Population and the environment: the role of fertility, education and life expectancy

F. Mariani, A. Perez Barahona, N. Raffin

Discussion Paper 2019-8

Institut de Recherches Économiques et Sociales
de l'Université catholique de Louvain

Population and the environment: the role of fertility, education and life expectancy*

Fabio Mariani†, Agustin Perez Barahona‡, Natacha Raffin§

April 2019

Abstract

This paper explores the interplay between population and environmental quality. After reviewing the existing literature, we set up a theoretical framework suitable to analyze two major endogenous forces of demographic change – fertility and life expectancy – and their dynamic interaction with human capital and environmental conditions. We thus revisit and encompass in a unified model some key results of the literature, and gain new insight on the consequences of policy intervention on environmental dynamics and economic development. In particular, we highlight (i) the possible perverse effects of pollution control, (ii) a demographic explanation of the environmental Kuznets curve, (iii) the opportunity of relying on educational subsidies to alleviate the pressure on natural resources, and (iv) the existence of poverty traps related to human capital and environmental quality.

Keywords: Environmental quality; Life expectancy; Education; Fertility.

JEL classification: J11; O44; Q56.

1 Introduction

This paper is concerned with the interplay between population and environmental quality. In particular, we set up a theoretical framework suitable to jointly analyze two major endogenous forces of demographic change, namely fertility and life expectancy, and relate them to human capital and environmental conditions in a dynamic perspective. This complements

*Fabio Mariani acknowledges the financial support of the Belgian French-Speaking Community (ARC Project 15/19-063 on "Family Transformations").

†Fabio Mariani: IRES, Université Catholique de Louvain; IZA. E-mail: fabio.mariani@uclouvain.be

‡Agustin Perez Barahona: THEMA, University of Cergy-Pontoise and Ecole Polytechnique. E-mail: agustin.perez-barahona@u-cergy.fr

§Natacha Raffin: Normandie Univ, UNIROUEN, CREAM and EconomiX, University Paris Nanterre. E-mail: natacha.raffin@univ-rouen.fr

the existing literature on environmental matters, which has, in most cases, separately studied the implications of longevity and fertility – thus missing some interesting elements of analysis.

To do so, we build an extension of our previous work (Mariani et al., 2010), which allows us to reproduce and revisit some key results of the previous literature and gain new insight on the consequences of policy measures such as environmental taxes and educational subsidies on environmental dynamics and economic development. Among others, we highlight (i) the potential perverse effect of environmental regulation, (ii) the possibility of relying on educational subsidies as an effective policy tool to alleviate the pressure on natural resources, and (iii) the existence of poverty traps related to human capital and environmental quality.

A key starting point of our work is that environmental care betrays some concern for the future, be it one's own or that of forthcoming generations. Yet, the way people value future is crucially affected, among others, by their life expectancy: a higher longevity – or better health – makes people more sympathetic to future generations and/or their future selves, thus pushing them to invest more in environmental quality and in the quantity and/or quality of their offspring. These investment decisions drive the future dynamics of the economy, affecting its demographic and economic trajectory, and therefore the state of the environment. The causal link between life expectancy and socio-economic and demographic outcomes (environmental quality, human capital accumulation and population growth) may, however, also go the other way around, with the latter being a major factor affecting health and longevity. This intricate interplay, and the way it can be shaped by policy, lie at the center of our analysis.

The paper is organized as follows. After this Introduction, Section 2 reviews some of the most relevant research in the field. Section 3 presents and develops our model, whose dynamics and the related policy implications are analyzed in Section 4. Finally, Section 5 provide some concluding remarks.

2 Literature review

Many economists have pointed out the importance of studying population growth and, in particular, how societies form their fertility decisions, as main determinants of environmental quality and natural resources. For instance, Dasgupta (1993) suggests the possibility of important childbearing externalities on common property assets such as natural resources. Very much in the same spirit as our contribution, Dasgupta (1995) also highlights that population growth can be both a cause and a consequence of underdevelopment and environmental degradation, thus recommending not to regard population as an exogenously given feature of the economy. This calls for the need of an appropriate analytical framework to study the interaction between endogenous population growth, environmental conditions and economic growth, and identify appropriate policy interventions.

In this context, Harford (1998) provides a stylized, two-period model of endogenous fertility, where population growth deteriorates the environment. Aggregate consumption induces pollution which, in turn, reduces individual welfare. With endogenous fertility, the usual Pigouvian tax on pollutant activities is not enough to decentralize the social optimum, since individuals should not only pay a tax covering the pollution cost generated by their own consumption, but also compensate for the externality created by their children. Harford's model, however, has important limitations since it overlooks the issues of economic growth and sustainability, and does not consider the quantity-quality trade-off inherent to parental decisions.[1]

A more recent paper by Schou (2002) proposes an alternative analytical framework, based on an infinite-time model with the quantity-quality trade-off. Like Harford (1998), he shows that implementing the social optimum requires to tax fertility, in the presence of population externalities. By assuming that agents are perfectly altruistic, however, the model underestimates the effect of intergenerational externalities on environmental conditions related to fertility choices.

The hypothesis of perfect altruism is relaxed by de la Croix and Gosseries (2011), who propose an overlapping generations model showing how considering endogenous fertility is crucial to gauge the implications of pollution control. Their OLG framework allows for "warm glow" altruism and the quantity-quality trade-off , and consider Pigouvian taxes or tradable quotas in order to control pollution. The key finding of that paper is that pollution control induces a natalist bias, and therefore a pernicious effect on the environment, when fertility is endogenous. In fact, for a given technology, environmental taxes pushes agents to shift away from production to tax-free activities such as procreation, thus increasing the demographic pressure on the environment and gradually impoverishing successive generations.[2]

In a recent study, Gerlagh et al. (2018) consider an OLG model with dynastic altruism, whose problem is fairly similar to Schou (2002). They consider that pollution, modeled as a stock that accumulates over time, damages the productive potential of the economy – rather than hurting utility. They also assume a non-linear technology for human capital accumulation in the fashion of de la Croix and Doepke (2003), and deliver a message largely consistent with the previous literature: family planning should be part of environmental and climate policies.

While considering fertility as exogenous, another branch of the literature focuses specifically on the interaction between environmental conditions and life expectancy – motivated by the intriguing two-way causal relationship between those two variables.[3] Initially, this literature studied environmental care under uncertain lifetime without considering, however, that environmental conditions can in turn affect longevity (see for instance Ono and Maeda, 2001). On the opposite, Jouvet et al. (2010) explicitly consider the state of the environment as a decisive factor influencing mortality, but ignore the role of life expectancy in determining the environmental choices made by economic agents, namely their investment

[1]Becker (1960) first introduced the idea that parents may substitute quality for quantity, choosing to have less but better educated children. See also Becker et al. (1973), de la Croix and Doepke (2003) and Doepke (2004), among others.

[2]One possible solution to this problem could consists in capping population.

[3]In particular, several studies in medicine and epidemiology have documented how environmental quality is a significant factor affecting health and, in particular, longevity. See for instance Pope (2000), Pope et al. (2004), and Evans and Smith (2005).

in environmental maintenance.

Building on this earlier literature, we have been the first (Mariani et al., 2010) to consider both directions of the aforementioned two-way causal relationship, and explore the implications of the interplay between life expectancy and environmental quality. In our paper, we integrated the well-established effect of environmental conditions on life expectancy with the idea that a higher longevity makes people more sympathetic to future generations and/or their future selves, thus making longer-lived agents more inclined to invest more in environmental quality. A major contribution of our analysis is that it can explain the existence of multiple equilibria: some countries might be caught in a low-life-expectancy/low-environmental-quality trap while the others reach a long-run equilibrium characterized by better living conditions and longer life expectancy.[4] This outcome is consistent with stylized facts relating life expectancy and environmental performance measures. In particular, using data on life expectancy and the EPI indicator, we have been able to show that environmental quality and life expectancy are bimodally distributed among countries.[5] In Mariani et al. (2010), we further show that our findings are robust to the introduction of growth dynamics based on physical or human capital accumulation, but do not explore the implications of endogenous fertility.

In a similar vein, Constant (2018) develops an OLG model where human capital is the source of endogenous growth and inequality among individuals, and emphasizes the role of heterogeneous effects of pollution on agents' longevity in determining multiple balanced growth paths. In this framework, she defines a new "kind" of environmental poverty trap also characterized by increasing inequality, and shows that taxing pollution can help the economy escape the environmental trap. Like Mariani et al. (2010), however, Constant (2018) abstracts from endogenous fertility decisions.

Introducing endogenous fertility choices in Mariani et al. (2010) constitutes the starting point of the present paper. This allows us to bridge the gap between the two above mentioned branches of literature: that concerned with the interplay between life expectancy and the environment (to which our previous paper belongs) and the one dealing more specifically with the effect of population growth on the environment. In fact, with the possible exception of Jouvet et al. (2011), the existing literature has proposed a separate treatment of the impact of fertility and life expectancy on the environment.[6] We believe that our original framework, by dealing with human capital driven growth (and thus the quality-quantity trade-off), can

[4]In the "environmental" literature pioneered by John and Pecchenino (1994), environmental quality and longevity have typically been identified as important elements to explain underdevelopment traps (see also Ikefuji and Horii, 2007). The role of life expectancy, however, has typically been overlooked – different to some papers such as Blackburn and Cipriani (2002) or Chakraborty (2004) that, although not focused on environmental problems, have put the spotlight on longevity as a possible source of multiple equilibria

[5]The bimodal distribution of life expectancy and the EPI has been further confirmed by Dao and Edenhofer (2018), who use updated data and identify more than two convergence clubs.

[6]In their paper, Jouvet et al. (2011) consider a possible trade-off between longevity and fertility and focus on population density as a threat to environmental quality. They do not consider, however, the possibility that agents directly affect the stock of the available resources through their choices, and abstract from the quality-quantity trade-off when studying fertility decisions.

be fruitfully extended in order to analyze the complex fertility-longevity-environment nexus.

3 The model

We set up a simple model in which agents allocate their income between consumption, environmental maintenance and children's education.

3.1 Demography, preferences and technology

We consider an infinite-horizon economy populated by overlapping generations of agents living for three periods: childhood, adulthood, and old age. Time is discrete and indexed by t. All decisions are taken in the adult period of life. Individuals live safely through the first two periods, while survival to the third period is subject to uncertainty. We also deal away with heterogeneity by assuming that agents are identical within each generation.

Adult agents maximize the following utility function

$$U_t = \ln c_t + \pi_t(\alpha \ln n_t h_{t+1} + \gamma \ln m_t), \tag{1}$$

where c_t denotes own consumption, m_t is the expenditure in environmental maintenance, while n_t and h_{t+1} refer to the quantity and quality (human capital) of children, respectively. In particular, n_t denotes the number of children per parent. The survival probability is $\pi_t \in (0, 1)$, whereas $\alpha > 0$ and $\gamma > 0$ represent the weight that agents give to children and environmental quality. The overall importance of those two arguments of utility is mediated by the survival probability as we assume that, contrary to current consumption, children and environmental quality are enjoyed in the third period of the agents' life. Note also that – for the sake of simplicity – environmental quality is introduced in a joy-of-giving fashion: agents derive utility directly from the actions they take in order to improve the environment, rather than from future environmental quality itself.[7] In this sense, γ may be interpreted as a measure of some kind of environmental sensitivity.

The individual budget constraint is given by

$$(1 - \tau)(1 - \phi n_t)w_t h_t = c_t + m_t + (1 - \sigma)n_t e_t. \tag{2}$$

On the left-hand side of the above equation, we have the agents' disposable income. In particular, the unit wage w_t multiplied by human capital h_t and working time $(1 - \phi n_t)$ (where $\phi \in (0, 1)$ is the time cost of raising each child) gives the gross income, while $\tau \in (0, 1)$ is the tax rate on production that, as will become clearer below, can account for some kind of environmental regulation. On the right-hand side, we have total expenditure, where e_t is per-child educational expenditure, and $\sigma \in (0, 1)$ stands for an educational subsidy.

[7] This is reminiscent of "warm glow" specification of altruism due to Andreoni (1989).

Our agents face technological constraints. Following de la Croix and Doepke (2003), human capital accumulates according to

$$h_{t+1} = \delta(\theta + e_t)^{\beta} h_t^{1-\beta}, \tag{3}$$

where $\delta > 0$ is a productivity parameter, $\theta > 0$ prevents human capital from falling to zero in the absence of educational investment, whereas $\beta \in (0, 1)$ regulates the importance of nature (parental human capital h_t) *vs* nurture (education e_t) in human capital formation.

Output is produced using human capital (of adult individuals) only, such that it is given by

$$Y_t = (1 - \tau)(1 - \phi n_t) w h_t P_t, \tag{4}$$

where P_t is the size of the active (i.e. adult) population at time t, and w is a productivity parameter that, for simplicity, we assume to stay constant over time. In this stylized framework, the tax rate τ can be interpreted as an environmental policy instrument: by imposing cleaner production standards, the government reduces the size of output that can be obtained for a given value of inputs, and thus the available income of workers employed in production.[8] Because of the structure of the production function, which is linear in labor, the profit-maximizing wage rate is

$$w_t = w. \tag{5}$$

As far as environmental quality X is concerned, it evolves over time according to the following dynamic equation:

$$X_t = (1 - \eta)X_{t-1} + (\mu m_t - \xi c_t - \kappa(1 - \tau)(1 - \phi n_t) w h_t) P_t. \tag{6}$$

In this formulation we can see that environmental quality may be improved through maintenance, while it is harmed by two potential sources of pollution: consumption and production. The impact of these three variables depends on population size P_t, and is further mediated by the parameters $\mu, \xi, \kappa > 0$. As far as production is concerned, its environmental impact is attenuated by τ. We also assume that $\eta \in (0, 1)$, such that environmental quality can be regarded as a stock (see among others, Mariani et al., 2010; Palivos and Varvarigos, 2017; and Gerlagh et al., 2018).[9]

Note also that we make the simplifying assumption that people do not consume as old and as children. Introducing this possibility in the model would bring about further analytic complications, without significantly altering the qualitative results of our analysis.

Finally, adult population varies over time according to

$$P_{t+1} = n_t P_t. \tag{7}$$

[8] This way of modeling environmental regulation does not require us to write down the government budget constraint.

[9] The case of $\eta = 1$, which is more appropriate to study pollution as a flow, rather than environmental quality as such, will be explored in further research.

Throughout the paper we will often use the term "population" to refer to adult population, since adults are the only economic agents who take relevant economic decisions. At any date t, however, the true size of population (which sums over the three overlapping generations) is equal to $P_t(1 + n_t + \pi_t/n_{t-1})$.

3.2 Optimal choices

Taking π_t as given, agents choose c_t, e_t, n_t and m_t so as to maximize their utility function (1) subject to Equations (2) and (3). From the first order conditions for e_t, n_t and m_t, we obtain:

$$e_t = \begin{cases} 0 & \text{if } h_t \leq \dfrac{(1-\sigma)\theta}{\beta\phi(1-\tau)w} \\[2ex] \dfrac{\beta\phi(1-\tau)wh_t - \theta(1-\sigma)}{(1-\beta)(1-\sigma)} & \text{if } h_t > \dfrac{(1-\sigma)\theta}{\beta\phi(1-\tau)w} \end{cases}, \tag{8}$$

$$n_t = \begin{cases} \dfrac{\alpha\pi_t}{\phi(1+(\alpha+\gamma)\pi_t)} & \text{if } h_t \leq \dfrac{(1-\sigma)\theta}{\beta\phi(1-\tau)w} \\[2ex] \dfrac{\alpha(1-\beta)(1-\tau)\pi_t wh_t}{(1+(\alpha+\gamma)\pi_t)(\phi(1-\tau)wh_t - \theta(1-\sigma))} & \text{if } h_t > \dfrac{(1-\sigma)\theta}{\beta\phi(1-\tau)w} \end{cases}, \tag{9}$$

$$m_t = \frac{\gamma(1-\tau)\pi_t wh_t}{1+(\alpha+\gamma)\pi_t}. \tag{10}$$

Residually, we can also obtain the value of consumption by replacing the above optimal choices into the budget constraint.[10]

From Equations (8) and (9), we can see that fertility is at its maximum as long as human capital is low enough, and parents choose not to educate their children ($e_t = 0$). If we restrict our attention to interior solutions ($e_t > 0$), we can look at some of the main determinants of the optimal choices.

Concerning the role of human capital, we have that $\partial e_t/\partial h_t > 0$ and $\partial n_t/\partial h_t < 0$, while $\partial m_t/\partial h_t > 0$. More educated parents, because of the higher opportunity cost of children, have lower fertility but invest more in the education of their offspring. Being richer, they also devote more resources to environmental maintenance – which has only a monetary cost and does not detract from their time endowment.

A higher probability to survive to the third period, by boosting their preference for the future, pushes parents to make more children ($\partial n_t/\partial \pi_t > 0$) and take better care of the environment ($\partial m_t/\partial \pi_t > 0$), while – different from Mariani et al. (2010) – it does not affect their investment in education ($\partial e_t/\partial \pi_t = 0$), because parents are also concerned about the

[10] More details on the derivation of optimal choices are provided in Appendix A.

quantity (and not only the quality) of their offspring.[11]

As far as policy parameters are concerned, we see that τ – which can be regarded as an environmental tax, as it hinges on polluting production – has some interesting effects on optimal choices. By making workers poorer, it discourages investment in education ($\partial e_t/\partial\tau < 0$), which may benefit the environment by reducing future production. However, it also hampers investment in maintenance ($\partial m_t/\partial\tau < 0$) and stimulates fertility ($\partial n_t/\partial\tau > 0$) by redirecting resources from the production of output to the production of children. By consequence, taxing pollution activities may have perverse effects on population growth, which may harm the environment in a dynamic perspective. This result echoes de la Croix and Gosseries (2011), who show how policies intended to control pollution through taxes make people more inclined to engage in tax-free activities such as procreation: this natalist bias may end up deteriorating the environment, through an increased demographic pressure of natural resources.

Finally, educational subsidies do not affect optimal maintenance but favor quality vs quantity of children ($\partial e_t/\partial\sigma > 0$, $\partial n_t/\partial\tau < 0$). This has potentially ambiguous effect on the environment, since a higher σ increases production (and thus pollution) per capita, but slows down population growth.

4 Dynamics

We now turn to the analysis of the dynamic behavior of our economy.

Once we substitute optimal choices – as given by expressions (9), (8) and (10) – into Equations (3), (6) and (7), we obtain a dynamic system of three equations, which governs the evolution of our economy over time.[12]

In order to simplify our analysis, we restrict our parameters to those values that allows to (i) rule out multiple equilibria, when the survival probability is constant, and (ii) focus on a balanced growth path with strictly increasing human capital. The implied parametric condition requires productivity to be high enough.

Assumption 1

$$w > \frac{1-\sigma}{\delta^{1/\beta}\beta\phi(1-\tau)}. \tag{11}$$

Under this condition, the long-run growth rate of human capital is given by

$$g_h^\star = \delta\left(\frac{\beta\phi(1-\tau)w}{(1-\beta)(1-\sigma)}\right)^\beta - 1. \tag{12}$$

[11] In de la Croix and Doepke (2003), who also have both quantity and quality of children in the parents' utility function, the discount rate affects fertility but not education. Here, we have the same result for the survival probability, which contributes to define the rate of preference for the future.

[12] Notice that Equation (3) can be solved independently of (6) and (7), if life expectancy is exogenous. By consequence, dynamics are one-dimensional. When, instead, life expectancy is endogenously determined by the stock of human capital and/or environmental conditions (see Section 4.2), the analysis of the dynamic system is much more complicate, since the three equations become interdependent.

It can be immediately seen that the parameters σ, β, w and ϕ all have a positive effect on the growth rate of the economy. [13] In particular, a higher time-cost of children, by pushing parents to prioritize quality over quantity, foster human capital accumulation and growth. On the other hand, τ hampers production and thus slows down growth in the long run.

We also assume, for the moment, that $\pi_t = \pi$ (the case of endogenous life expectancy will be explored in Section 4.2). Along the balanced growth path population grows at a rate given by

$$\lim_{h\to\infty} n_t = \frac{\alpha(1-\beta)\pi}{\phi(1+(\alpha+\gamma)\pi)}. \tag{13}$$

Note that, while α and π have a positive effect on population growth, parameters such as ϕ, β and γ – by making parents less interested in reproduction (and more inclined to invest in children's education and environmental maintenance, respectively) tend to reduce demographic growth.

Since we cannot fully characterize analytically the dynamical system, in what follows we resort to numerical simulations in order to describe the dynamics of the model. Although largely arbitrary, the parametrization upon which our numerical examples are based is intended to have plausible implications. In particular, we will rely on a common set of parameter values and play with (i) policy parameters (τ and σ) and (ii) initial conditions on environmental quality and human capital, so as to discuss some interesting implications of our analysis.

In our benchmark parametrization we set $w = 30$, $\delta = 6/5$, $\beta = 1/5$, $\phi = 1/5$, $\eta = 1/5$, $\mu = 1/100$, $\gamma = 1/4$, $\xi = 0$, $\alpha = 1/2$, $\pi_t = p = 4/5$, $\theta = 1$, $\kappa = 1/1000$.[14] We have chosen a subset of our parameters with the objective of stabilizing population in the long run, i.e. $\lim_{h\to\infty} n_t = 1$. For what concerns initial conditions, we have chosen to start with $h_0 = 1/2$, $P_0 = 1000$ and $X_0 = 800$.

4.1 Policy intervention

We start by considering the possible dynamic effects of the two policy parameters of our model, τ and σ.

4.1.1 Environmental regulation

We first focus on the role of environmental regulation. From Section 3.2, we already know that a higher τ decreases the opportunity cost of having children, thus encouraging fertility. In order to assess the dynamic implication of pollution controls, we compare the simulated time paths of h_t, P_t and X_t under two alternative scenarios: in the first one (that we take as

[13] The derivation of Equation (12) is presented in Appendix B, where it becomes clear why some parameters (such as θ) do not influence growth in the long run.

[14] By setting $\xi = 0$, we deal away with consumption-generated pollution. This is not of primary importance, as we want to focus on the effect of environmental taxes hitting production. Introducing consumption taxes, and making environmental quality depend on consumption has only quantitative implications.

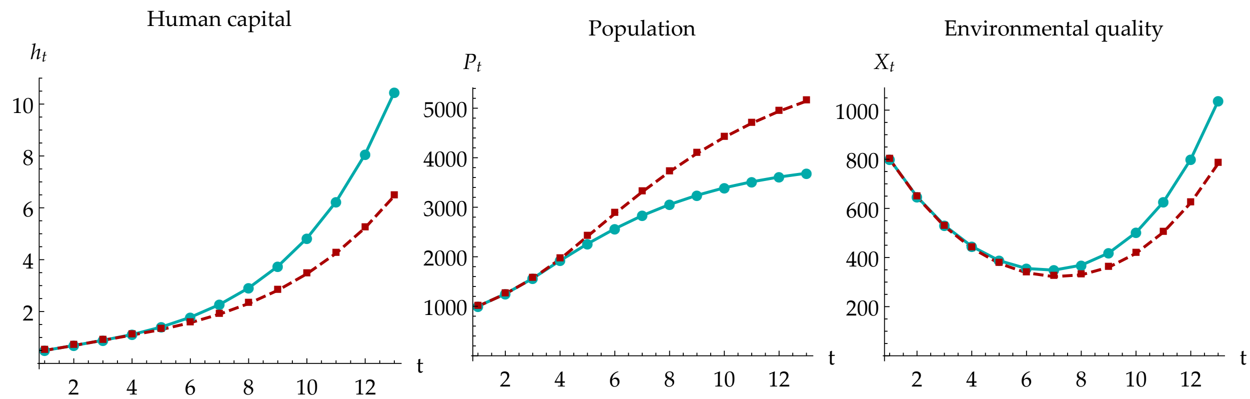

Figure 1: Pollution control: simulated time paths for $\tau = 0$ (solid) and $\tau = 1/5$ (dashed)

a benchmark) we set $\tau = 0$ and $\sigma = 0$, while in the second one we introduce environmental taxation, by setting $\tau = 1/5$.

Let us start by focusing on the benchmark simulation, as described by the solid lines in Figure 1. We can observe that, as our parametrization satisfies Assumption 1, human capital converges to a positive growth rate in the long run. Moreover, population growth vanishes to zero on the BGP. Finally, as far as environmental quality is concerned, we have selected a parameter configuration compatible with a kind of environmental Kuznets curve.[15] Our notion of environmental quality, as summarized by Equation 6 (with $\eta \in (0, 1)$), implies that the state of the environment tends to deteriorate, in the absence of maintenance activities. This is what happens in the first few periods. As the economy grows sufficiently rich, however, demographic pressure weakens and agents devote an increasing quantity of resources to environmental care. Under the chosen parametrization, this translates into an improving quality of the environment.

If we introduce pollution controls (under the form of production taxes), we see that it hampers human capital accumulation and increases, in each period, population size. As far as the aggregate impact of τ on the environment is concerned, it depends on three distinct effects. On the one hand, by hindering human capital formation, τ decreases economic activity, which is in itself a potential source of pollution. It also directly reduces production and its impact on the environment, as implied by Equations 6 and 4. On the other hand, however, a higher τ makes parent more inclined to invest in the quantity (rather than quality) of their offspring, thus increasing the demographic pressure on the environment. In our

[15]As a sample of the literature concerned with the EKC, see for instance Dinda (2004) or Kijima et al. (2010). The specificity of our analysis consists in relating the non-monotonic evolution of the environment to demographic dynamics.

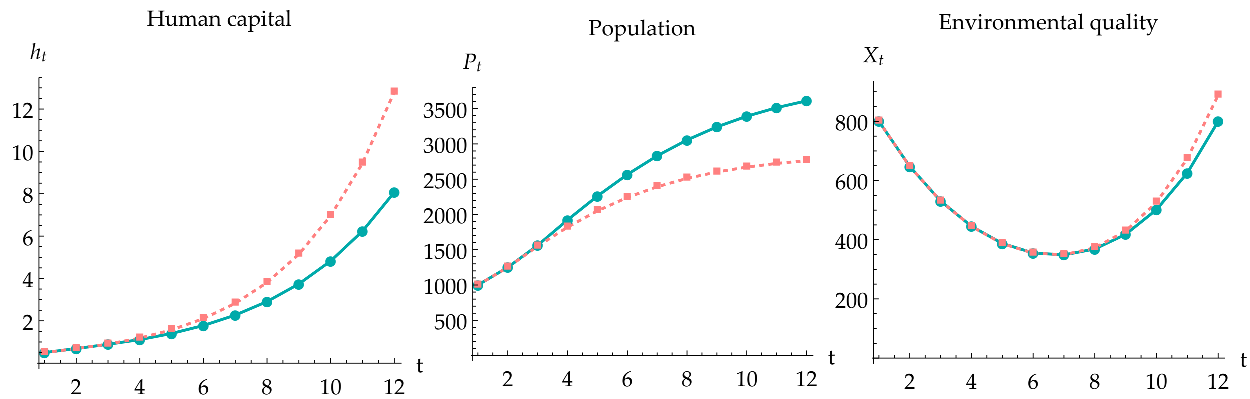

Figure 2: Educational subsidies: simulated time paths for $\sigma = 0$ (solid) and $\sigma = 1/5$ (dashed)

numerical example, this negative effect prevails - as can be seen from the third panel of Figure 1. This illustrates the possible dynamic consequences of the perverse effect of environmental policy, which have been also highlighted – although in a different framework – by de la Croix and Gosseries (2011).

4.1.2 Educational subsidies

We now turn to the analysis of the dynamic consequences of subsidies. Figure 2 contrasts the benchmark ($\tau = 0$, $\sigma = 0$) with the case in which $\sigma = 1/5$ (and $\tau = 0$). The results are not surprising, in light of Section 3.2: subsidizing education bends the quality-quantity trade-off towards education, so that growth is faster along the balanced growth path, and population stabilizes at a smaller size. Overall, the chosen parametrization shows a beneficial effect of subsidies on environmental quality, which tends to amplify when the economy gets richer.[16]

These findings seem to suggest that educational subsidies may be used as an effective environmental policy. In particular, if the objective of the policy-maker is to reduce demographic pressure on natural resources, subsidizing education may be a viable alternative to controversial policies like taxing birth, even in the presence of a polluting effect of human capital-driven growth.[17] Such normative implication highlights the importance of considering endogenous fertility: in the presence of a quality-quantity tradeoff, subsidizing human

[16]Figure 2 suggests, however that such beneficial effect is of limited size (and smaller, in modulus, than the impact of τ depicted in Figure 1. In fact, the increased output due to faster human capital accumulation almost offsets the alleviation of demographic pressure.

[17]As pointed out before, several papers suggest that family planning should be part of climate policies (for instance, Harford, 1998; Shou, 2002; or Gerlagh et al., 2018).

capital accumulation would still bring about more environmental degradation through faster growth, but at the same time alleviates the demographic pressure on the environment through reduced fertility (with the latter effect prevailing, in our example).

4.2 Endogenous life expectancy: poverty traps

In our past research (Mariani et al., 2010), we highlighted the possibility of environmental poverty traps related to endogenous life expectancy. In particular, we showed that if life expectancy (and, more in general, health) depends on environmental quality and/or human capital, multiple equilibria may arise and economies characterized by different initial conditions may converge either to a good equilibrium (characterized by high life expectancy, high human capital and good environmental quality) or to a worse one (with short life expectancy, modest levels of development and a very deteriorated environment).

In what follows we see how things change if, different to our previous study, we introduce endogenous fertility. In the same fashion as Mariani et al. (2010), we now make the survival probability depend on human capital and the state of the environment. In particular,

$$\pi_t = \begin{cases} \underline{\pi} & \text{if } X_t + \chi h_t < J \\ \overline{\pi} & \text{if } X_t + \chi h_t \geq J \end{cases}, \tag{14}$$

where $\chi, J > 0$. The survival probability is introduced as a binary variable for analytical simplicity, and in order to ensure comparability with Mariani et al. (2010).[18] Equation (14) also allows for some substitutability (accounted for by χ) between human capital and environmental quality as determinants of longevity. There is in fact ample empirical evidence that a healthy environment is key to having a long life expectancy (among others, Pope, 2000; Pope et al., 2004; and Evans and Smith, 2005). As far as the role of human capital is concerned, its theoretical importance has been highlighted by Blackburn and Cipriani (2002) and de la Croix and Licandro (2013, 2015) among others, while its empirical relevance has been assessed by several studies, such as Lleras-Muney (2005).[19]

In our numerical simulation, the new parameters introduced in Equation (14) are set to the following values: $\underline{\pi} = 1/2$, $\overline{\pi} = 4/5$ and $J = 600$. The value of χ, as well as initial conditions, will be chosen so as to illustrate different types of poverty traps.

[18] Moreover, this kind of step function captures the idea that a substantial improvement in life expectancy can be achieved only if environmental quality reaches some minimal level. A step function is, in a sense, an extreme case of a convex–concave relationship, which is a rather appropriate description of the cumulative effects of environmental degradation on human health.

[19] Apart from income-related effects, human capital might translate into higher life expectancy because better educated people have access to more accurate information about health and are less inclined to take up health-threatening behaviors.

4.2.1 Environmentally induced poverty traps

We start by considering environmentally induced poverty traps. To do so, we deal away with human capital as a determinant of longevity by setting $\chi = 0$. Since life expectancy depends on environmental quality only, two economies that differ only with respect to the initial state of their environment may be driven to different equilibria. This non-ergodic behavior is related to π_t being a key determinant of the optimal choices (namely fertility and maintenance) that govern the time evolution of the economic system.

Figure 3 describes two otherwise identical economies, which start from different levels of environmental quality ($X_0 = 550$ and $X_0 = 1300$, respectively) that place them on the two sides of the threshold J, so that the two economies are initially characterized by different survival probabilities. We can see that, as π_t does not affect parental investment in education, the trajectory of h_t is the same for both economies. The two economies, however, display a divergent behavior in terms of population and environmental quality. In particular, the economy that starts from better initial conditions manages to keep the state of its environment always above the threshold J, even after an initial decrease. This implies that this "luckier" economy can sustain a larger population in the long run, and also experience an improvement in environmental conditions, driven by the larger investments in maintenance related to a longer life expectancy.

A similar situation is depicted in Figure 4. The only difference, with respect to Figure 3, is that now the "worse" economy starts from $X_0 = 900$ (rather than $X_0 = 550$). This means that, for some periods, it behaves exactly as the "better" one in terms of human capital, population and survival probability. Path dependency, however, implies that its environmental quality keeps lagging behind that of the other economy, and eventually falls below the threshold J. At this point, life expectancy drops in the economy with worse initial conditions, and the two economies diverge.[20]

4.2.2 Human capital related poverty traps

We now want to put the spotlight on divergence as determined by differential initial levels of development (rather than environmental quality).

To do so, we reactivate the channel through which human capital affects life expectancy and set $\chi = 120$. In Figure 5, we present the simulated time paths of two economies that start from the same level of environmental quality ($X_0 = 300$), but differ in their initial human capital ($h_0 = 1/5$ and $h_0 = 4/3$, respectively).

Here we can notice that the initially less developed economy remains stuck in a poverty trap defined by slower human capital accumulation, shorter life expectancy, declining population and diminishing environmental quality. The other economy starts off with a higher human capital: at the beginning this is not enough to raise the survival probability, and just translates into a faster demographic decline (since more educated parents prefer quality to

[20] The possibility of pollution-driven mortality resurgence is highlighted by McMichael et al. (2004) among others, and is usually exemplified by the trajectories of several ex-USSR republics – see for instance Feachem (1994) and Jedrychowski (1995).

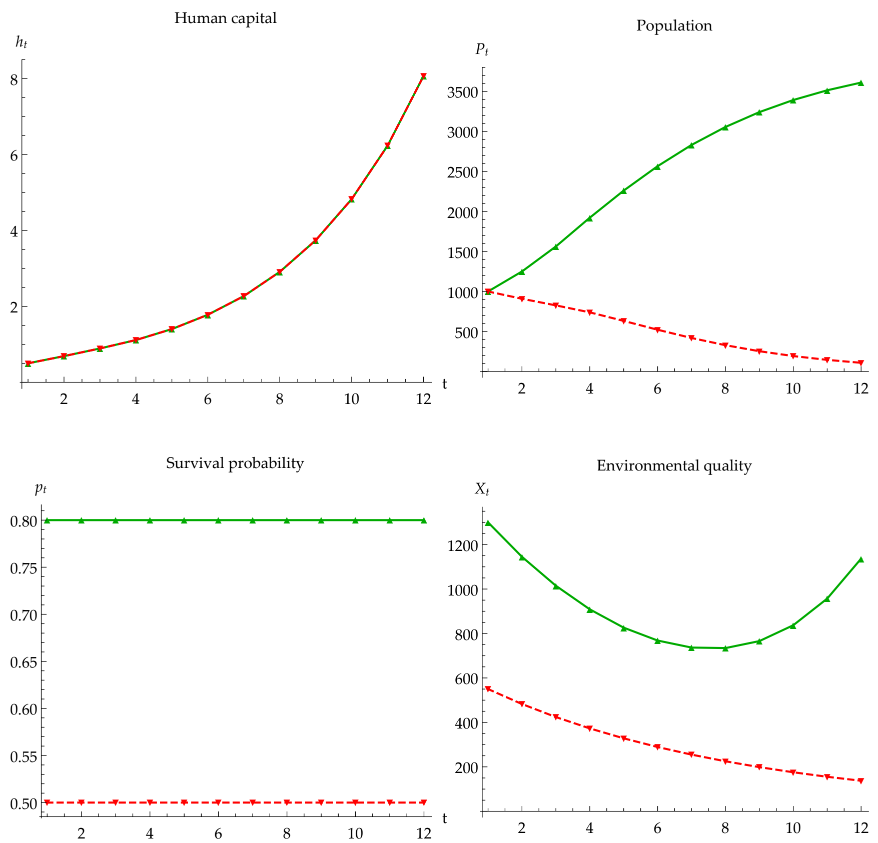

Figure 3: Multiple equilibria: simulated time paths when $X_0 = 1300$ (solid, green) and $X_0 = 550$ (dashed, red)

quantity of children), without allowing the richer country to do better than the poorer one in terms of pollution. Eventually, however, the richer economy reaches a level of human capital that brings about an increase in life expectancy: at that point the demographic and environmental trends are reversed, with both population and environmental quality that start increasing, thus generating a divergent trajectory with respect to the other economy.

This case is interesting since, different from Figure 4, the survival probability is shown to increase over time – because of the beneficial effect of human capital accumulation, which more than compensates the impact of a deteriorating environment on longevity.

4.2.3 Escaping the trap

One may wonder, at this stage, under which circumstances an economy starting from unfavorable initial conditions can avoid being stuck in a poverty trap, and which role can be played by policy intervention.

Without presenting additional simulations, we can briefly discuss a few channels through which an initially-trapped economy may ultimately converge to the equilibrium characterized

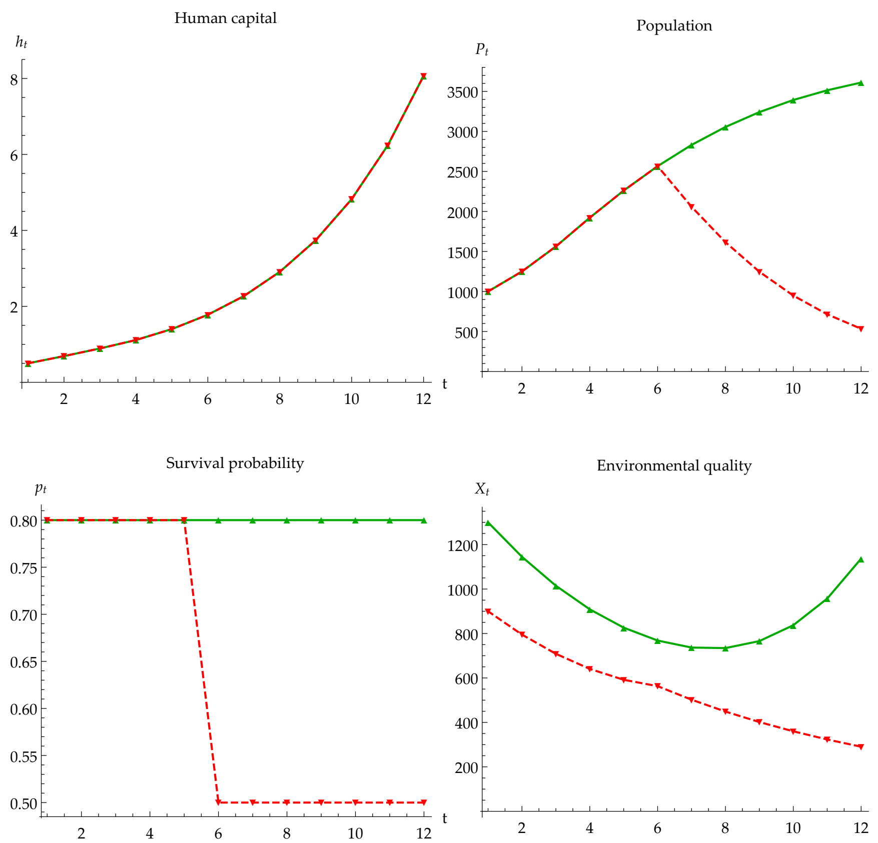

Figure 4: Multiple equilibria: simulated time paths when $X_0 = 1300$ (solid, green) and $X_0 = 900$ (dashed, red)

by a longer life-expectancy, a higher level of economic development, and possibly a better environmental quality. Technically, this would be possible through (i) a permanent reduction of the threshold value of J in Equation 14 (so that the economy finds itself automatically out of the trap), or (ii) an enhanced dynamic evolution of environmental quality and/or human capital. The first mechanism, as suggested by Mariani et al. (2010) may correspond to exogenous improvements in medicine and/or technological transfers in the fields of health and environmental care. Perhaps more interestingly, the policy instruments τ and σ may also be used in order to sort an economy out of the trap. In particular, a sufficiently large increase in σ, and possibly a reduction in τ may drive the economy towards the superior equilibrium, by pushing parents to invest more in education, rather than in the quantity of their children. These policy measure would significantly alleviate the demographic pressure on the environment, and stimulate human capital accumulation that can in turn stimulate environmental maintenance.[21]

The above mechanisms, however, may work in the opposite direction. Even temporary

[21]Growth can, however, also bring about more pollution. Here, we stay consistent with the findings of our dynamic simulations, according to which human capital has a net beneficial effect.

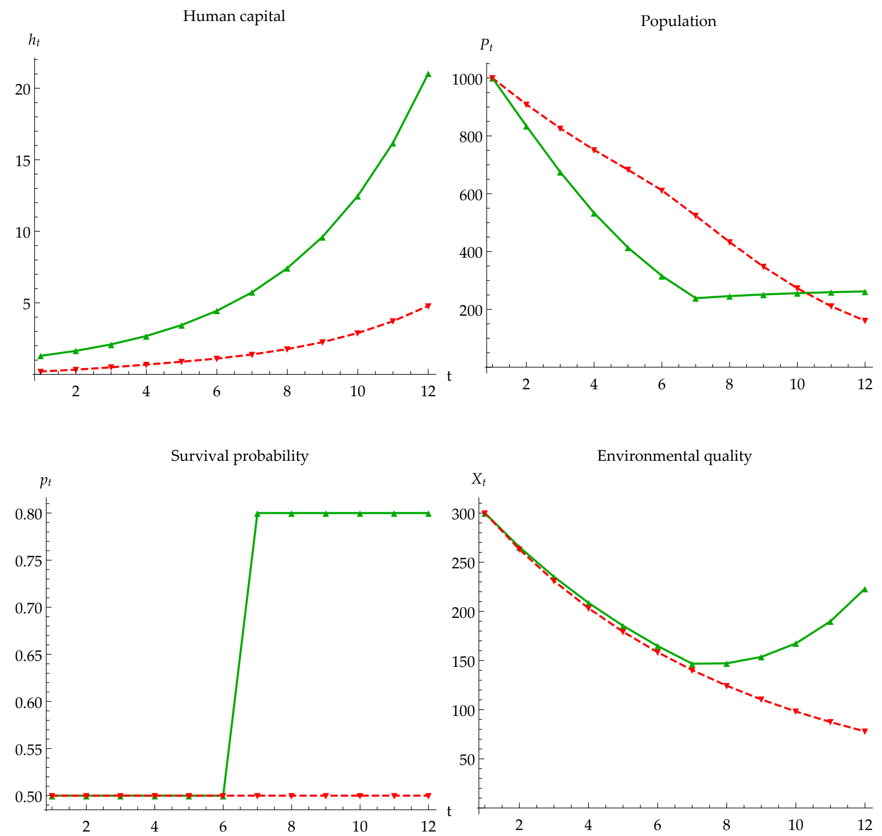

Figure 5: Multiple equilibria: simulated time paths when $h_0 = 1/5$ (solid, green) and $h_0 = 4/3$ (dashed, red)

shocks (such as natural disasters or episodes of acute environmental stress and pollution) may be sufficient to throw an economy back into a poverty trap.[22] The same applies to policy intervention. In particular, the possible perverse effects of environmental taxes may even be deeper and very long-lasting, if an economy is at risk of being pulled back into a trap.

4.2.4 The role of endogenous fertility

Overall, considering endogenous fertility helps us to improve our understanding of the dynamic challenges implied by the management of environmental quality. In fact, introducing a quality-quantity trade-off into the framework proposed by Mariani et al. (2010) allows us to deal with population as a dynamic variable, and better understand the interplay between demographic and environmental variables along the growth process of the economy. By doing so, we have been able – for instance – to draw new policy implications and gauge the trade-offs associated with normative intervention (as explained in Section 4.1). Our dy-

[22] See Mariani et al. (2010) for a more detailed analysis.

namic analysis also reveals that a better initial environmental quality allows the economy to sustain a larger population, thus making the demographic constraint less binding. Finally, the dynamic simulations developed in Section 4.2 suggest that, in the presence of multiple equilibria, the "superior" steady state is not necessarily associated with a smaller population – an interesting results that depends on endogenous fertility and education choices.

5 Conclusions

In this paper, we have presented a growth model in which education, fertility, environmental quality and life expectancy can all be endogenously determined. Such model provides a general framework of analysis, which can encompasses both original features and some results already known in the literature. In particular, we put together two key elements often studied separately in the literature: the two-way causality between life expectancy and the environment, and the link between fertility decisions and environmental quality.

In particular, our model highlights (i) the potentially perverse effect of environmental policies, (ii) the role of demographic dynamics in explaining (at least partially) the environmental Kuznets curve, (iii) the opportunity of using educational subsidies as an effective policy tool to alleviate the pressure on natural resources, and (iv) the possibility of poverty traps related to human capital and environmental quality.

References

[1] Andreoni J. (1989). Giving with impure altruism: applications to charity and Ricardian equivalence, Journal of Political Economy, 97, 1447-1459.

[2] Becker G.S. (1960). An economic analysis of fertility, in: Demographic and Economic Change in Developed Countries, Princeton University Press, Princeton.

[3] Becker, G.S. and Lewis, H.G. (1973). On the interaction between the quantity and quality of children, Journal of Political Economy, 81, 279-88.

[4] Blackburn, K., Cipriani, G.P. (2002). A model of longevity, fertility and growth. Journal of Economic Dynamics and Control 26, 187-204.

[5] Chakraborty, S. (2004). Endogenous lifetime and economic growth. Journal of Economic Theory 116, 119-137.

[6] Constant, K. (2018). Environmental Policy and Human Capital Inequality: a Matter of Life and Death, Journal of Environmental Economics and Management, forthcoming.

[7] de la Croix, D. and Doepke, M. (2003). Inequality and growth: Why differential fertility matters. American Economic Review, 93, 1091-1113.

[8] de la Croix, D. and Licandro, O. (2013). The child is father of the man: Implications for the demographic transition. The Economic Journal, 123(567), 236-261.

[9] de la Croix, D. and Licandro, O. (2015). The longevity of famous people from Hammurabi to Einstein. Journal of Economic Growth, 20, 263-303.

[10] de la Croix D. and Gosseries, A. (2011). The natalist bias of pollution control, Journal of Environmental Economics and Management, 63, 271-287.

[11] Dao, N. T., and Edenhofer, O. (2018). On the fiscal strategies of escaping poverty-environment traps towards sustainable growth. Journal of Macroeconomics, 55, 253-273.

[12] Dasgupta P. (1993). An inquity into well-being and destitution. Oxford: Clarendon Press.

[13] Dasgupta P. (1995). The Population Problem: Theory and Evidence, Journal of Economic Literature, 33, 1879-1902.

[14] Dinda, S. (2004). Environmental Kuznets Curve Hypothesis: A Survey, Ecological Economics, 49, 431-455.

[15] Doepke, M. (2004). Accounting for fertility decline during the transition to growth, Journal of Economic Growth, 9, 347-383.

[16] Evans, M.F., Smith, V.K. (2005). Do new health conditions support mortality-air pollution effects?, Journal of Environmental Economics and Management, 50, 496-518.

[17] Feachem, R. (1994). Health decline in Eastern Europe, Nature, 367, 313-314.

[18] Gerlagh R., Lupi, V. and Galeotti, M. (2018). Family Planning and Climate Change, mimeo.

[19] Harford, J.D. (1998). The Ultimate Externality, The American Economic Review, 88, 260-265.

[20] Ikefuji, M. and Horii, R. (2007). Wealth heterogeneity and escape from the poverty-environment trap, Journal of Public Economic Theory, 9, 1041-1068.

[21] Jedrychowski, W. (1995). Review of recent studies from Central and Eastern Europe associating respiratory health effects with high levels of exposure to "traditional" air pollutants, Environmental Health Perspectives, 103(2),15-21.

[22] John, A. and Pecchenino, R. (1994). An overlapping generations model of growth and the environment, Economic Journal, 104, 1393-1410.

[23] Jouvet, P.-A., Pestieau, P. and Ponthiere, G. (2010). Longevity and environmental quality in an OLG model, Journal of Economics, 100, 191-216.

[24] Jouvet, P.-A., Pestieau, P. and Ponthiere, G. (2011). Survival, reproduction and congestion: the spaceship problem re-examined, Journal of Bioeconomics, 13, 233-273.

[25] Kijima, M., Nishide, K. and Ohyama, A. (2010). Economic models for the environmental Kuznets curve: A survey, Journal of Economic Dynamics and Control, 34, 1187-1201.

[26] Lleras-Muney, A. (2005). The relationship between education and adult mortality in the United States, Review of Economic Studies, 72(1), 189-221.

[27] Mariani F., Perez-Barahona, A. and Raffin, N. (2010). Life expectancy and the environment, Journal of Economic Dynamics and Control, 34, 798-815.

[28] McMichael, A., McKee, Shkolnikov, V., and Valkonen, T. (2004). Mortality trends and set backs: global convergence or divergence?, Lancet, 363, 1155-1159.

[29] Ono, T. and Maeda, Y. (2001). Is aging harmful to the environment?, Environmental and Resource Economics, 20, 113-127.

[30] Palivos, T. and Varvarigos, D, (2017). Pollution abatement as a source of stabilization and long-run growth, Macroeconomic Dynamics, 21, 644-676.

[31] Pope III, C.A., (2000). Epidemiology of fine particulate air pollution and human health: biologic mechanisms and who's at risk?, Environmental Health Perspectives, 108, 713-723.

[32] Pope III, C.A., Burnett, R.T., Thurston, G.D., Thun, M.J., Calle, E.E., Krewski, D. and Godleski, J.J. (2004). Cardiovascular mortality and long term exposure to particulate air pollution: epidemiological evidence of general pathophysiological pathways of disease, Circulation, 109, 71-77.

[33] Schou P. (2002). Pollution Externalities in a Model of Endogenous Fertility and Growth, International Tax and Public Finance, 9, 70-725.

A Derivation of optimal choices, as in Equations (8), (9) and (10)

After replacing (2) and (3) into the utility function (1), we can solve the optimization program by relying on the following Lagrangian:

$$\mathcal{L} = \ln[(1-\tau)(1-\phi n_t)wh_t - c_t + m_t + (1-\sigma)n_t e_t] + \pi_t \alpha[\ln(\delta(\theta+e_t)^\beta h_t^{1-\beta}) + \gamma \ln m_t]. \quad (15)$$

We then have to solve the system composed by the following first-order conditions:

$$\frac{\partial \mathcal{L}}{\partial m_t} = 0 \;\Leftrightarrow\; \frac{1}{(1-\tau)(1-\phi n_t)wh_t - c_t + m_t + (1-\sigma)n_t e_t} = \frac{\gamma \pi_t}{m_t}, \quad (16)$$

$$\frac{\partial \mathcal{L}}{\partial e_t} = 0 \;\Leftrightarrow\; \frac{(1-\sigma)n_t}{(1-\tau)(1-\phi n_t)wh_t - c_t + m_t + (1-\sigma)n_t e_t} = \frac{\alpha\beta\pi_t}{(\theta + e_t)}, \tag{17}$$

$$\frac{\partial \mathcal{L}}{\partial n_t} = 0 \;\Leftrightarrow\; \frac{(1-\tau)\phi w h_t + (1-\sigma)e_t}{(1-\tau)(1-\phi n_t)wh_t - c_t + m_t + (1-\sigma)n_t e_t} = \frac{\alpha\pi_t}{n_t}. \tag{18}$$

Solving the system, we obtain

$$e_t = \frac{\beta(1-\tau)\phi w h_t - (1-\sigma)\theta}{(1-\sigma)(1-\beta)}, \tag{19}$$

and we can see that we have an interior solution for education (i.e. $e_t > 0$), only if

$$h_t > \frac{(1-\sigma)\theta}{\beta(1-\tau)\phi w}.$$

Otherwise, we are in a corner solution, with agents choosing not to invest in education ($e_t = 0$).

In the lower part of Equations (8), (9) and (10), we report the optimal choices associated to an interior solution for e_t, which can be immediately obtain from the first-order conditions specified above. In the case of corner solution, we must replace $e_t = 0$ in the agents' budget constraint, and re-optimize with respect to n_t and m_t only. The implied solution are reported in the upper part of Equations (8), (9) and (10).

B Derivation of the long-run growth rate of human capital

The rate of growth of human capital g_h is obtained as

$$g_h = \frac{h_{t+1} - h_t}{h_t} = \delta \left[\frac{\beta}{1-\beta} \left(\frac{\phi(1-\tau)w}{(1-\sigma)} + \frac{\theta}{h_t} \right) \right]^{\beta} - 1. \tag{20}$$

In the long run, we have that $h_t \to \infty$ and therefore $\theta/h_t \to 0$. It follows that

$$g_h^{\star} = \delta \left(\frac{\beta\phi(1-\tau)w}{(1-\beta)(1-\sigma)} \right)^{\beta} - 1. \tag{21}$$

Institut de Recherches Économiques et Sociales
Université catholique de Louvain

Place Montesquieu, 3
1348 Louvain-la-Neuve, Belgique

ISSN 1379-244X D/2019/3082/8