



NOTA DI LAVORO

05.2009

**Macroeconomic Implications
of Demography for the
Environment: A Life-Cycle
Perspective**

By **Xavier Pautrel**, Nantes Atlantique
Université

SUSTAINABLE DEVELOPMENT Series

Editor: Carlo Carraro

Macroeconomic Implications of Demography for the Environment: A Life-Cycle Perspective

By Xavier Pautrel, Nantes Atlantique Université

Summary

This article studies how demography affects the outcome of the environmental policy in a macro-economic perspective, incorporating age-earning profiles in an OLG model à la Blanchard (1985) to capture the age structure effect of the demographic shocks. It first demonstrates, conversely to previous works of the related literature that a decrease in the birth rate may lower the steady-state per capita stock of physical capital even if the aggregate labor supply is exogenous. It also demonstrates that the ageing of population influences the macro-economic impact of the environmental policy according to the cause of the ageing and the life-cycle earnings assumption. Thus, with decreasing age-earning profiles, a lower birth rate reduces the detrimental impact of the environmental policy on the steady-state per capita stock of physical capital for low values of this birth rate, while a reduction of the mortality rate reinforces the negative outcome of the environmental policy. When earnings profiles are independent of age, ageing always strengthens the negative impact of the environmental policy.

Keywords: Demography, Environment

JEL Classification: Q56

I thank Masha Maslianskaia-Pautrel for their helpful comments on a previous version. I also thank an anonymous member of the FEEM for English proofreading. The usual disclaimer applies.

Address for correspondence:

Xavier Pautrel
Nantes Atlantique Université
LEMNA, Laboratoire d'Économie et de Management de Nantes-Atlantique
Institut d'Économie et de Management de Nantes
- IAE, Chemin de la Censive du Tertre, BP 81307
44313 Nantes Cedex 3
France
E-mail: xavier.pautrel@univnantes.fr

1 INTRODUCTION

At the beginning of the XXIst century, most of the industrialized economies face an unprecedented double challenge: the rapid deterioration of the environment which calls for immediate and important environmental policies at a large scale, and a continuous ageing of the population which has major macro-economic implications in terms of saving, retirement, ... (see Bloom et al., 2003, for example)

The purpose of this paper is to merge demographics and environmental economics to examine how the current demographic changes (the decline of the birth rate and the mortality rate) affect the amplitude of the macro-economic impact of environmental policy.

To investigate this point, we use a Yaari (1965)-Blanchard (1985)-Buiter (1988)-Weil (1989) overlapping generations model in which we introduce environmental concerns. We also integrate life-cycle properties by adding age-earning profiles to capture the effect of the population age-structure on the per capita labor supply highlighted by Bloom et al. (2002), Bloom et al. (2004), Bloom et al. (2003) and Sevilla (2007) as a major component of the impact of demographics on the economy.¹

To the best of my knowledge, only a few articles deal with the question of ageing and the environment in a macro-economic perspective.² They mainly rely on the John and Pecchenino (1994) and John et al. (1995)'s two-period overlapping generations model where the environment is bequeathed to future generations and consumption (or output) is the source of pollution flow. Ono (2005) adds uncertain lifetime to this framework and studies how political decision-making on the environmental tax and the environmental quality are modified by ageing, assuming greater longevity and a lower rate of population growth as two alternative sources of ageing. He demonstrates

¹The argument relies on the concept of “demographic dividend”: an individual contributes to the economy (in terms of productivity, etc) in different ways, depending on whether he/she is young, adult or old. Consequently, when the birth rate rises, the number of young people increases and their contribution to the economy becomes positive when they become adult. On the contrary, when the mortality rate declines, the elderly are more numerous and the dependent population increases. Sevilla (2007), on cross-country macro data from developing countries for the period 1970 to 2000, find an empirical evidence of the “demographic dividend”: entry of the baby boom cohort into the adult stage is correlated with higher labor productivity, even after controlling for capital accumulation and past productivity.

²On the contrary, there are numerous theoretical and empirical works examining the impact of ageing on consumption and energy demand. For a recent contribution, see Fougère et al. (2007) and references herein for example.

that the environmental tax is not affected and that environmental quality is never improved by greater longevity whereas a lower rate of population growth has a negative effect on the tax and has a positive effect on the environmental quality. In a similar framework, Ono and Maeda (2001) assume that population ageing modifies the decisions on environmental preservation (the willingness to preserve the environment increases if people die later) and increases the detrimental effect produced by an individual's consumption. They also assume that the per capita environmental quality enters the utility function rather than aggregate environmental quality and they find that ageing harms the environment if the relative risk aversion of agents is greater than one. Ono and Maeda (2002) use a framework similar to John and Pecchenino (1994) with a look at unintended bequests and the annuity market. On the one hand ageing leads to a decrease in the unintended bequests that reduces the young agent's wealth. This implies a negative income effect on investment in capital and the environment. On the other hand, ageing leads to more investment in capital and in the environment due to longer life expectancy. The authors demonstrate that perfect annuity eliminates the negative income effect of aging through unintentional bequests and therefore ageing is positive for the environment. Conversely, under imperfect annuity there are two competing effects of ageing, and greater longevity leads to either higher or lower levels of capital and environmental quality. Finally, the authors demonstrate that a higher annuitisation rate leads to lower levels of capital and environmental quality.

The present article contrasts with the aforementioned works insofar as no assumption is made about the link between ageing and the environment. Furthermore, ageing and its impact on demand, both for goods and for energy is not considered. Finally, only the effects of the demography on the macro-economic outcome of the environmental policy are examined.

Our contribution is twofold. First, conversely to previous works (see Heijdra and Ligthart, 2000, 2006, for references about models with finite- and infinite-lived households), we demonstrate that a decrease in the birth rate may lower the steady-state per capita stock of physical capital even if the aggregate labor supply is exogenous. The reason is that per capita labor supply increases with the birth rate when age-earning profiles are taken into account. It may limit or offset the negative impact of the birth rate on the per worker stock of physical capital leading to a global effect in per capita terms which is positive with respect to the birth rate.

Second, we demonstrate that the ageing of population modifies the macro-economic impact of the environmental policy according to the cause of the ageing (a decrease in the birth rate, a drop in the mortality rate or a demographic shock lowering both the birth rate and the mortality rate that keeps constant the population growth rate) and the life-cycle earnings assumption. Thus, with decreasing age-earning profiles, a lower rate of birth alone or a demographic shock with constant population growth reduces the detrimental impact of the environmental policy on the steady-state per capita stock of physical capital for low (and realistic) values of the birth rate, while a decrease in the mortality rate (a rise of life expectancy) reinforces the negative outcome of the environmental policy. When earning profiles are independent of age, both a reduction of the birth rate and a rise of life expectancy strengthens the negative impact of the environmental policy.

This article is built as follows. Section 2 exposes the model. Section 3 investigates the steady-state equilibrium. Section 4 examines the impact of demography on the macro-economic equilibrium and on the environmental policy. Section 5 concludes.

2 A LIFE-CYCLE MODEL OF OVERLAPPING GENERATIONS

We use the Yaari (1965)-Blanchard (1985) model of overlapping generations in which we introduce environmental concerns, demographic change and life-cycle through age-earning profiles. Time is continuous. Each individual born at time s faces a constant probability of death per unit of time $p \geq 0$. Consequently his life expectancy is $1/p$. When p increases, the life span decreases. In the economy, there are insurance companies and there is no bequest motive.

2.1 DEMOGRAPHICS AND LIFE-CYCLE DIMENSION

We introduce demographic change following Buiter (1988). We distinguish between the (exogenous) probability of death $p \geq 0$ and the (exogenous) birth rate $b \geq 0$. The growth rate of the population, g_N , is the difference between the birth rate and the growth rate:

$$g_N \equiv \frac{\dot{N}(t)}{N(t)} = b - p$$

with $N(t)$ the size of the population at time t . Solving this equation subject to the initial condition $N(0) = 1$, we obtain $N(t) = e^{gNt} = e^{(b-p)t}$. The size of a newborn generation is proportional to the current population $N(s, s) = bN(s) = e^{(b-p)s}$ where $N(s, s)$ is the size at time s of a cohort born at s . Because the death rate is constant and cohorts are assumed to be large, the size of each existing generation falls exponentially and its size at time t is:

$$N(s, t) = e^{-p(t-s)} N(s, s) = be^{bs-pt}, \quad t \geq s$$

We introduce a life-cycle dimension in this model by assuming that productivity (and earning) is age-specific, in the same vein as Blanchard (1985). Nevertheless, following Faruqee (2002), we consider that the individual effective (exogenous) labor supply (measured in efficiency units) varies across agents with respect to their age, such that:³

$$h(s, t) = \phi e^{-\psi(t-s)}, \quad \psi \geq 0, \phi > 0 \quad (1)$$

for an agent born at $s \leq t$. Parameter ψ captures the age-specific productivity.

If we assume that each agent supplies an exogenous unit of labor, $h(s, t)$ also measures the individual effective (exogenous) labor supply (measured in efficiency units). In this case, the aggregate supply of labor (expressed in efficient units) is

$$L(t) = \int_{-\infty}^t h(s, t) be^{bs-pt} ds = \mathcal{L}N(t)$$

where

$$\mathcal{L} \equiv \frac{\phi b}{b + \psi} > 0$$

represents the (exogenous) per capita labor supply, and

$$\frac{\partial \mathcal{L}}{\partial b} = \frac{\phi \psi}{(b + \psi)^2} > 0 \quad (2)$$

When a decreasing age-earning profile is assumed ($\psi > 0$), an increase in fertility raises the per capita labor supply. This demographic impact on the exogenous per capita labor supply introduces an age-structure effect which may have major economic implications as reported by Bloom et al. (2002); Sevilla (2007). Note that for $\psi = 0$, productivity and earnings are independent of age, and in such a case, the exogenous per capita labor supply is independent of demography (see Figure 1).

★ *Insert Figure # 1* ★

³In his paper, Faruqee (2002) does not study all the implications of this modelling on the aggregate supply of labor and does not deal with environmental concerns.

2.2 INDIVIDUAL AND AGGREGATE HOUSEHOLD BEHAVIOURS

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

$$\int_s^\infty [\log c(s, t) - \eta \log \mathcal{P}(t)] e^{-(\varrho+p)(t-s)} dt \quad (3)$$

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 and η measures the weight in utility attached to the environment, that is environmental care.

Households face the following budget constraint:

$$\dot{a}(s, t) = [r(t) + p] a(s, t) + h(s, t)w(t) - c(s, t) \quad (4)$$

where $\dot{a}(s, t) \equiv da(s, t)/dt$, $a(s, t)$ are real financial assets in period t and $w(t)$ represents the wage rate per effective unit of labor. The representative agent chooses the time path for $c(s, t)$ by maximizing (3) subject to (4) with the transversality condition precluding private agent's Ponzi games

$$\lim_{v \rightarrow \infty} a(s, v) e^{-\int_t^v [r(\mu) + p] d\mu} = 0$$

It gives the intertemporal evolution of the individual consumption:

$$\frac{\dot{c}(s, t)}{c(s, t)} = r(t) - \varrho$$

The amount of consumption at time $t \geq s$ of an agent born at s is:

$$c(s, t) = (\varrho + p) [a(s, t) + \omega(s, t)] \quad (5)$$

where $\omega(s, t) \equiv \int_t^\infty h(s, \nu)w(\nu) e^{-\int_t^\nu ([r(\zeta) + p] d\zeta)} d\nu$ being the expected present value of lifetime earning.

Due to the simple demographic structure, all individual variables are additive across individuals. Consequently, recalling that $N(s, t) = be^{bs-pt}$, the aggregate consumption equals

$$C(t) = \int_{-\infty}^t c(s, t) be^{bs-pt} ds = (\varrho + p) [\mathcal{A}(t) + \Omega(t)] \quad (6)$$

where the aggregate human wealth $\Omega(t)$ is given by

$$\Omega(t) \equiv \int_{-\infty}^t \omega(s, t) be^{bs-pt} ds$$

and the aggregate financial wealth $\mathcal{A}(t)$ is defined by

$$\mathcal{A}(t) = \int_{-\infty}^t a(s, t) be^{bs-pt} ds$$

Differentiating (6) with respect to time gives the intertemporal evolution of the aggregate consumption:

$$\dot{C}(t) = [r(t) - \varrho + b - p + \psi] C(t) - (\psi + b)(\varrho + p)\mathcal{A}(t) \quad (7)$$

The parameter ψ affects aggregate consumption growth through two channels. First, when $\psi > 0$, the decreasing age profile encourages agents to save more when young to compensate the decreasing shape of their earnings during lifetime. The aggregate consumption growth rises. Second, the elderly have more human wealth than the younger population when they die and consequently, the growth rate of the aggregate consumption is reduced.

2.3 FIRMS AND POLLUTION

The productive sector is competitive. Firms produce the aggregate final good Y with the following technology:

$$Y(t) = K(t)^\alpha [A(t)L(t)]^{1-\alpha}, \quad 0 < \alpha < 1, \quad A(t) > 0$$

with $K(t)$ being the aggregate stock of physical capital and $A(t)$ is a technology index.

Following Hettich (1998), we assume that pollution flow increases with the level of output and decreases with private abatement activities $F(t)$ which use units of output one for one:

$$\mathcal{P}(t) = \left[\frac{Y(t)}{F(t)} \right]^\gamma, \quad \gamma > 0 \quad (8)$$

We assume that the government implements an environmental policy to encourage firms to reduce their net flow of pollution. To do so, the government taxes the net flow of pollution by firms and transfers to them the fruit of the taxes to fund their abatement activities. Consequently, firms under perfect competition pay a pollution tax on their net pollution $\mathcal{P}(t)$ and they choose their abatement activities $F(t)$ (whose cost equals $F(t)$) and the amount of factors which maximize their profits $\pi(t) = Y(t) - r(t)K(t) - w(t)L(t) - \vartheta(t)\mathcal{P}(t) - F(t) + T^p(t)$ where $\vartheta(t)$ is the pollution tax rate and $T^p(t)$ denotes transfers from the public sector with $T^p(t) = \vartheta(t)\mathcal{P}(t)$.

The manufacturing firms, operating under perfect competition, pay each production factor at its marginal productivity to maximize profit:

$$r(t) = \left[1 - \gamma\vartheta(t) \frac{\mathcal{P}(t)}{Y(t)} \right] \alpha K(t)^{\alpha-1} [A(t)L(t)]^{1-\alpha}$$

$$w(t) = \left[1 - \gamma \vartheta(t) \frac{\mathcal{P}(t)}{Y(t)} \right] (1 - \alpha) K(t)^\alpha A(t)^{1-\alpha} L(t)^{-\alpha}$$

$$F(t) = \vartheta(t) \gamma \mathcal{P}(t) \quad (9)$$

From equations (8) and (9), we obtain $\mathcal{P}(t) = \left[\gamma \frac{\vartheta(t)}{Y(t)} \right]^{-\gamma/(1+\gamma)}$. Because in the long-run the net flow of pollution must be constant to have a constant environmental quality, the environmental tax is assumed to evolve at the same rate of growth as the output. Intuitively, $\vartheta(t)$ increases over time to encourage firms to increase abatement activities to limit pollution which rises with the output. Consequently, we define $\tau \equiv \vartheta(t)/Y(t)$, the environmental tax normalized by the output and we obtain:

$$\mathcal{P} = \chi(\tau)^{-\gamma}$$

$$F(t) = \chi(\tau) Y(t)$$

with $\chi(\tau) \equiv (\gamma\tau)^{1/(1+\gamma)}$. Because τ is fixed by the government and therefore has no transitional dynamics, \mathcal{P} is independent of time.⁴

The interest rate in the economy becomes:

$$r(t) = \alpha (1 - \chi(\tau)) K(t)^{\alpha-1} [A(t)L(t)]^{1-\alpha}$$

and the wage rate is

$$w(t) = (1 - \alpha) (1 - \chi(\tau)) K(t)^\alpha A(t)^{1-\alpha} L(t)^{-\alpha}$$

2.4 MARKET EQUILIBRIUM

Factor markets clear instantly and financial market equilibrium implies that households' claims of capital equal the physical capital stock ($\mathcal{A}(t) = K(t)$) and the equilibrium on the goods market implies that:

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

with $F(t) = \chi(\tau) Y(t)$.

Therefore, using the previous sections, the behaviour of the economy may be summarized by the two following differential equations:

$$\dot{K}(t) = (1 - \chi(\tau)) K(t)^\alpha (A(t)L(t))^{1-\alpha} - C(t) \quad (10)$$

⁴Here, we do not examine the impact of the environmental policy on the net flow of pollution, but on the rest of the economy, consequently, it is not important that the net flow of pollution depends on and instantly adjusts to the tax level.

$$\begin{aligned} \dot{C}(t) = & \left[\alpha (1 - \chi(\tau)) K(t)^{\alpha-1} (A(t)L(t))^{1-\alpha} - \varrho + b - p + \psi \right] C(t) \\ & - (\psi + b)(\varrho + p)K(t) \end{aligned} \quad (11)$$

with

$$L(t) = \frac{\phi b}{b + \psi} N(t) \quad (12)$$

and

$$\dot{N}(t) = (b - p)N(t) \quad (13)$$

Equations (10) to (13) summarize the economy and enable us to solve the model in the steady-state equilibrium.

3 THE STEADY-STATE EQUILIBRIUM

In this section, we characterize the steady-state equilibrium when $A(t)$ remains constant all the time such that $A(t) = A^{1/(1-\alpha)}$. In such a case, all variables grow at the exogenous growth rate of the population $b - p$.

Because of age-earning profiles, the labor force differs from the population. To clarify the exposition we solve the steady-state equilibrium using per worker values (denoted by a “ $\tilde{\cdot}$ ”), recalling that the per capita value of a variable $X(t)$ is $x(t) = \frac{X(t)}{N(t)} = \mathcal{L}\tilde{x}(t)$. We denote $\tilde{k}(t) \equiv \frac{K(t)}{L(t)}$ and $\tilde{c}(t) \equiv \frac{C(t)}{L(t)}$, respectively the per worker stock of physical capital and the per worker aggregate consumption. The dynamical system becomes:

$$\dot{\tilde{k}}(t) = (1 - \chi(\tau)) A\tilde{k}(t)^\alpha - \tilde{c}(t) - (b - p)\tilde{k}(t) \quad (14)$$

$$\dot{\tilde{c}}(t) = \left[\alpha (1 - \chi(\tau)) A\tilde{k}(t)^{\alpha-1} - \varrho + \psi \right] \tilde{c}(t) - (\varrho + p)(b + \psi)\tilde{k}(t) \quad (15)$$

In the steady-state, $\tilde{k}(t)$ and $\tilde{c}(t)$ are constant, and such that:

$$\tilde{c}^* = A(1 - \chi(\tau))\tilde{k}^{*\alpha} - (b - p)\tilde{k}^*$$

From $\dot{\tilde{c}}(t) = 0$ in the steady-state and the previous expression, \tilde{k}^* is defined by:

$$\begin{aligned} \left[\alpha (1 - \chi(\tau)) A\tilde{k}^{*\alpha-1} - \varrho + \psi \right] \left[A(1 - \chi(\tau))\tilde{k}^{*\alpha-1} - (b - p) \right] \\ - (\varrho + p)(\psi + b) = 0 \end{aligned}$$

The solution of this equation is the per worker stock of capital at the steady-state:

$$\tilde{k}^* = [2\alpha(1 - \chi(\tau))A]^{\frac{1}{1-\alpha}} \mathcal{D}^{\frac{-1}{1-\alpha}} \quad (16)$$

where

$$\mathcal{D} \equiv -\psi + \alpha(b - p) + \varrho + \sqrt{(\psi - \alpha(b - p) - \varrho)^2 + 4(\psi + p)\alpha(b + \varrho)} > 0$$

depends on the demographic variables (b and p) and on the age-earning profiles ψ .

Therefore, the steady-state equilibrium is unique. When we linearize the system of the two differential equations (14) and (15), we obtain

$$\begin{bmatrix} \dot{\tilde{k}} \\ \dot{\tilde{c}} \end{bmatrix} = \begin{bmatrix} \alpha(1 - \chi(\tau))A\tilde{k}^{\alpha-1} - (b - p) & -1 \\ -[\alpha(1 - \chi(\tau))A\tilde{k}^{\alpha-1} - \varrho + \psi]\tilde{c}^*/\tilde{k}^* & \alpha(1 - \chi(\tau))A\tilde{k}^{\alpha-1} - \varrho + \psi \end{bmatrix} \times \begin{bmatrix} \tilde{k} - \tilde{k}^* \\ \tilde{c} - \tilde{c}^* \end{bmatrix}$$

with $\tilde{c}^*/\tilde{k}^* = (1 - \chi(\tau))A\tilde{k}^{\alpha-1} - (b - p)$. The determinant of the Jacobian matrix is:

$$\det = [\alpha(1 - \chi(\tau))A\tilde{k}^{\alpha-1} - \varrho + \psi] \left[\alpha(1 - \chi(\tau))A\tilde{k}^{\alpha-1} - (b - p) - \frac{\tilde{c}^*}{\tilde{k}^*} \right] < 0$$

because $\alpha < 1$. There exists one forward-looking variable (\tilde{c}) and a predetermined variable (\tilde{k}), consequently the system is saddle-path stable.

To further investigate the impact of demographics on the economy, we use numerical simulations.⁵ We first calibrate the model using data from the United States at the beginning of the XXI century. Thus, because life-expectancy at birth is around 77 years with a rate of population growth equal to 1%, we fix the probability of death p to $1/77 = 0.013$ and the birth rate b equals to $0.01 + 0.013 = 0.023$. The parameter ψ is fixed to 0.05 and ϕ to 1 in order to obtain an individual effective labor supply close to 0 at 80 years old. The other parameters are set to replicate the 2005 US per capita GDP around 45,700US\$. The benchmark value of parameters is reported in Table 1. The steady-state values of per capita and per worker variables are reported in Table 2.

A	α	γ	τ	ϱ	p	b	ψ	ϕ
3.54	0.3	0.3	0.02	0.05	0.013	0.023	0.05	1

Table 1: Benchmark value of parameters

⁵In this version of the paper, we restrict our attention to the steady-state equilibrium and we do not deal with the effects of demographic changes on the transitional dynamics towards this steady-state.

\tilde{k}^*	\tilde{c}^*	\tilde{y}^*	k^*	c^*	y^*
110.419	13.131	14.518	34.790	4.137	4.574

Table 2: Steady-state per worker and per capita values

4 DEMOGRAPHICS AND THE IMPACT OF THE ENVIRONMENTAL POLICY

Here, we are interested in per capita variables $k(t) \equiv K(t)/N(t)$ and $c(t) \equiv C(t)/N(t)$. Because all steady-state variables may be expressed in terms of per worker physical capital stock and because the per capita stock of physical capital is just the per worker capital stock multiplied by the per capita supply of labor, we can use the implicit expression of \tilde{k}^* found in the previous section (equation 16) to study the comparative statics.

The influence of the environmental policy on the per worker capital stock is thus given by (from equation 16):⁶

$$\tilde{k}_\tau^* = \frac{-\chi_\tau(\tau)}{(1-\alpha)(1-\chi(\tau))} \tilde{k}^* < 0$$

As expected the environmental policy has a negative effect on the economy because it reduces the amount of resources for investment. Furthermore, the higher the per worker capital stock (\tilde{k}^*), the higher the part of physical capital in production (α), the more detrimental the environmental policy.

An increase in the environmental tax τ also reduces the per capita stock of physical capital:

$$k_\tau^* = \mathcal{L}\tilde{k}_\tau^* = \frac{-\chi_\tau(\tau)}{(1-\alpha)(1-\chi(\tau))} k^* < 0$$

and therefore the output per capita in the steady-state $y^* = Ak^{*\alpha}$. Finally, the influence of τ on the per capita consumption at the steady-state is given by:

$$c_\tau^* = \frac{-\chi_\tau(\tau)}{(1-\alpha)(1-\chi(\tau))} c^* < 0$$

The environmental policy reduces the per capita consumption at the steady-state because it decreases the per worker non-human wealth \tilde{k}^* and the per capita human wealth (wages lower through the rise of $\chi(\tau)$ and the decrease in \tilde{k}^*).

How is the negative impact of the environmental policy modified by the demographic structure of the economy and by the deformation of (change

⁶We note $x_z = \partial x / \partial z$ and $x_{z,z} = \partial x_z / \partial z$.

in) the age-earning profiles? To answer this question, we investigate three cases which are typical of the demographic evolution of many countries: a decrease in the birth rate (what Heijdra and Ligthart (2006) called the *pure “baby-bust” case*), an increase in life expectancy (a decrease in the mortality rate) and a decrease in both the birth rate and the mortality rate that keeps the population’s growth rate constant. In each case, we look at the macro-economic effect of the demographics, and its influence on the detrimental effect of environmental policy. We also look at the role of the age-earning profiles in the outcome of the environmental policy.

4.1 THE PURE “BABY-BUST” CASE: A DECREASE IN THE FERTILITY RATE

The influence of the birth rate on the per worker stock of capital is given by

$$\tilde{k}_b^* = -(1 - \alpha)^{-1} \left(\frac{\tilde{k}^*}{\mathcal{D}} \right) \mathcal{D}_b < 0$$

with $\mathcal{D}_b = \alpha \left[\frac{\psi + 2p + \alpha(b - p) + \varrho}{\sqrt{(\psi - \alpha(b - p) - \varrho)^2 + 4(\psi + p)\alpha(b + \varrho)}} + 1 \right] > 0$. Consequently, a decrease in the birth rate increases the per worker stock of capital. Nevertheless, the effect on the per capita stock of capital (and therefore on the per capita output) is less clear because the per capita labor supply \mathcal{L} is positively influenced by the birth rate:

$$k_b^* = \underbrace{\frac{\partial \mathcal{L}}{\partial b}}_{+} \tilde{k}^* + \mathcal{L} \underbrace{\tilde{k}_b^*}_{-} = k^* \left\{ \frac{\psi}{b(b + \psi)} - (1 - \alpha)^{-1} \frac{\mathcal{D}_b}{\mathcal{D}} \right\} \geq 0$$

With no age-earning profiles ($\psi = 0$), the first term into brackets in the right-hand side of the equation vanishes and therefore the decrease in the fertility rate raises the per capita stock of capital as emphasized by Heijdra and Ligthart (2006) in the overlapping generations model à la Blanchard (1985) with exogenous labor supply.

★ *Insert Figure # 2* ★

With age-earning profiles ($\psi > 0$) an increase in the fertility rate raises the per capita supply of effective labor, as shown by equation (2). Indeed, a higher birth rate means a greater proportion of young people who supply more efficient units of labor, and that increase the per capital labor supply.

This reduces or offsets the negative impact of the birth rate on the per worker stock of capital and as a result the per capita stock of physical capital may increase with the birth rate. Using a numerical simulation, we show that the case $k_b^* > 0$ may exist for the realistic value of the parameters (see Figure 2 and Table 3).⁷ Note that we find that k_b^* is independent of the value of the mortality rate p . Plotting k^* with respect to b , according to the value of ψ enables to show that, for the chosen parameter values, the higher is ψ , the higher is the b for which k^* begins to decrease in b (see Figure 3).

b	0.01	0.023	0.03	0.035	0.1
k_b^*/k^*	952.381	10.210	2.97619	0	-6.191

The central column represents the benchmark case.

Table 3: k_b^* with respect to b (for $p = 0.013$).

★ *Insert Figure # 3* ★

PROPOSITION 1. *When age-earning profiles are taken into account, the birth rate may have an ambiguous effect on the per capita stock of physical capital, even if the labor supply is exogenous. For a realistic value of the parameters, a decrease in the birth rate lowers the steady-state per capita stock of physical capital.*

PROOF. See above. □

Proposition 1 contrasts with the previous results found in the overlapping-generations model without age-earning profiles. As recalled by Heijdra and Ligthart (2006), in such a model the impact of the birth rate on the steady-state per capita stock of physical capital is positive when labour supply is exogenous. And, as demonstrated by these authors, this impact may be ambiguous when labour supply is endogenous, but never for the realistic value of the parameters. Our contribution is to show that such an ambiguous effect may exist when labor supply is assumed exogenous, through the effect of the birth rate on per capita labor supply as documented by Bloom et al. (2004).

⁷For low values of b , the first term into brackets becomes higher than the second one, consequently, $k_b^* > 0$. It is straightforward that the first term tends towards positive infinity when b tends to 0 while the second term tends towards a non negative finite value. Consequently, there is a range of low values of b for which $k_b^* > 0$.

The influence of a pure “baby-burst” on the detrimental impact of the environmental policy is given by:

$$k_{\tau,b}^* = \frac{-\chi_{\tau}(\tau)k_b^*}{(1-\alpha)(1-\chi(\tau))} = \frac{-\chi_{\tau}(\tau)}{(1-\alpha)(1-\chi(\tau))} \left\{ \frac{\psi}{b(b+\psi)} - (1-\alpha)^{-1} \frac{\mathcal{D}_b}{\mathcal{D}} \right\} k^* \geq 0 \quad (17)$$

PROPOSITION 2. *Without age-earning profiles, baby-burst reinforces the detrimental impact of the environmental policy on the per capita stock. With decreasing age-earning profiles, the effect becomes ambiguous. A drop in the birth rate reduces the detrimental effect of the environmental policy for low values of this birth rate.*

PROOF. See below. □

With earning profiles independent of age ($\psi = 0$), we have $\partial\mathcal{L}/\partial b = 0$ (see equation 2) and $\partial k_{\tau}^*/\partial b > 0$: a fall in the birth rate contributes to reinforce the detrimental impact of the environmental policy on the per capita stock of capital (see Figure 4 for the case $\psi = 0$).

★ *Insert Figure # 4* ★

Age-earning profiles modify this result. First, decreasing age-earning profiles affect the environmental policy on the per capita stock of capital at the steady-state. Whatever the positive birth rate, the first term into brackets in the right-hand side of equation (17) is always positive, and therefore a decreasing age-earning profile reduces the negative impact of the environmental taxation on the per capita stock of physical capital with respect to the case where earning profiles are constant over age. Second, as demonstrated for the previous proposition, with decreasing age-earning profiles, for sufficiently low values of b , the difference into brackets is positive and therefore $k_{\tau,b}^* > 0$: a drop in the birth rate reduces the detrimental effect of the environmental policy when the birth rate is low. Our numerical simulations show that for realistic values of the birth rate and for the chosen value of parameters, we obtain such a result (see Table 3 and Figures 4 & 5).

★ *Insert Figure # 5* ★

4.2 THE INCREASE IN LIFE-EXPECTANCY

As emphasized in the introduction, the demographic evolution in many industrialized countries is characterized by a continuous increase in life expectancy. What is its impact on the detrimental effect of the environmental policy?

The influence of the mortality rate in the per worker stock of capital is given by (from equation 16)

$$\tilde{k}_p^* = -(1 - \alpha)^{-1} \left(\frac{\tilde{k}^*}{\mathcal{D}} \right) \mathcal{D}_p < 0$$

with $\mathcal{D}_p = \alpha \left[\frac{\psi + 2b - \alpha(b - p) + \varrho}{\sqrt{(\psi - \alpha(b - p) - \varrho)^2 + 4(\psi + p)\alpha(b + \varrho)}} - 1 \right] > 0$. The increase in the life expectancy (p drops) raises the per worker stock of capital in the steady-state, because agents increase their savings to face their longer life without labor earnings. Because per capita labor supply is independent of the mortality rate p , a rise in life expectancy also increases the per capita stock of capital.

Finally, the influence of the probability of death on the effect of the environmental policy is given by:

$$k_{\tau,p}^* = \frac{-\chi_\tau(\tau)}{(1 - \alpha)\chi(\tau)} \mathcal{L}\tilde{k}_p^* > 0 \quad (18)$$

PROPOSITION 3. *The increase in life expectancy contributes to strengthen the detrimental impact of an increase in the environmental taxation in the steady-state.*

PROOF. See equation (18). □

The mechanisms transit through the effect of the mortality rate on the per worker stock of physical capital.

4.3 DEMOGRAPHIC CHANGES WITH CONSTANT POPULATION GROWTH

In this section, we investigate the case where both the birth rate and the mortality rate decrease such that population growth remains constant (that is $db = dp < 0$ and thus $dg_N = 0$). The influence of this demographic change on the per worker stock of capital is given by (from equation 16)

$$\tilde{k}_{bp}^* = -(1 - \alpha)^{-1} \left(\frac{\tilde{k}^*}{\mathcal{D}} \right) \mathcal{D}_{bp} < 0$$

with $\mathcal{D}_{bp} = 2\alpha \frac{\psi + p + b + \varrho}{\sqrt{(\psi - \alpha(b - p) - \varrho)^2 + 4(\psi + p)\alpha(b + \varrho)}} > 0$.

The two negative effects shown in the two previous sections cumulate despite the constancy of the population growth, and the same decrease in the birth rate and in the mortality rate increases the per worker stock of physical capital in the steady-state. Nevertheless, because the drop of the birth rate reduces the per capita labor supply when age-earning profiles are taken into account, the effect on the per capita stock of physical capital is ambiguous:

$$k_{bp}^* = \underbrace{\frac{\partial \mathcal{L}}{\partial b}}_{+} \tilde{k}^* + \mathcal{L} \underbrace{\tilde{k}_{bp}^*}_{-} = k^* \left\{ \frac{\psi}{b(b + \psi)} - (1 - \alpha)^{-1} \frac{\mathcal{D}_{bp}}{\mathcal{D}} \right\} \geq 0$$

Tables 4 and 5 report results of numerical simulations Table 4 shows that the impact of the demographic shock with constant population growth (equal decrease in the birth rate and in the mortality rate) increases the per capita stock of physical capital for low (and realistic) values of the birth rate. Table 5 highlights that the value of the mortality rate does not influence the sign of the derivative.

b	0.01	0.023	0.03	0.04	0.1
k_{bp}^*/k^*	59.519	10.173	2.8872	-2.16	-6.801

The central column represents the benchmark case.

Table 4: k_{bp}^* with respect to b (for $p = 0.013$).

p	0.001	0.013	0.02	0.1	1
k_{bp}^*/k^*	9.991	10.173	10.2071	9.339	1.240

The central column represents the benchmark case.

Table 5: k_{bp}^* with respect to p (for $b = 0.023$).

PROPOSITION 4. *Demographic change that leads to simultaneously decreasing the birth rate and mortality rate so as to keep population growth constant (that is, $db = dp < 0$ and thus $dq_N = 0$), has an ambiguous effect on the steady-state per capita stock of physical capital when decreasing age-earning profiles are taken into account. It is positive for low and realistic values of the birth rate.*

PROOF. See above

□

For the same reasons of the “baby-burst” case, our result contrasts with the effect found by Heijdra and Ligthart (2006). And the influence of the demographic change with constant population growth has an ambiguous impact on the influence of the environmental policy:

$$k_{\tau, bp}^* = \left\{ \frac{\psi}{b(b + \psi)} - (1 - \alpha)^{-1} \frac{\mathcal{D}_{bp}}{\mathcal{D}} \right\} k^* \geq 0$$

From Tables 4 and 5, we can write the following proposition.

PROPOSITION 5. *Demographic change that leads to simultaneously decreasing the birth rate and mortality rate so as to keep population growth constant (that is, $db = dp < 0$ and thus $dg_N = 0$) reinforces the detrimental effect of the environmental policy without age-earning profiles. With decreasing age-earning profiles, the effect becomes ambiguous. For the chosen value of parameters, an equal decrease in the birth rate and the mortality rate reduces the detrimental impact of the environmental policy.*

PROOF. See above. □

5 CONCLUSION

The aim of this paper was to investigate the effects of demographic changes on the macro-economic impact of the environmental policy, in an overlapping generations model where decreasing age-earning profiles are taken into account. Built upon the Yaari (1965)-Blanchard (1985)-Buiter (1988)-Weil (1989) overlapping generations model, without any specific assumptions about the effect of demography on the environment, it also enables us to investigate the macro-economic impact of demographic changes in the vein of Heijdra and Ligthart (2006), emphasizing the role of the per capita labor supply documented by Bloom et al. (2004), Sevilla (2007) amongst others.

Our contribution is twofold. First, contrary to previous results of the related literature, we demonstrate that a decrease in the birth rate may reduce the steady-state per capita stock of physical capital while the labor supply is exogenous. This comes from the fact that the decreasing birth rate increases the per worker stock of physical capital but lowers the per capita labor supply, leading to an ambiguous effect on the per capita stock of physical capital. Numerical simulations show that, for a realistic value of the parameters, the positive influence of the birth rate on the per capita stock of physical capital is verified.

Second, we demonstrate that the ageing of population modifies the macro-economic impact of the environmental policy according to the cause of the ageing (a decrease in the birth rate, a decrease in the mortality rate or an equal lowering of both the birth rate and the mortality rate that keeps the population's growth rate constant) and the life-cycle earnings assumption. Thus, with decreasing age-earning profiles, a lower birth rate or a demographic change with constant population growth reduces the detrimental impact of the environmental policy for low (and realistic) values of this birth rate, while an increase in life expectancy reinforces the negative outcome of the environmental policy. When earnings profiles are independent of age, both a reduction of the birth rate and a rise of life expectancy strengthens the negative impact of the environmental policy.

These results call for further investigations on how ageing affects the environmental policy.

REFERENCES

- Blanchard, O. (1985). Debt, deficits and finite horizon. *Journal of Political Economy*, 93:223–247.
- Bloom, D., Canning, D., and Graham, B. (2003). Longevity and life cycle savings. *Scandinavian Journal of Economics*, 105:319–338.
- Bloom, D., Canning, D., and Jamison, D. (2004). Health, wealth and welfare. *Finance and Development*, pages 10–15.
- Bloom, D., Canning, D., and Sevilla, J. (2002). The demographic dividend: A new perspective on the economic consequences of population change. Technical report, RAND, Santa Monica, CA.
- Buiter, W. (1988). Death, birth, productivity growth and debt neutrality. *Economic Journal*, 98:279–293.
- Faruqee, H. (2002). Population aging and its macroeconomic implications: A framework for analysis. IMF Working Paper 02/16, I.M.F.
- Fougère, M., Mercenier, J., and Mérette, M. (2007). A sectoral and occupational analysis of population ageing in canada using a dynamic cge overlapping generations model. *Economic Modelling*, 24(4):690–711.

- Heijdra, B. and Ligthart, J. (2000). The dynamic macroeconomic effects of tax policy in an overlapping generations model. *Oxford Economic Papers*, 52:677–701.
- Heijdra, B. and Ligthart, J. (2006). The macroeconomic dynamics of demographic shocks. *Macroeconomic Dynamics*, 10:349–370.
- Hettich, F. (1998). Growth effects of a revenue-neutral environmental tax reform. *Journal of Economics*, 67(3):287–316.
- John, A. and Pecchenino, R. (1994). An overlapping generations model of growth and the environment. *The Economic Journal*, 104:1393–1410.
- John, A., Pecchenino, R., Schimmelpfening, D., and Schreft, S. (1995). Short-lived agents and the long-lived environment. *Journal of Public Economics*, 58:127–141.
- Ono, T. (2005). The political economy of environmental taxes with an aging population. *Environmental and Resource Economics*, 30:165–194.
- Ono, T. and Maeda, Y. (2001). Is aging harmful to the environment? *Environmental and Resource Economics*, 20:113–127.
- Ono, T. and Maeda, Y. (2002). Sustainable development in an aging economy. *Environment and Development Economics*, 7:9–22.
- Sevilla, J. (2007). Age structure and productivity growth. Arbetsrapport 10, Institute for Futures Studies.
- Weil, P. (1989). Overlapping families of infinite-lives agents. *Journal of Public Economics*, 38:183–198.
- Yaari, M. (1965). Uncertain lifetime, life insurance and the theory of consumer. *Review of Economic Studies*, 32:137–150.

APPENDIX

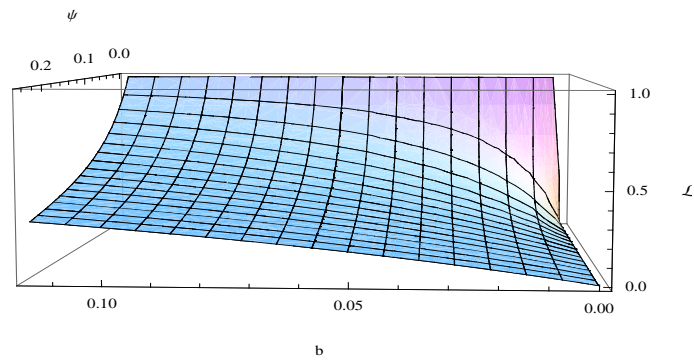
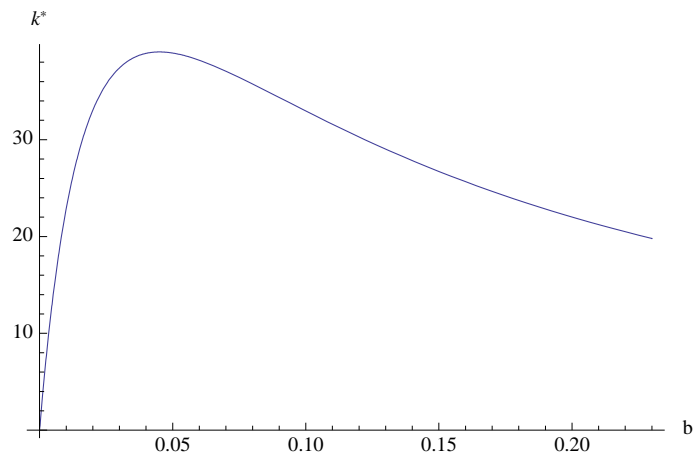
Figure 1: The per capita labor supply \mathcal{L} with respect to ψ and b Figure 2: Influence of the birth rate on k^* , with $\psi = 0.05$ 

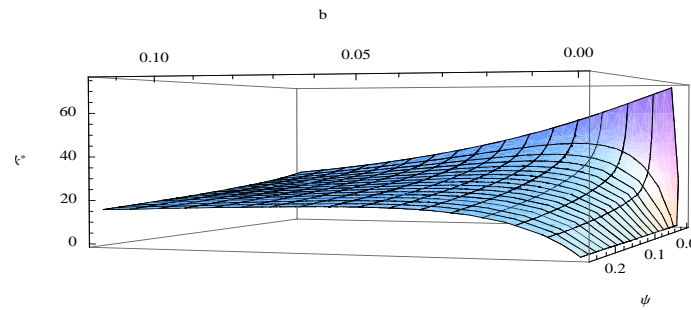
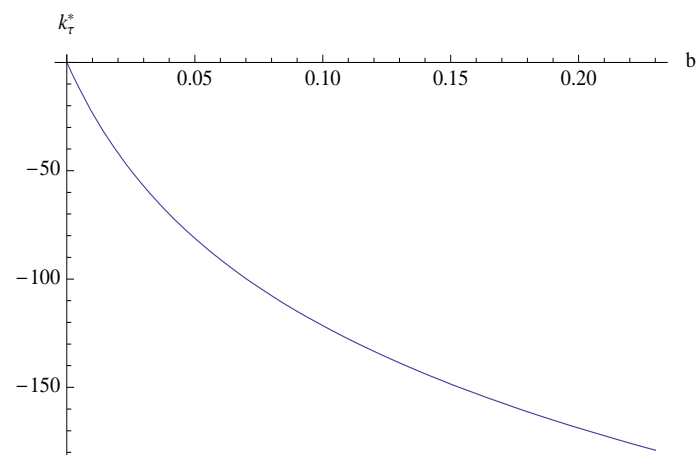
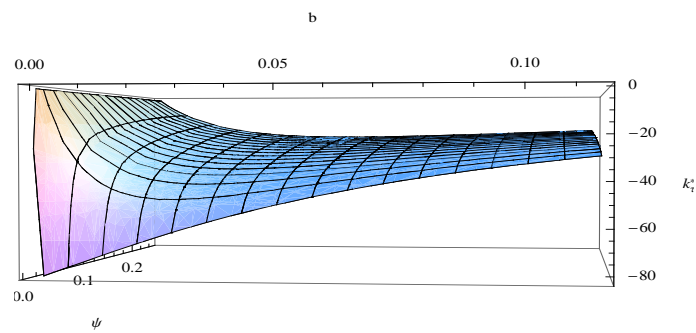
Figure 3: Influence of the birth rate on k^* with respect to ψ Figure 4: Influence of the birth rate on k_{τ}^* , with $\psi = 0.05$ 

Figure 5: Influence of the birth rate on k_t^* , with respect to ψ 

NOTE DI LAVORO DELLA FONDAZIONE ENI ENRICO MATTEI

Fondazione Eni Enrico Mattei Working Paper Series

Our Note di Lavoro are available on the Internet at the following addresses:

<http://www.feem.it/Feem/Pub/Publications/WPapers/default.htm>

<http://www.ssrn.com/link/feem.html>

<http://www.repec.org>

<http://agecon.lib.umn.edu>

<http://www.bepress.com/feem/>

NOTE DI LAVORO PUBLISHED IN 2009

- | | | |
|----|--------|---|
| SD | 1.2009 | Michael Hoel: <u>Bush Meets Hotelling: Effects of Improved Renewable Energy Technology on Greenhouse Gas Emissions</u> |
| SD | 2.2009 | Abay Mulatu, Reyer Gerlagh, Dan Rigby and Ada Wossink: <u>Environmental Regulation and Industry Location</u> |
| SD | 3.2009 | Anna Alberini, Stefania Tonin and Margherita Turvani: <u>Rates of Time Preferences for Saving Lives in the Hazardous Waste Site Context</u> |
| SD | 4.2009 | Elena Ojea, Paulo A.L.D. Nunes and Maria Loureiro: <u>Mapping of Forest Biodiversity Values: A Plural Perspective</u> |
| SD | 5.2009 | Xavier Pautrel : <u>Macroeconomic Implications of Demography for the Environment: A Life-Cycle Perspective</u> |