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Environmental Policy, Education and Growth with Finite Lifetime: the Role of Abatement Technology

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This note shows that the assumptions about the abatement technology modify the impact of the environmental taxation (both the size and the "direction") on the long-run growth driven by human capital accumulation à la Lucas (1988), when the source of pollution is private consumption and lifetime is finite. When the human capital's share in the abatement services production is higher (respectively lower) than in the final output production, a higher environmental tax reduces (resp. increases) the allocation of human capital in production sectors (abatement service and final output) and boostes (resp. decreases) the BGP rate of growth. When abatement services are produced with the final output, the environmental taxation does not influence growth.

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I thank Fabien Tripier for a stimulating discussion about a previous version of this paper, Yan Rebillé for helpful comments. The usual disclaimer applies.

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ENVIRONMENTAL POLICY, EDUCATION AND GROWTH WITH FINITE LIFETIME: THE ROLE OF THE ABATEMENT TECHNOLOGY

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ABSTRACT

This note shows that the assumptions about the abatement technology modify the impact of the environmental taxation (both the size and the "direction") on the long-run growth driven by human capital accumulation à la Lucas (1988), when the source of pollution is private consumption and lifetime is finite.

When the human capital's share in the abatement services production is higher (*respectively lower*) than in the final output production, a higher environmental tax reduces (*resp. increases*) the allocation of human capital in production sectors (abatement service and final output) and boostes (*resp. decreases*) the BGP rate of growth. When abatement services are produced with the final output, the environmental taxation does not influence growth.

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1 INTRODUCTION

The influence of the environmental policy on long-run growth driven by human capital accumulation à la Lucas (1988) has been studied by several authors. They highlighted the importance of assumptions about the influence of pollution on the productivity of education (Gradus and Smulders, 1996; van Ewijk and van Wijnbergen, 1995), about endogenous labor supply (Hettich, 1998), about preferences for schooling (Grimaud and Tournemaine, 2007), about finite lifetime (Pautrel, 2008a) or about the negative impact of pollution on health (Pautrel, 2008b, 2009), on the outcome of the environmental taxation on long-run human capital accumulation.

All these works give insightful results on the way the deterioration of the environment affects growth when the channel of transmission is education. Unfortunately, some of these results are very sensitive to the source of pollution: when pollution originates from final output rather than physical capital, Hettich (1998) with endogenous labor supply and Pautrel (2008a) with finite lifetime do not find any influence of the environmental policy on education in the long-run, anymore.

This note re-investigates the impact of the environmental tax when the channel of transmission is education, in the case of finite lifetime, by considering an alternative source of pollution, that is private consumption, and by assuming a Cobb-Douglas technology using physical capital and human capital to produce abatement services.[1] It demonstrates that the existence and the sign of the environmental tax' impact on human capital accumulation along the balanced growth path depends on the technology in the abatement services production. When the human capital's share in the abatement sector is higher (*respectively lower*) than in the final output sector, the environmental tax on consumption boosts (*resp. decreases*) human capital accumulation.

2 THE MODEL

Let's consider a Yaari (1965)-Blanchard (1985) overlapping generations model with human capital accumulation and environmental concerns. Time is continuous. Each individual born at time s faces a constant probability of death per unit of time $\beta \geq 0$. Consequently his life expectancy is $1/\beta$. When β increases, the life span decreases. At time s, a cohort of size β is born. At time $t \geq s$, this cohort has a size equal to $\beta e^{-\beta(t-s)}$ and the constant population is equal to $\int_{-\infty}^{t} \beta e^{-\beta(t-s)} ds = 1$. There are insurance companies and there is no bequest motive.

The expected utility function of an agent born at $s \leq t$ is:

$$\int_{s}^{\infty} \left[\log c(s,t) - \zeta \log S(t)\right] e^{-(\varrho+\beta)(t-s)} dt \tag{1}$$

where $c(s,t)$ denotes consumption in period t of an agent born at time s, $\varrho \geq 0$ is the rate of time preference, $S(t)$ is the stock of pollution at date t and $\zeta > 0$ measures the weight in utility attached

[1] That assumption enables us to distance our analysis to the existing literature by taking into account that abatement services could be produced with a technology different from the one used to produce final output.

to the environment.

The representative agent can increase his stock of human capital by devoting time to schooling, according to Lucas (1988):

$$\dot{h}(s,t) = B\left[1 - u(s,t)\right] h(s,t) \tag{2}$$

where B is the efficiency of schooling activities, $u(s,t) \in]0,1[$ is the part of human capital allocated to productive activities at time t for the generation born at s and $h(s,t)$ is the stock of human capital at time t of an individual born at time s. We assume that the human capital of the agent when he borns, $h(s,s)$, is inherited from the dying generation (Song, 2002). Because the mechanism of intergenerational transmission of knowledge is complex, we consider that newborn inherit from the dying generation the average aggregate human capital stock, that is $h(s,s) = H(s)$ (population being equal to unity).[2]

Households face the following budget constraint:

$$\dot{a}(s,t) = \left[r(t) + \beta\right] a(s,t) + u(s,t)h(s,t)w(t) - (1+\tau)c(s,t) \tag{3}$$

where $a(s,t)$ is the financial wealth in period t and $\omega(t)$ represents the wage rate per effective unit of human capital $u(s,t)h(s,t)$. τ represents the environmental tax that the government imposes on individual consumption which is the source of pollution (see below). In addition to the budget constraint, there exists a transversality condition which must be satisfied to prevent households from accumulating debt indefinitely:

$$\lim_{v\to\infty}\left[a_{s,v}e^{-(r+\beta)(v-t)}\right] = 0$$

The representative agent chooses the time path for $c(s,t)$ and his working time $u(s,t)$ by maximizing (1) subject to (2) and (3). It yields

$$\dot{c}(s,t) = \left[r - \varrho\right] c(s,t) \tag{4}$$

Integrating (3) and (4) and combining the results gives the consumption at time t of an agent born at time s:

$$c(s,t) = \left(\frac{\varrho + \beta}{1+\tau}\right)\left[a(s,t) + \omega(s,t)\right] \tag{5}$$

where $\omega(s,t) \equiv \int_t^\infty \left[u(s,\nu)h(s,\nu)w(\nu)\right] e^{-\int_t^\nu [r(\zeta)+\beta]d\zeta} d\nu$ is the present value of lifetime earning. It also gives the equality between the rate of returns to human capital and the effective rate of interest (the interest rate on the debt r plus the insurance premium β the agent has to pay when borrowing (see Blanchard and Fisher, 1989)):

$$\frac{\dot{w}(t)}{w(t)} + B = r(t) + \beta \tag{6}$$

[2]Assuming that $h(t,t) = \eta H(t)$ with $\eta \in]0,1[$, like Song (2002), would not modify our qualitative results. Proof upon request.

Due to the simple demographic structure, all individual variables are additive across individuals. Consequently, the aggregate consumption equals

$$C(t) = \int_{-\infty}^{t} c(s,t)\beta e^{-\beta(t-s)} ds = \left(\frac{\varrho+\beta}{1+\tau}\right)[K(t)+\Omega(t)] \tag{7}$$

where $\Omega(t) \equiv \int_{-\infty}^{t} \omega(s,t)\beta e^{-\beta(t-s)} ds$ is aggregate human wealth in the economy. The aggregate stock of physical capital is defined by

$$K(t) = \int_{-\infty}^{t} a(s,t)\beta e^{-\beta(t-s)} ds$$

and the aggregate human capital is

$$H(t) = \int_{-\infty}^{t} h(s,t)\beta e^{-\beta(t-s)} ds, \tag{8}$$

In the economy, a government taxes the source of pollution (the individual consumption) at an exogenous tax rate $\tau \in]0,1[$ and uses the revenues from the tax $\tau\ C(t)$ to provide abatement services that improve the environmental quality. His budget is balanced at each date (see below).

There are two production sectors that operate under perfect competition: one produces final output denoted Y, the other produces abatement services denoted D. The final output is produced with the following technology:

$$Y(t) = (\phi(t)K(t))^{\alpha}(\mu(t)H_p(t))^{1-\alpha}, \qquad \text{with } \phi,\ \mu,\ \alpha\ \in]0,1[\tag{9}$$

where $\mu(t)H_p(t)$ is the amount of the aggregate stock of human capital devoted to production ($H_p(t) \equiv \left[\int_{-\infty}^{t} u(s,t)h(s,t)\beta e^{-\beta(t-s)} ds\right]$) that is used in output production (with represent a part $\mu \in]0,1[$ of $H_p(t)$). And $\phi(t)K(t)$ is the part of the physical capital stock used in output production. Firms in the final output sector maximize profit $Y(t) - r(t)\phi(t)K(t) - w(t)\mu(t)H_p(t)$ by equating factor rewards to marginal productivity:

$$r(t) = \alpha Y(t)/(\phi(t)K(t)), \qquad \text{and} \qquad w(t) = (1-\alpha)Y(t)/(\mu(t)H_p(t)) \tag{10}$$

The abatement sector produces abatement services aimed at curbing the emissions of pollution. Physical and human capital are used in the abatement sector with the following constant-returns technology:

$$D(t) = [(1-\phi(t))K(t)]^{\psi}\,[(1-\mu(t))H_p(t)]^{1-\psi}, \qquad \text{with } \psi \in [0,1] \tag{11}$$

Note that when $\psi = \alpha$ the abatement services sector uses the same technology than output sector, that is abatement services are produced with output. When $\psi = 1$ we are in the case of Michel and Rotillon (1995) where only physical capital is used in the production of abatement services. The government purchases the abatement services $D(t)$ at a price $P_D(t)$, defined by profit maximization and publicly provides them to the economy. Its budget being balanced at each date the revenue of the environmental tax funds the abatement services expenditures

$$\tau C(t) = P_D(t)D(t) \tag{12}$$

Profit maximisation in the abatement services sector gives:

$$w(t) = (1-\psi)P_D(t)D(t)/((1-\mu(t))H_p(t)) \qquad \text{and} \qquad r(t) = \psi P_D(t)D(t)/((1-\phi(t))K(t)) \tag{13}$$

From equations (10), (11) and (12), we obtain:

$$r(t) = \frac{\psi\tau\, C(t)}{(1-\phi(t))K(t)} \qquad \text{that is} \qquad \phi(t) = 1 - \psi\frac{\tau C(t)/K(t)}{r(t)} \tag{14}$$

and

$$w(t) = \frac{(1-\psi)\tau\, C(t)}{(1-\mu(t))H_p(t)} \qquad \text{that is} \qquad \mu(t) = 1-(1-\psi)\frac{\tau C(t)/H_p(t)}{r(t)} \tag{15}$$

Furthermore, because physical capital and human capital are used in output production and abatement production, their rewards in both sectors are the same, that is from (10) and (13)

$$\frac{1-\mu(t)}{\mu(t)} = \left(\frac{1-\psi}{\psi}\right)\left(\frac{\alpha}{1-\alpha}\right)\frac{1-\phi(t)}{\phi(t)} \tag{16}$$

The stock of pollution, denoted by $S(t)$, evolves according to two opposite forces. On the one hand, it increases in the net flow of pollution, the pollutant emissions to abatement services ratio $C(t)/D(t)$. On the other hand, it decreases due to a natural rate of decay $\zeta > 0$, such that:

$$\dot{S}(t) = f\left(\frac{C(t)}{D(t)}\right) - \zeta S(t), \qquad \text{with } f(\cdot) > 0,\ f'(\cdot) > 0,\ f''(\cdot) > 0 \tag{17}$$

3 The environmental taxation and the Balanced Growth Path

The final output is used either to consume, either to invest in physical capital. Therefore, the market clearing condition is:

$$Y(t) = C(t) + \dot{K}(t).$$

with $\dot{K}(t) = dK(t)/dt$. Differentiating (8) with respect to time and using the fact that $u(s,t) = u(t)$,[3] the aggregate accumulation of human capital is:

$$\dot{H}(t) = B\left[1-u(t)\right]H(t) \tag{18}$$

[3]Using (10), the equalization of the rates of returns given by equation (6) implies that the rate of returns to human capital is independent of s, therefore all individuals allocate the same effort to schooling: $u(s,t) = u(t)$.

and differentiating (7) with respect to time gives

$$\frac{\dot{C}(t)}{C(t)} = \frac{\dot{c}(s,t)}{c(s,t)} - \frac{1}{C(t)}\left[\beta C(t) - \beta c(t,t)\right] \tag{19}$$

Aggregate consumption growth differs from individual consumption growth by the term into brackets $-[\beta C(t) - \beta c(t,t)]$ which represents what Heijdra and Ligthart (2000) called the "*generational turnover effect*". This effect appears because at each date a cross-section of the existing population dies (reducing aggregate consumption growth by $\beta C(t)$) and a new generation is born (adding $\beta c(t,t)$). Because new agents born without financial assets, their consumption $c(t,t)$ is lower than the average consumption $C(t)$ and therefore the "*generational turnover effect*" reduces the growth rate of the aggregate consumption.

Using the expression of $dK(t)/dt$, $d\Omega(t)/dt$ and equation (4) we obtain:

$$\dot{C}(t)/C(t) = r(t) - \varrho - \beta\left(\frac{\varrho+\beta}{1+\tau}\right)K(t)/C(t) \tag{20}$$

The *generational effect* rises with the probability to die β: on one hand, agents die at a higher frequency (that increases the generational turnover) and on the other hand the propensity to consume out of wealth $\varrho+\beta$ increases due to the shorter horizon.

Along the balanced growth path, C, K, H, D, and Y evolve at a common positive rate of growth (denoted $g^\star$, where a $\star$ means "*along the BGP* ") and the allocation of human capital across sectors is constant. As a consequence, denoting $x(t) \equiv C(t)/K(t)$ and $b(t) \equiv H(t)/K(t)$, along the balanced growth path $\dot{x} = \dot{b} = \dot{u} = \dot{w}(t) = \dot{\phi}(t) = \dot{\mu}(t) = 0$, $x = x^\star$, $b = b^\star$, $u = u^\star$ and $g^\star > 0$.

As a result, $\dot{K}/K = \dot{H}/H$ gives

$$\phi^\star\left(\frac{\phi^\star}{\mu^\star}\right)^{\alpha-1}(b^\star u^\star)^{1-\alpha} - x^\star = B(1-u^\star) \tag{BGP 1}$$

In a similar way, $\dot{K}/K = \dot{H}/H$ gives

$$\alpha\left(\frac{\phi^\star}{\mu^\star}\right)^{\alpha-1}(b^\star u^\star)^{1-\alpha} - \varrho - \beta\left(\frac{\varrho+\beta}{1+\tau}\right)x^{\star-1} = \phi^\star\left(\frac{\phi^\star}{\mu^\star}\right)^{\alpha-1}(b^\star u^\star)^{1-\alpha} - x^\star \tag{BGP 2}$$

and finally the equalization of returns (see equation 6) gives

$$\alpha\left(\frac{\phi^\star}{\mu^\star}\right)^{\alpha-1}(b^\star u^\star)^{1-\alpha} = B - \beta \tag{BGP 3}$$

that defines the interest rate (the LHS member) along the BGP as exogenous. Finally, we have

$$\phi^\star = 1 - \psi\tau\frac{x^\star}{\alpha\left(\frac{\phi^\star}{\mu^\star}\right)^{\alpha-1}(b^\star u^\star)^{1-\alpha}} \tag{BGP 4}$$

Combining equations (BGP 1)-(BGP 4) enables us to write

Proposition 1. *There exists a unique allocation of human capital into the production sectors (output and abatement)* $u^\star \left]\frac{\varrho+\beta}{B},1\right[$ *solving* $\Gamma(u^\star;\tau)=0$ *where* $\Gamma(u;\tau)$ *is defined as follows*

$$\Gamma(u;\tau) \equiv \left(\frac{1+\tau}{\alpha+\psi\tau}\right)\left[\alpha B(u+\alpha^{-1}-1)-\beta\right]\left[Bu-\beta-\varrho\right]-\beta(\varrho+\beta)$$

When $\beta>0$ *(finite lifetime):*

if $\alpha<\psi$ *then* $\partial u^\star/\partial\tau>0$

if $\alpha=\psi$ *then* $\partial u^\star/\partial\tau=0$

if $\alpha>\psi$ *then* $\partial u^\star/\partial\tau<0$

When $\beta=0$ *(inifinite lifetime),* $\partial u^\star/\partial\tau=0,\forall\alpha,\psi$*.*

Proof. Combining (BGP 1), (BGP 2) and (BGP 3) gives an expression of $x^\star$ with respect to $u^\star$. Combining (BGP 1) and (BGP 3) gives a second expression of $x^\star$ with respect to $u^\star$. Equating the two expressions of $x^\star$ gives

$$\left(\frac{1+\tau}{\alpha+\psi\tau}\right)\left[\alpha B(u^\star+\alpha^{-1}-1)-\beta\right]\left[Bu^\star-\beta-\varrho\right]-\beta(\varrho+\beta)=0$$

The unicity of $u^\star\in\left]\frac{\varrho+\beta}{B},1\right[$ results from the fact that $\Gamma(\cdot)$ is a continuous increasing function of u with $\Gamma(\frac{\varrho+\beta}{B};\tau)<0$ and $\Gamma(1;\tau)>0$. Furthermore

$$\partial\Gamma(\cdot)/\partial\tau=\frac{\alpha-\psi}{(\alpha+\psi\tau)^2}\left[\alpha B(u+\alpha^{-1}-1)-\beta\right]\left[Bu-\beta-\varrho\right]\gtreqless 0 \qquad \text{if } \alpha\gtreqless\psi$$

Using the implicit function theorem $\partial u^\star/\partial\tau \lesseqgtr 0$ if $\alpha\gtreqless\psi$. When $\beta=0$, $\Gamma(u^\star;\tau)=0$ for $u^\star=\varrho/B$, independent from τ. ■

Furthermore

Corollary 1. *From Proposition 1 and equation* (18) *that gives* $g^\star=B(1-u^\star)$ *it comes:*

When $\beta>0$ *(finite lifetime):*

if $\alpha<\psi$ *then* $\partial g^\star/\partial\tau<0$

if $\alpha=\psi$ *then* $\partial g^\star/\partial\tau=0$

if $\alpha>\psi$ *then* $\partial g^\star/\partial\tau>0$

When $\beta=0$ *(inifinite lifetime),* $\partial g^\star/\partial\tau=0,\forall\alpha,\psi$*.*

Therefore when final consumption is the source of pollution and lifetime is finite, the influence of the environmental tax on the BGP growth rate depends on the technology in the abatement sector with respect to the technology in the output production sector (that is consumed by the agents).

Thus, when the human capital's share in the abatement sector is higher (*respectively lower*) than in the final output sector, that is $\alpha > \psi$ (*resp.* $\alpha < \psi$), a higher environmental tax reduces (*resp. increases*) $u^\star$ the allocation of human capital in production sectors and boostes (*resp. decreases*) the BGP rate of growth. When abatement services are produced with the final output ($\alpha = \psi$), the environmental taxation does not influence growth.

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