)}\right]} = 1+g_{3,t}$$

In the steady-state, the health-status is constant at $h^\star$ defined by equation (14) with $\varepsilon = 0$:

$$h^\star = \left(\frac{z_\psi A}{\xi z_k}\right)^{\gamma}(1-\alpha)\tau^h(1-\tau^p)(\tau^p)^{\gamma}$$

and the probability of surviving is also constant: $\pi_{t-1} = \pi_t = \pi_{t+1} = \pi^\star$. Using (26), the growth rate in the steady-state is defined as

$$1+g_3 = \alpha(1-\alpha)\delta A(1-\tau^h)(1-\tau^p)\mathcal{H}(\tau^p) \qquad (27)$$

where $\mathcal{H}(\tau^p) \equiv \dfrac{\pi(h^\star)\left[1+\pi(h^\star)\right]^{1-\alpha}}{\alpha+\alpha\delta\pi(h^\star)\left[1+\pi(h^\star)\right]+\pi(h^\star)}$. This ratio accounts for the positive effect of the probability of surviving (through the saving propensity) and the negative effect of the probability of surviving (through the increase in the labor force and the decrease in the wage rate). The first effect offsets the second one and the ratio is an increasing function of $\pi(h^\star)$.[12]

The environmental tax positively influences the growth rate $g_3^\star$ when

$$\frac{d\mathcal{H}(\tau^p)}{d\tau^p} > \frac{\mathcal{H}(\tau^p)}{1-\tau^p}$$

In the appendix we demonstrate that $\dfrac{d\mathcal{H}(\tau^p)}{d\tau^p}$ is positive only if $\tau^p < \gamma/(1+\gamma)$ and that the previous condition is verified when environmental tax is lower than a threshold value.

Consequently, for low value of the environmental tax, environmental policy is positive for steady-state growth and for higher tax, it becomes harmful. It remains to find the determinants of the threshold tax rate.

When pollution does not influence health ($\gamma = 0$), the influence of the environmental taxation on the growth rate is always negative.

6 Conclusion

The aim of this paper was to investigate the impact of environmental policy on long-term economic growth focusing on the detrimental impact of pollution on health and the several ways by which health promotes long-run performances.

[12]The derivative with respect to $\pi(h^\star)$ is:

$$\frac{\alpha+\pi(h^\star)\left[(1-\alpha)\pi(h^\star)+\alpha\left[2-\alpha(1+\pi(h^\star)(1+\pi(h^\star))\delta)\right]\right]}{(1+\pi(h^\star))^\alpha\left[\pi(h^\star)+\alpha+\pi(h^\star)(1+\pi(h^\star))\alpha\delta\right]^2} > 0$$

because $0 < \delta < 1$ and $0 < \pi(h^\star) < 1$.

Merging environmental economics, health economics and growth theory in a two-period overlapping generations model, we demonstrate that pollution taxes have two opposite effects on economic growth. The positive effect relies on the reduction of pollution which makes workers healthier and then increases their productivity. The negative effect arises because emission taxes reduce the reward to factors and then saving. For pollution taxes under a threshold value, environmental policy enhances growth, oterwise it is harmful to growth. Examining the determinants of this threshold value, we show that the more pollution hits health and the more health affects the productivity of workers, the more government can tax pollution with a positive impact on growth, but the lower will be the growth rate. When investment in health-status by the agents is taken into account, we demonstrate that environmental policy may be positive for growth for values of environmental taxation lower than a threshold only when the detrimental influence of pollution on health-status is high enough. In such a case, the effect of health on workers' productivity affects neither the steady-state level of pollution nor the steady-state rate of growth. Furthermore, the threshold value under which the environmental tax is positive when the influence of pollution on health is the highest positively depends on the capacity of the physical capital to generate pollution. Since the detrimental influence of pollution on health is well-documented and the capacity of production to generate pollution remains high, this result calls for an active environmental policy.

Assuming that the channel of transmission between health and growth is not workers productivity but rather the lifetime of agents, we obtain the same qualitative result of an ambiguous impact of environmental taxation on growth. Finally, we demonstrate that all these results are robust when we consider that agents invest scarce resources in health promoting activities.

References

Arora, S.: 2001, Health, human productivity, and long-term economic growth, *Journal of Economic History* **61**(3), 699–749.

Blanchard, O.: 1985, Debt, deficits and finite horizon, *Journal of Political Economy* **93**, 223–247.

Bloom, D. and Canning, D.: 2005, Health and economic growth: Micro and macro evidence, *working papers 42*, CDDRL, Stanford IIS.

Bloom, D., Canning, D. and Jamison, D.: 2004, Health, wealth and welfare, *Finance and Development* pp. 10–15.

Brunekreef, B. and Holgate, S. T.: 2002, Air pollution and health : review, *The Lancet* **360**, 1233–1242.

Chakraborty, S.: 2005, Endogenous lifetime and economic growth, *Journal of Economic Theory* **116**, 119–137.

Chay, K. and Greenstone, M.: 2003, The impact of air pollution on infant mortality: evidence from geographic variation in pollution shocks induced by a recession, *Quarterly Journal of Economics* pp. 1121–1167.

Chen, S. and Liao, C.: 2005, Health risk assessment on humans exposed to environmental polycyclic aromatic hydrocarbons pollution sources, *Science of the Total Environment* .

Cropper, M.: 1981, Measuring the benefits from reduced morbidity, *The American Economic Review* **71**, 235–240.

Dominici, F., Samet, J. and Zeger, S.: 2000, Combining evidence on air pollution and daily mortality from the 20 largest US cities: a hierarchical modelling strategy, *Journal of the Royal Statistical Society: series A* **163**(3), 263–302.

Evans, M. F. and Smith, V.: 2005, Do new health conditions support mortility-air pollution effects?, *Journal of Environmental Economics and Management* **50**, 496–518.

Gradus, R. and Smulders, S.: 1993, The trade-off between environmental care and long-term growth-pollution in three prototype growth models, *Journal of Economics* **58**(1), 25–51.

Grossman, M.: 1972, On the concept of health capital and the demand for health, *Journal of Political Economy* **80**, 223–255.

HEI International Scientific Oversight Committee: 2004, Health effects of outdoor air pollution in developing countries of Asia: A literature review, *Technical report*, Special Report 15. Health Effects Institute, Boston, MA.

Howitt, P.: 2005, Health, human capital and economic growth: A schumpeterian perspective, *in* G. López-casasnovas, B. Rivera and L. Currais (eds), *Health and economic growth*, MIT Press, pp. 19–40.

López-Casanovas, G., Rivera, B. and Currais, L.: 2005, *Health and Economic Growth: Findings and Policy Implications*, MIT Press.

Nadal, M., Schuhmacher, M. and Domingo, J.: 2004, Metal pollution of soils and vegetation in an area with petrochemical industry, *Science of the Total Environment* **321**, 59–69.

Nakada, M.: 2004, Does environmental policy necessarily discourage growth?, *Journal of Economics* **81**(3), 249–275.

Ono, T.: 2003, Environmental tax policy and long-run economic growth, *The Japanese Economic Review* **54**(2), 203–217.

Paulu, C., Aschengrau, A. and Ozonoff, D.: 1999, Tetrachloroethylene-contaminated drinking water in Massachusetts and the risk of colon-rectum, lung, and other cancers, *Environmental Health Perspectives* **107**(4), 265–271.

Pecchenino, R. and Pollard, P.: 1997, The effects of annuitie, bequests, and aging in an overlapping generations model of endogenous growth, *The Economic Journal* **107**, 26–46.

Pope, C., Burnett, R., Thun, M., Calle, E., Krewski, D., Ito, K. and Thurston, G.: 2002, Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution, *The Journal of American Medical Association* **287**, 1132–1141.

Romer, P.: 1986, Increasing returns and long run growth, *Journal of Political Economy* **94**, 1002–1037.

Schuhmacher, M. and Domingo, J.: 2006, Long-term study of environmental levels of dioxins and furans in the vicinity of a municipal solid waste incinerator, *Environment International* **32**, 397–404.

Valent, F., Little, D., Bertollini, R., Nemer, L., Barbone, F. and Tamburlini, G.: 2004, Burden of disease attributable to selected environmental factors and injury among children and adolescents in Europe, *The Lancet* **363**, 2032–2039.

van Zon, A. and Muysken, J.: 2001, Health and endogenous growth, *Journal of Health Economics* **20**, 169–185.

Yaari, M.: 1965, Uncertain lifetime, life insurance and the theory of consumer, *Review of Economic Studies* **32**, 137–150.

Appendix

Endogenous lifetime

We know that $\dfrac{d\mathcal{H}(\tau^p)}{d\tau^p} = \dfrac{d\mathcal{H}(\tau^p)}{d\pi(h^\star)}\dfrac{d\pi(h^\star)}{dh^\star}\dfrac{dh^\star}{d\tau^p}$. The two first terms in the right-hand side of the equation is positive. Indeed, if we assume that, like Chakraborty (2005), $\pi(h) \equiv \zeta\dfrac{h}{1+h}$ with $0 < \zeta < 1$ and $\eta = \zeta$, we have:

$$\frac{d\pi(h^\star)}{dh^\star} = \frac{\zeta}{(1+h^\star)^2} > 0$$

which is a decreasing function of τ^p. Furthermore

$$\frac{d\mathcal{H}(\tau^p)}{d\pi(h^\star)} = \frac{\alpha + \pi(h^\star)\left[(1-\alpha)\pi(h^\star) + \alpha\left[2 - \alpha(1+\pi(h^\star)(1+\pi(h^\star))\delta)\right]\right]}{(1+\pi(h^\star))^\alpha\left[\pi(h^\star) + \alpha + \pi(h^\star)(1+\pi(h^\star))\alpha\delta\right]^2} > 0$$

And the last term

$$\frac{dh^\star}{d\tau^p} = \left(\frac{z_\psi A}{\xi z_k}\right)^\gamma \tau^{p\gamma-1}\left[\gamma - (1+\gamma)\tau^p\right]$$

is positive when $\tau^p < \gamma/(1+\gamma)$ and decreasing in τ^p. Therefore

$$\frac{d\mathcal{H}(\tau^p)}{d\tau^p} > 0 \qquad \text{if} \qquad \tau^p < \gamma/(1+\gamma)$$

Furthermore, $\lim_{\tau^p\to 0} d\mathcal{H}(\tau^p)/d\tau^p = +\infty$ from the previous derivatives. Consequently $d\mathcal{H}(\tau^p)/d\tau^p$ is decreasing in τ^p.

On the other hand, we have $\lim_{\tau^p\to 0}\mathcal{H}(\tau^p) = 0$ and $\lim_{\tau^p\to 1}\mathcal{H}(\tau^p) = 0$. Consequently, $\lim_{\tau^p\to 0}\mathcal{H}(\tau^p)/(1-\tau^p) = 0$ and from the L'Hospital rule $\lim_{\tau^p\to 1}\mathcal{H}(\tau^p)/(1-\tau^p) = +\infty$ because we demonstrated that $\lim_{\tau^p\to 0} d\mathcal{H}(\tau^p)/d\tau^p = +\infty$.

We can conclude that $d\mathcal{H}(\tau^p)/d\tau^p$ and $\mathcal{H}(\tau^p)/(1-\tau^p)$ intersects for $\tau^p \in]0, \gamma/(1+\gamma)[$ and the condition $d\mathcal{H}(\tau^p)/d\tau^p > \mathcal{H}(\tau^p)/(1-\tau^p)$ is verified for values of τ^p lower than the intersection value.