The great transition: Implication from environmental policy on the quality-quantity trade-off on children

Abstract

We develop an overlapping-generations model with human capital accumulation and endogenous fertility containing a pollution externality. In such a framework, we study the effects of an environmental policy change on individuals' quality-quantity trade-off on children. In a Malthusian poverty trap, we show that a more stringent policy induces a reduction of the fertility rate. In a state of perpetual development, however, not only is this policy likely to have a positive effect on fertility, but we also obtain that environmental quality, growth, and welfare are compatible goals. Moreover, we show that an abatement pollution policy can be used as an instrument for initiating a country's "great transition" from a state of poverty to a state of development.

JEL Classification: O41.

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1 Introduction

The relation between economic development and environmental quality is a complex issue which is the subject of a long-lasting debate in the literature (see, e.g., Ricci, 2007, for a comprehensive survey). While some argue that higher growth and better environment are competing goals (see, e.g., Ligthart and van der Ploeg, 1994; Grimaud, 1999), others suggest that there is no conflict between the two (see, e.g., Porter and Van der Linde, 1995; Bovenberg and Smulders, 1995; Hart, 2004; Grimaud and Tournemaine, 2007). The present paper joins into this debate and, specifically, it aims at showing that not only can growth and environmental quality be mutually compatible, but also environmental regulation can be used as an instrument to switch an economy from a state of poverty to a state of perpetual development.

It is by now well admitted that pollution, notably via its impact on individuals' health, represents a serious predicament for economic development.[1] **As argued by Aloi and Tournemaine (2011) among others, improvements in health represent the main benefits from environmental regulations because it affects individuals' participation to the labour market and learning abilities. In effect, on the empirical side, Young et al. (2005) argue for instance that the greatest benefits of the U.S. air pollution regulation are those associated with improved human health: The authors have evaluated the market and non market effects of air pollution in the U.S. for the period 1970 to 2000, and found that the greatest benefits of the regulation are those associated with improved human health. Formally, they computed that air pollution regulation led to a welfare gain increase from about $50 billion in 1975 to about $400 billion in 2000 (in 1997 dollars).[2] Similarly, the World Bank (2007) has evaluated the health damages caused by air pollution in China at nearly 4% of GDP. On the theoretical side several authors such as Gradus and Smulders (1993), van Ewijk and van Wijnbergen (1994) and Pautrel (2008, 2009) have therefore developed frameworks accounting for a link between individual human capital and pollution**

[1]See, for instance, Kunzli (2002) and the World Health Organisation report on Health Aspect of Air Pollution (2004).

[2]See Pautrel (2008) for further and more detailed observations on this issue.

emissions.[3] Their common finding is that a better quality of the environment is compatible with a higher level of growth. The reason is that, in their framework, a better environmental quality leads to an increase of individual productivity in the human capital accumulation sector (e.g. Gradus and Smulders; van Ewijk and van Wijnbergen) or life expectancy (Pautrel, 2008; 2009). Thereby, individuals allocate more time to skills acquisition which is growth enhancing.

An important choice variable which is omitted in the analyses, however, is the number of children individuals decide to bring up. As mentioned by Barro and Sala-i-Martin (2004), it is surprising that such variable is rarely a focus of its own in growth models: this variable is often treated as an exogenous parameter although it is obviously endogenous. Furthermore, the link between human capital and fertility has been recognized for many years in the literature **both theoretically and empirically (see, e.g., Cochrane, 1979 and other references cited below). It is usually argued that there exists a trade-off regarding individuals' decisions between the quality and quantity of their children. Interestingly, not only does such trade-off allow to capture the observed negative correlation between the level of human capital of individuals and the number of children they decide to bring up but also to explain the transition of economies from a stage of stagnation (poverty trap) to perpetual growth (see, e.g., Becker, Murphy and Tamura, 1990; hereafter BMT), i.e. the idea according to which** economic development goes along with a general decline in fertility rates and an increase in investment in education (see, e.g., Galor and Weil, 1999; Doepke, 2004; Galor, 2005). **The bottom line of this is that if an abatement pollution policy can affect the human capital accumulation process of individuals as stated above, it is also likely to alter their fertility choice via the quality-quantity trade-off they face. That is, in this paper, we argue that a more stringent environmental policy could be a factor helping to initiate a "great transition" for some developing countries, i.e. a tool favouring a switch**

[3] The idea that health represents an important component of human capital can be attributed to Grossman (1972). **More recently, several authors, among which Weil (2008), have provided empirical evidence supporting the idea that health affects productivity both directly (healthier individuals make better workers) and indirectly (healthier individuals acquire more skills).**

from a poverty trap to a state of perpetual development. Interestingly, such channel of transmission of environmental policy to growth and development is reminiscent of the concluding remarks by Ricci (2007, p. 697) stating, about the empirical work by Chay and Greenstone (2003) among others,[4] that the observation of the negative impact of pollution on children's health and mortality supports the idea (suggested and developed here) of a parallel increase in education.

In line with this strand of reasoning, we thus develop a model connecting the ideas of endogenous human capital accumulation and fertility choices (or endogenous population growth) in which environmental quality plays a key role. To the best of our knowledge, capturing all these features in a single model has not been done in the environmental economic literature, although some authors have discussed, to some extent, the connections between them. For instance, Cronshaw and Requate (1997) study the effects of a change in the exogenous population growth rate on the environment in a static context; Harford (1997, 1998) investigates the issue in a dynamic model with endogenous fertility, but does not include any production sector. Finally, Schou (2002), who has the closest framework to ours, builds on Harford (1997, 1998) to analyse in which case an explicit family policy is necessary to implement an optimal allocation of resources.

The advantage of our approach with respect to the aforecited literature is twofold. First, we can study how changes in environmental policy affects the decisions of individuals to invest in human capital accumulation and to bring up children. Second, we can assess both the immediate and long-run impact of an environmental policy on growth and welfare, as well as its transitional dynamic implications. To get there, we borrow the endogenous growth model with human capital accumulation developed by BMT in which we introduce the notion that pollution affects individuals' human capital accumulation process (i.e. learning abilities), and thus in turn, the so-called quality-quantity trade-off on children. Interestingly, the framework has the nice property to display two stable steady-state equilibria: i) a Malthusian poverty trap where individuals choose to

[4] **Specifically, Chay and Greenstone (2003) estimate that a one percent decrease in total suspended particles in the US during the period 1981-1982 has led to a 0.35 percent decline in the infant mortality.**

have a high number of children but do not invest in their human capital accumulation; and ii) a stable state of persistent and self-sustaining growth where individuals choose to have less children but invest a strictly positive amount of resources in their human capital accumulation process.

In a nutshell, we show that, in the long run, an abatement pollution policy induces individuals to reduce the number of children they bring up when the economy is stuck in a (poor) Malthusian steady state. The reason is that the policy change leads to a reduction of the rate of return to investments in the number of children parents choose to bring up. Interestingly, in the perpetual growing steady state this effect is further accompanied by a productivity gain in the human capital accumulation sector which offsets the negative impact on fertility. In other words, in this case there is a positive impact both on the number of children and on their rate of skills acquisition.[5]

Another noteworthy result of the paper is that a better environmental quality and a greater level of growth and welfare are compatible goals. The reason is that we obtain a non linear (inverted U-shaped) relationship between environmental regulation and growth reminiscent of the seminal work by Barro (1990). Unlike the author, however, we show that, in general, the welfare maximising amount of abatement is lower than the growth maximising one; moreover, its level should be set lower in the Malthusian steady state than in the perpetual growing one. In this context, given that the abatement policy level positively affects the return to investments in human capital, we demonstrate that such policy can be used as an instrument to switch an economy from the Malthusian to the perpetual growing steady state.

The remainder of the paper is organized as follows. In Section 2, we present the model. In Section 3, we examine its key properties. We conclude in Section 4.

[5] **These results are close to those derived by Tournemaine and Tsoukis (2010) who develop a similar setup to ours. However, the authors mainly focus on socio-macroeconomic issues, namely the potential impact of social status on the quality-quantity trade-off on children, thereby its potential effect on economic development.**

2 Model

The main building block of the model is taken from BMT and Tournemaine and Tsoukis (2011). We depart from the authors and go one step further as we add the environmental dimension to the standard framework. This will allow us to analyse the impact of an abatement policy on the number of children, human capital accumulation, long-term growth and welfare.

We consider an economy where time, denoted by t, is discrete and goes from 0 to ∞. The economy is populated by overlapping generations of people who live for two periods: childhood and adulthood. All decisions are made in the adult period of life. Each adult individual is endowed with $T > 0$ units of labor-time supplied inelastically between the production of a polluting output and raising children to adulthood. Technologies and preferences are described below.

The technology for output is given by:

$$y_t = l_t h_t, \tag{1}$$

where l_t is the time spent by an adult to the production of output and h_t is her level of human capital.

Each unit of output production yields one unit of pollution emissions that can be reduced through abatement activities, a_t. For simplicity, abatements are public activities, though it would be equivalent to consider that these were private activities. Our approach can be rationalised by appealing to the fact that governments may actually promote the adoption of technologies that reduce pollution originating from the use of resources - such as coal or fuel - impairing air quality. Abatements are financed through a flat tax rate τ levied on output production: $a_t = \tau y_t$. Moreover, we focus on the immediate effects of emissions, such as air pollution, whose implications on human capital are for the most part direct and are drastically reduced when addressed (see, e.g., Kunzli 2002). Accordingly, we treat pollution, p_t, as a flow and set

$$p_t = \left(\frac{y_t}{a_t}\right)^{\chi} = (\tau)^{-\chi} \ , \tag{2}$$

where $\chi > 0$. Treating pollution emissions as a by-product of production that can be reduced by devoting part of output to abatement is common practice in the environmental literature. This is motivated by two main reasons. First, its simplicity: as the flow of pollution is constant at each instant of time, it facilitates the investigation of the main properties of the model at steady state and along the transition. Second, as pointed out by Forster (1973) among others, the functional form (2) can be taken as an approximation for emissions due to air pollution; that is the polluting factor at the centre of our analysis.[6]

One consequence of pollution is the deterioration of individuals' human capital. For simplicity, following van Ewijk and van Wijnbergen (1994) and Pautrel (2008, 2009), Aloi and Tournemaine (2013) among others, we set the technology of human capital as

$$h_{t+1} = \phi \left(p_t\right)^{-\omega} e_t + h_0, \tag{3}$$

where $\phi > 0$ is a productivity parameter, $\omega > 0$ measures the strength of pollution emissions on human capital accumulation, e_t is the amount of material resources invested and h_0 is the innate level of skills. Note that a strictly positive and constant long-run growth rate can be achieved if $e_t > 0$ and e_t grows at the same rate as h_t which will be the case in steady state. Moreover, even if there is no labour-time in the production function (3), and thus, even if teachers are not explicitly modelled, the main idea is that their existence is implicitly assumed. Such technology has been used and discussed by de la Croix and Michel (2002, see e.g. chapter 5) among others. The justification is that the standard trade-off which occurs between output production (consumption) and human

[6] As mentioned by Aloi and Tournemaine (2013), the functional form (2) implies that with zero abatement ($a_t = 0$) pollution tends to infinity. This undesirable property can easily be fixed by assuming that technological change affects the productivity of abatement. As clarified by Bretschger and Smulders (2007), for consistency, technology and input effects of abatement should be distinct. Formally, this amounts to replace technology (2) with

$$p_t = \frac{y_t}{q_{p,t}} \min\left\{ \left(\frac{y_t}{q_{p,0}}\right)^{\chi-1}, \left(\frac{y_t}{a_t}\right)^{\chi-1} \right\},$$

where $\chi > 1$ and $q_{p,t} = \max\{q_{p,0}, a_t\}$. The latter captures the learning-by-abating technology, or productivity effect of abatement. The lower bound on $q_{p,t}$ ensures that: (i) with zero abatement, pollution is proportional to output, and (ii) a minimum initial amount is required for abatement to start to be effective. Our specification (2) remains valid, as long as a minimum level of abatement is in place, and satisfies $q_{p,0} < a_t < y_t$. Hence, the pollution technology adopted in the paper should be interpreted as a specific case of this more general functional form.

capital accumulation in the case of a model where labour-time is an input of the human capital accumulation process, is directly taken into account via the amount of resources devoted to human capital accumulation.[7]

Another consequence of pollution is the deterioration of individuals' utility given by

$$V_t = \frac{\left[(c_t)\,(p_t)^{-\varphi}\right]^{1-\sigma}}{1-\sigma} + \alpha\,(n_t)^{1-\varepsilon}\,V_{t+1}, \tag{4}$$

where $0 < \alpha < 1$, $0 < \varepsilon < \sigma < 1$, $\varphi > 0$ measures the strength of the negative impact of pollution on individuals' utility, c_t is the per-capita level of consumption of an adult individual, n_t is the number of children that a parent has and V_{t+1} is the level of utility that a child will attain as an adult, i.e. parents and children are linked through altruism (see, e.g., Barro and Becker, 1988 and 1989). In that sense, parameters ε and α are the elasticity of altruism with respect to the number of children and the degree of altruism of parents toward children.

To close the model, we assume that, to bring up each child to adulthood, it also takes a fixed amount of time, $\nu > 0$, and of consumption good, $f > 0$. Therefore, the resource and time constraints of an individual are given by

$$(1-\tau)\,l_t h_t = c_t + (e_t + f)n_t, \tag{5}$$

and

$$l_t + \nu n_t = T. \tag{6}$$

3 Equilibrium

In this section, we characterise the equilibrium of the model. We proceed in three steps. First, we derive the efficiency conditions. Second, we characterise the steady state and analyse the implications of a change in the abatement policy level on economic variables and individuals' welfare. Finally, we characterise and analyse the transitional dynamics.

[7] It is possible to argue that h_0 should be affected by pollution. However, such assumption would imply a long-run level of human capital equal to zero if $e_t = 0$. Thus, we choose to rule out this possibility.

3.1 The representative individual's problem

Using (1)-(6), after substitution, the individual's maximisation problem can be written as

$$\max_{n_t,h_{t+1}} \frac{1}{1-\sigma}\left\{\left[(1-\tau)(T-\nu n_t)h_t-\left(\frac{h_{t+1}-h_0}{\phi\tau^{\chi\omega}}+f\right)n_t\right]\tau^{\chi\varphi}\right\}^{(1-\sigma)} \\ +\alpha(n_t)^{1-\varepsilon}V_{t+1}(h_{t+1}).$$

Manipulation of the first order condition with respect to n_t yields

$$\alpha(1-\varepsilon)(n_t)^{-\varepsilon}V_{t+1}(h_{t+1})=[(1-\tau)\nu h_t+(e_t+f)](c_t)^{-\sigma}\tau^{\chi\varphi(1-\sigma)}, \tag{7}$$

stating that the marginal utility gain of an additional child on the left hand side equals its cost in terms of time and output on the right hand side.

Manipulation of the first order condition with respect to h_{t+1} yields

$$\frac{n_t}{\phi\tau^{\chi\omega}}(c_t)^{-\sigma}\tau^{\chi\varphi(1-\sigma)}\geq\alpha(n_t)^{1-\varepsilon}\frac{dV_{t+1}}{dh_{t+1}}, \tag{8}$$

where equality holds if $e_t>0$. Moreover, the envelope condition implies

$$\frac{dV_{t+1}}{dh_{t+1}}=(1-\tau)(T-\nu n_{t+1})(c_{t+1})^{-\sigma}\tau^{\chi\varphi(1-\sigma)}. \tag{9}$$

Combining (8) and (9) yields

$$\left(\frac{c_{t+1}}{c_t}\right)^{\sigma}\geq\alpha\phi\tau^{\chi\omega}(1-\tau)(n_t)^{-\varepsilon}(T-\nu n_{t+1}), \tag{10}$$

where the left hand side is the marginal rate of substitution between consumption of parents and children and the right hand side represents the return of investments in human capital.

3.2 Steady state

3.2.1 Characterisation and properties

Using the results derived in the previous sub-section, we can show that two stable steady-state equilibria can emerge depending on whether individuals invest in education of their children or not. First, there is a stable Malthusian poverty trap. In this case, (10) reads with a strict inequality implying $e_t=0$ and $h_t=h_0$ at each instant. Second, there is a stable state of persistent and self-sustaining growth. In this case, (10) reads with equality. Investments in education put the economy on a development path characterised by $e_t > 0$ and $h_{t+1} > h_t$ at each instant. Let us mention that there exists an unstable state of intermediate development, as well. In this case, (10) reads with equality, but parents invest an amount of resources which is just enough to maintain the level of human capital constant over-time implying zero long-run growth: $e_t > 0$ and $h_{t+1} = h_t$ at each instant. Due to its unstable nature, we relegate its characterisation to Appendix 5.1.3 to focus on the two stable steady states which are more meaningful for the analysis. For simplicity, results are gathered in Proposition 1 where we drop the time index for constant variables and use the symbols "M" and "d" to denote the value of variables in the Malthusian and perpetual growing steady states, respectively. Furthermore, for convenience, we assume the following parameter restrictions:

Assumption 1:

$$\frac{(1-\tau)\left[T-\nu(\alpha)^{1/(\varepsilon-1)}\right]h_0 - f(\alpha)^{1/(\varepsilon-1)}}{(1-\tau)\nu h_0 + f} < 0.$$

Assumption 2:

$$\frac{\phi\nu\tau^{\chi\omega}(1-\tau)(1-\sigma)}{(\sigma-\varepsilon)} > 1.$$

Assumption 1 guarantees the uniqueness of the solution for the equilibrium number of children in the Malthusian steady state. Assumption 2 guarantees the existence of a growing steady state where the amount of resources allocated to teaching activities is strictly positive.

Proposition 1 *In the Malthusian steady state, parents do not invest in education of their children ($e_M = 0$) which leads to zero economic growth ($g_M = 0$). The number of children they bring up, n_M, is unique. It is solution of the following equation:*

$$\frac{(1-\tau)(T-\nu n_M)h_0 - f n_M}{(1-\tau)\nu h_0 + f} = \frac{(1-\sigma)\left[(n_M)^{\varepsilon} - \alpha n_M\right]}{\alpha(1-\varepsilon)}, \tag{11}$$

and verifies

$$0 < \alpha\phi\tau^{\chi\omega}(1-\tau)(n_M)^{-\varepsilon}(T - v n_M) < 1. \tag{12}$$

In the growing steady state, the relative amount of output allocated to human capital accumulation, e_t/h_t, is constant and given by

$$\frac{e_t}{h_t} = \frac{(1-\sigma)(1-\tau)\nu}{(\sigma-\varepsilon)}. \tag{13}$$

The number of children, n_d, parents bring up is given by

$$\left[\frac{(1-\sigma)\nu}{(\sigma-\varepsilon)}\right]^{\sigma} = \alpha\left[\phi\tau^{\chi\omega}(1-\tau)\right]^{1-\sigma}(n_d)^{-\varepsilon}(T-\nu n_d). \tag{14}$$

The common growth rate of consumption and human capital, g_d, is given by

$$g_d = \frac{\phi\nu\tau^{\chi\omega}(1-\tau)(1-\sigma)}{(\sigma-\varepsilon)} - 1. \tag{15}$$

Proof. *See Appendix 5.1.* ■

Beyond the intuitive result that the Malthusian steady state is characterised by a greater number of children compared to the state of perpetual development (i.e. $n_M > n_d$, evident from equations 12 and 14 under the parameter restrictions given in Appendix 6.1), Proposition 1 allows us to examine the effects of a change in the abatement policy level on the choice of the number of children per individual and human capital investments. We can check that the abatement policy level has a different impact on the choice of the number of children, depending on whether the economy is in the Malthusian state or if it is on the path of perpetual development. Starting with equation (11), we notice that $dn_M/d\tau < 0$. Intuitively, a higher abatement policy level reduces the available income of individuals which, in turn, increases the relative cost of bringing up additional children.

Interestingly, in the growing steady state, this effect is accompanied by an increase of the productivity in the human capital accumulation sector (see 3), synonymous with a greater income level. This means that the contribution of abatements to the reduction of pollution emissions can compensate the resource withdrawal effect depicted previously. More precisely, we have $dn_d/d\tau > 0$ for low initial values of τ and $dn_d/d\tau < 0$ for high initial values of τ. The noteworthy feature of these two effects is that they also apply for growth (see equation 15) despite the lower relative amount of resources devoted to human capital accumulation (see equation 13). Specifically, the number of children per individual, n_d, and the long-run level of growth, g_d, are characterised by an inverted-U relation with respect to τ. The maximum for both variables is attained if the abatement policy level verifies:

$$\tau_d^{\max} = \frac{\chi\omega}{\chi\omega + 1} \ . \tag{16}$$

Accordingly, in a perpetual growing steady state, if the level of abatement policy is initially low (i.e., $0 < \tau < \tau^{\max}$), it is possible for the government to improve environmental quality and foster long-term growth. The crucial issue however, concerns the impact of such policy on welfare, which we tackle next.

3.2.2 Abatement policy choice and welfare

In this sub-section, we determine the abatement policy level which maximises individuals' welfare in the Malthusian steady state, $\tau_{_M}^{w}$, and in the perpetual growing one, τ_d^w. Under the maintained assumption that the parameters of the model verify $0 < \alpha\left(n_x\right)^{1-\varepsilon}\left(1+g_x\right)^{1-\sigma} < 1$, with $x = M, d$, to ensure a bounded utility level at the steady state, we use (4), Proposition 1 and Appendix 5.1 to find the utility of an individual at time t:

$$V_t = \frac{\left[\left(c_{x,t}/h_t\right)\left(\tau^{\varphi\chi}\right)\right]^{1-\sigma}}{(1-\sigma)} \frac{\left(h_t\right)^{1-\sigma}}{1-\alpha\left(n_x\right)^{1-\varepsilon}\left(1+g_x\right)^{1-\sigma}}, \ x = M, d.$$

Deriving this expression with respect to τ, we obtain:

$$\frac{dV_t}{d\tau}\frac{1}{V_t} = \left[\begin{array}{c} \frac{(1-\sigma)\varphi\chi}{\tau} + \frac{(1-\sigma)}{c_x}\frac{dc_{x,t}}{d\tau} \\ + \frac{\alpha(1-\varepsilon)(n_x)^{-\varepsilon}(1+g_x)^{1-\sigma}}{1-\alpha(n_x)^{1-\varepsilon}(1+g_x)^{1-\sigma}}\frac{dn_x}{d\tau} + \frac{\alpha(1-\sigma)(n_x)^{1-\varepsilon}(1+g_x)^{-\sigma}}{1-\alpha(n_x)^{1-\varepsilon}(1+g_x)^{1-\sigma}}\frac{dg_x}{d\tau} \end{array}\right], \ x = M, d. \tag{17}$$

From equation (17), we can count four channels through which the abatement policy can impact on individuals' welfare. Starting with the first term on the right hand side of (17), we observe that this effect is common to both the Malthusian and perpetual growing steady states. It represents the direct (positive) effect on welfare of a more stringent policy. That is, a better environmental quality is welfare enhancing simply because it is an argument of individuals' utility function. The second term, on the other hand, represents a reduction in welfare coming from the consumption loss incurred due to a positive policy change. A more stringent policy is indeed synonymous of a greater amount of resources allocated to abatement. This means, ceteris paribus, that individuals have fewer resources left for private consumption. The size of this effect is different whether the economy is stuck in the Malthusian steady state or has reached a state of perpetual development. We have:

$$\frac{d\left(c_t/h_t\right)_M}{d\tau} = -\left(1-\nu n_{_M}\right) - \left(1-\tau\right)\nu \frac{dn_{_M}}{d\tau} - f\frac{dn_{_M}}{d\tau},$$

and

$$\frac{d\left(c_t/h_t\right)_d}{d\tau} = -\left(1-\nu n_d\right) - \left(1-\tau\right)\nu \frac{dn_d}{d\tau} - \frac{e_t}{h_t}\frac{dn_d}{d\tau} - n_d\frac{d(e_t/h_t)}{d\tau}.$$

Simple manipulations of these two expressions show that $\left|d\left(c_t/h_t\right)_M/d\tau\right| < \left|d\left(c_t/h_t\right)_d/d\tau\right|$ if $\tau < \tau_d^{\max}$. I.e., the consumption loss incurred by individuals is lower in a Malthusian steady state than in a state of perpetual growth. This is because in the Malthusian steady state, individuals reduce their fertility rate and reallocate labour-time to output production. In the perpetual growing steady state, however, individuals allocate more resources to education and more labour-time to fertility.

Finally, the third and fourth terms on the second line of the right hand side of (17) represent the welfare impact of the policy coming from the change in the number of children per individual, n_x, $x = M, d$, and growth, g_x, $x = M, d$. As explained in the previous sub-section, the effect on the number of children per individual is negative in the Malthusian steady state, while its sign depends on the initial value of the policy in the perpetual growing steady state (i.e. whether $\tau < \tau^{\max}$ or $\tau > \tau^{\max}$). Regarding growth, this effect is zero in the Malthusian steady state due to the properties of this latter, but is strictly positive (negative) in the perpetual growing steady state if $\tau < \tau^{\max}$ ($\tau > \tau^{\max}$).

Gathering the results depicted above, we can deduce that the welfare maximising abatement policy level in the Malthusian and perpetual growing steady states verify: $0 < \tau_{_M}^w < \tau_d^w < 1$.[8] Moreover, under the reasonable assumption that the strength of the negative welfare impact of pollution, φ, is not too high (as suggested by van Ewijk and van Wijnbergen, 1995), we can expect $\tau_d^w < \tau_d^{\max} = \chi\omega/(\chi\omega+1)$ (see equation 16). Accordingly, we can state:

Proposition 2 *As long as the strength of the negative impact of pollution on welfare, φ,*

[8] We can easily check that, in the case $\varphi = 0$, $\tau_{_M}^w$ should be set to zero. Of course, such solution is valid only if the functional form given in footnote 3 prevails.

is not too high, the optimal policy levels in the Malthusian and perpetual growing steady states verify: $0 < \tau_M^w < \tau_d^w < \tau_d^{\max} = \chi\omega/(\chi\omega + 1) < 1$.

Proposition 2 states that the optimal abatement policy level should be set higher in the perpetual growing economy than in the Malthusian steady state. Interestingly, this result fits with the economic intuition. But more importantly, it implies that if the government were to implement τ_d^w, there should not be any trade off between environmental quality, welfare and growth in the long run in the perpetual growing steady state if, at the outset, the abatement policy level is not too stringent (i.e. $\tau < \tau_d^{\max}$). Therefore, Proposition 2 implies:

Corollary 1 *In a perpetual growing economy, as long as the strength of the negative impact of pollution on welfare,* φ*, is not too high, and if the actual abatement policy verifies* $0 < \tau < \tau_d^w$*, a more stringent abatement policy should lead to a reduction of pollution emissions and an increase of long-term growth and welfare.*

Let us mention that, although we have characterised the welfare maximising abatement policy level in the Malthusian steady state, τ_M^w, we doubt if it is optimal for a government to actually implement such policy. Put differently, we wonder if the main goal of the government should not be, instead, to attempt to reach the perpetual growing steady state first, and then, later, implement the welfare maximising policy, τ_d^w. We raise this issue because we can observe that condition (12) becomes less stringent as τ increases when $\tau < \tau_d^{\max}$ initially. Intuitively, when the government chooses to increase the level of the abatement policy in the Malthusian steady state, it, in turn, decreases the rate of return to investments in the number of children parents choose to bring up. Therefore, it affects the quality-quantity trade-off on children towards quality and makes this steady state less likely to occur.[9] In other words, the abatement policy can serve as an instrument of economic development in the sense that it can be used to switch the economy from a Malthusian steady state (or poverty trap) to a state of perpetual growth. To verify this noteworthy hypothesis, it is necessary to characterise the transitional dynamics of

[9] We show in Appendix 5.1.3 that, as the abatement policy level increases, the minimum level of human capital required to switch from the Malthusian to the perpetually growing steady state decreases.

the model to clearly assess the effects of a change in the abatement policy level both on impact and during the adjustment path. We thus tackle this important issue in the next section.

3.3 Transitional dynamics

3.3.1 Characterisation

We develop a 2×2 linearised system in the relative amount of resources devoted to human capital, e_t/h_t, and human capital itself, h_t, around the asymptotic steady state of perpetual development. For simplicity, we give a more intuitive exposition here, and relegate the more formal details to Appendix 5.2.

To proceed, we first re-write the model in deviation from the reference paths for the number of children, n_t, relative investments to human capital accumulation, e_t/h_t, consumption, c_t, and human capital, h_t, during the transition. We can show that the change in the number of children is linked to the change in the relative amount of resources devoted to human capital according to the following relation:

$$\Delta n_t = -\Gamma \Delta \left(e_t/h_t \right), \tag{18}$$

where, for any variable x, we use the standard notation $\Delta x_t = x_{t+1} - x_t$, and:

$$\Gamma \equiv \frac{\frac{\varepsilon(1-\tau)\nu(e_t/h_t)+[(e_t/h_t)]^2}{[(1-\tau)\nu+(e_t/h_t)]^2} + \frac{n_d}{(1-\tau)(T-\nu n_d)-n_d(e_t/h_t)}}{\frac{\varepsilon}{n_d} + \frac{(1-\tau)\nu+(e_t/h_t)}{(1-\tau)(T-\nu n_d)-n_d(e_t/h_t)}} > 0.$$

Equation (18) shows that the number of children and educational effort move in opposite directions both on impact and during transition. Using this information, we obtain that, along the transition, the consumption path is given by

$$\frac{\Delta c_t}{c_t} = \Upsilon \Delta \left(e_t/h_t \right) + \frac{\Delta h_t}{h_t},$$

where

$$\Upsilon \equiv \left[\frac{\varepsilon \left(1-\tau\right) \nu (e_t/h_t) + (e_t/h_t)^2}{\left[\left(1-\tau\right) \nu + (e_t/h_t) \right]^2} - \frac{\varepsilon \Gamma}{n} \right] < 0.$$

Finally, after tedious computations, we obtain the following system:

$$\begin{bmatrix} \frac{\Delta h_{t+1}}{h_{t+1}} \\ \Delta\left(e_{t+1}/h_{t+1}\right) \end{bmatrix} = \begin{bmatrix} 1 & \frac{1}{(e_t/h_t)} \\ 0 & \Omega \end{bmatrix} \begin{bmatrix} \frac{\Delta h_t}{h_t} \\ \Delta\left(e_t/h_t\right) \end{bmatrix}, \tag{19}$$

where

$$0 < \Omega \equiv \frac{\frac{\varepsilon\Gamma}{n_d} - \frac{\sigma}{(e_t/h_t)} + \sigma\Upsilon}{\sigma\Upsilon - \frac{v\Gamma}{1-vn_d}} < 1. \tag{20}$$

We assume that the parameters of the model are such that $0 < \Omega < 1$ to ensure saddle-point stability and avoid oscillatory trajectories. Requiring saddle-point stability makes sense as e_t/h_t is a "jump variable" (closely linked to n_t, the number of children per parent). Human capital, h_t, however, is a state variable and likely to change more slowly: it is a "predetermined" variable. We now turn to the analysis of an abatement policy change.

3.3.2 The great transition

In this part, we show that the abatement policy can serve as an instrument to switch an economy from the Malthusian poverty trap to a state of perpetual economic development. As mentioned before, the mechanism allowing such result relies on the notion that a positive change in the abatement policy level should increase the return to investment in children's education relative to the return to investment in children's quantity. In other words, the policy change affects the opportunity cost of rising additional children and then induces individuals to start investing in their education. This, in turn, should initiate the great transition to the state of perpetual development.

Let us assume that the economy is initially in the Malthusian steady state (i.e. $e_t = 0$) with an abatement policy level verifying: $0 < \tau < \tau_{_M}^w < \tau_d^w$ (see Proposition 2). At time $t = t_0$, the government decides to implement a permanent and marginal increase in τ. At the time of the policy change, $t = t_0$, there is an increase in the return to investment in children's education (quality) relative to the return in investment in children's quantity. Moreover, as shown in Appendix 6.1, the minimum level of human capital to switch from the Malthusian to the perpetual growing steady state becomes lower. Thus, this can induce individuals to start investing in their children's education: we obtain a jump of the relative amount of resources devoted to human capital given by e_{t_0}/h_{t_0} (see 3) which puts the economy on a state of perpetual development. To illustrate this result, a numerical simulation is conducted in Appendix 5.2.

After the policy change, from (19), we can check that e_t/h_t decreases to its steady-state value given by (13), i.e. attains it from above (see Figure 1).

Figure 1 about here

This means that the number of children per individual jumps down on impact and then sluggishly decreases to its new steady state value (see Figure 2 and equation 18 in Appendix 6.2).

Figure 2 about here

Finally, human capital, state variable, does not change on impact as $h_{t_0} = \phi e_{t_0 - 1} h_0 + h_0 = h_0$ and $e_{t_0-1} = 0$ in the Malthusian steady state. Afterwards, however, due to the strictly positive investments, e_t, human capital increases and its growth rate sluggishly approaches its steady state from below (see Figure 3).

Figure 3 about here

To summarise, we can state:

Proposition 3 *Under the assumptions* $0 < \tau < \tau_d^w < 1$ *and the economy is stuck in a Malthusian poverty trap, a more stringent abatement policy can initiate the great transition to a self-sustained growth steady state. During the transition, individuals invest an increasing amount of resources in education and reduce their fertility rate. As a result, growth and welfare increase.*

4 Conclusion

In a simple model of overlapping generations with endogenous fertility inspired by BMT, we have investigated the effects of a pollution abatement policy supported by a flat income tax rate. Growth results from human capital, financed by the provision of education from parents to children, and aided by environmental quality. The tax-supported abatement policy induces a fundamental trade-off between resources available for private use and growth because environmental quality enhances the generation of human capital.

As long as the tax rate is below its welfare maximising level, we have shown that the government can foster both growth and environmental quality without any conflict between the two goals. Moreover, a more intensive abatement policy (a higher tax rate) may lower the threshold of the initial human capital that differentiates the Malthusian from the perpetually growing steady-state equilibrium. Therefore, this policy may facilitate a switch from stagnation to perpetual growth.

For analytical tractability, and for the purpose of establishing a first set of relevant results, we have opted for the simplest endogenous growth framework in which individuals decide both investments in human capital accumulation and the number of children to bring up. Another important channel through which pollution can affect growth and welfare is individuals' life expectancy (see, e.g. Chakraborty, 2004; Gutierrez, 2008; Pautrel, 2008, 2009; Varvarigos, 2010). Thus, assuming that the length of individuals's second period of life depends on pollution emissions, appears as a natural extension of our framework. Another possible limitation of our work is that, although fertility is treated as endogenous, the role of population growth is not explicitly treated: a greater population may for instance cause greater congestion and pollution effects, notably in mega-cities of developing countries. As mentioned by Schou (2002), such problems naturally call for family planning policies to regulate these additional externalities. It would then be interesting to see how these notions may affect the results derived in the present paper. **We must also admit that the present analysis did not tackle the important issue of the relation between environment and distribution. As argued by Aloi and Tournemaine (2013), the prevailing debate is whether the trade-off between tighter environmental protection and faster economic growth affects more the**

poor than the rich. In light of the present article, the policy could also affect the quality-quantity on children. Therefore, it would be interesting to take into account this feature to assess whether there could be a conflict between environmental and distributional concerns. Finally, an important issue which remains open at this stage but is worth to tackle concerns the confrontation of the model to real world data to test the validity of its results. This is obviously an empirical question which goes beyond the scope of the present article and could be the object of another research of its own.

5 Appendix

5.1 Steady state

5.1.1 Malthusian steady state

As explained in the main text, in a Malthusian steady state, adult individuals do not invest in human capital: $e_t = 0$ in all periods. This implies that economic growth is zero: $h_{t+1} = h_t = h_0$ in all periods. Then, the levels of consumption and utility of any individual are respectively given by $c_t = c_{t+1}$ and $V_t = V_{t+1}$ in all periods. Using this information, equation (12) follows directly from equation (10) where $c_t = c_{t+1}$. This condition must hold with strict inequality because we have a corner solution. To compute (11), we use (4), (7) and the fact that $c_t = c_{t+1}$ and $V_t = V_{t+1}$ in all periods.

5.1.2 Perpetual growing steady state

When growth is strictly positive, the level of innate human capital of an individual, h_0, and the fixed cost of raising a child in terms of the consumption good, f, become negligible in the long-run (as ratios over h_t). Thus, we can skip these variables in the computation of the steady state. From (3) and (5), we have: $1 + g = c_{t+1}/c_t = h_{t+1}/h_t = \phi(e_t/h_t)$ at the steady state. As equation (8) reads with equality with strictly positive investments in education, we can combine this equation with (7) to obtain:

$$\frac{h_{t+1}}{h_t} = \frac{\phi \tau^{\chi\omega} \left[(1-\tau)\,\nu + \frac{e_t}{h_t} \right]}{(1-\varepsilon)} \frac{dV_{t+1}}{dh_{t+1}} \frac{h_{t+1}}{V_{t+1}}. \tag{21}$$

Since the growth rate of human capital and consumption are the same at steady state, we have

$$\frac{dV_{t+1}}{dh_{t+1}}\frac{h_{t+1}}{V_{t+1}}=\frac{dV_{t+1}/V_{t+1}}{dh_{t+1}/h_{t+1}}=\frac{dV_{t+1}/V_{t+1}}{dc_{t+1}/c_{t+1}}=\frac{dV_{t+1}}{dc_{t+1}}\frac{c_{t+1}}{V_{t+1}}.$$

Assuming that the economy has reached the steady state, recursive substitution leads to

$$V_{t+1}=\frac{\left[\left(c_{t+1}\right)\left(\tau^{\varphi\chi}\right)\right]^{1-\sigma}}{1-\sigma}\sum_{i=0}^{\infty}\left[\alpha\left(n_d\right)^{1-\varepsilon}\left(1+g\right)^{1-\sigma}\right]^{i}.$$

Thus, from the above equation we have

$$\frac{dV_{t+1}}{dc_{t+1}}\frac{c_{t+1}}{V_{t+1}}=1-\sigma. \tag{22}$$

Plugging the above result in (21), we obtain e_t/h_t. Then, using (10) which holds with equality, we obtain n_d.

5.1.3 Intermediate steady state

In this sub-section, we characterise the intermediate state of development. As growth is zero in the intermediate steady state, from (10), the number of children per individual is given by

$$\alpha\phi\tau^{\chi\omega}\left(1-\tau\right)\left(\widehat{n}\right)^{-\varepsilon}\left(T-v\widehat{n}\right)=1, \tag{23}$$

where a "$\widehat{}$" on a variable denotes its value in steady state. As in the main text, we can easily check from (23) that there exists a tax value for which the number of children is maximum. It is given by: $\tau=\tau_d^{\max}=\chi\omega/(\chi\omega+1)$.

Then, from (4) we obtain

$$\frac{\alpha\left(1-\varepsilon\right)}{\left(1-\sigma\right)\left[\left(\widehat{n}\right)^{\varepsilon}-\alpha\widehat{n}\right]}=\frac{\left(1-\tau\right)\nu\widehat{h}+\left(\widehat{e}+f\right)}{\left(1-\tau\right)\left(T-\nu\widehat{n}\right)\widehat{h}-\left(\widehat{e}+f\right)\widehat{n}}, \tag{24}$$

and from (3), the level of investment in education, $\widehat{e}$, is given by

$$\widehat{e}=\frac{\widehat{h}-h_0}{\phi\tau^{\chi\omega}}. \tag{25}$$

It is interesting to note that, for $\tau<\tau_d^{\max}$, $d\widehat{n}/d\tau>0$ and for τ close enough to $\tau_d^{\max}$ (i.e. $\tau\approx\tau_d^{\max}$), the threshold level of human capital, $\widehat{h}$, required to switch to the self sustained growth steady state is negatively related with τ : $d\widehat{h}/d\tau<0$, confirming the result depicted in the main text. We can indeed compute

$$\frac{d\widehat{h}}{d\tau}_{\tau=\tau_d^{\max}}=-\frac{\chi\omega f\phi\tau^{\chi\omega-1}}{\nu+1}<0.$$

5.2 Transitional dynamics

5.2.1 Characterisation

Combining (7) and (8) (with equality in (8) as we are considering the endogenous growth case of $e_t > 0$), we obtain

$$\frac{dV_{t+1}}{dh_{t+1}} = \frac{(1-\varepsilon)}{\phi\tau^{\chi\omega}} \frac{V_{t+1}}{[(1-\tau)\,\nu h_t + (e_t + f)]},$$

which is a differential equation in V_{t+1} and dV_{t+1}/dh_{t+1}. The solution is:

$$V_{t+1} = \Theta_t \exp\left[\frac{(1-\varepsilon)}{\phi\tau^{\chi\omega}} \frac{h_{t+1}}{[(1-\tau)\,\nu h_t + (e_t + f)]}\right],$$

where Θ_t is a variable independent of h_{t+1} that must grow at the same rate as $(c_t)^{1-\sigma}$ (see equation 7). For simplicity, we specify $\Theta_t = (c_t)^{1-\sigma}$. Plugging back the above equation in (7), and skipping the terms f and h_0 which do not play any role in the growing steady state, we obtain

$$\alpha\,(1-\varepsilon)\,(n_t)^{-\varepsilon} \exp\left[\frac{(1-\varepsilon)\,(e_t/h_t)}{(1-\tau)\,\nu + (e_t/h_t)}\right] = [(1-\tau)\,\nu + (e_t/h_t)]\,h_t\,(c_t)^{-1}\,\tau^{\chi\varphi(1-\sigma)}.$$

Linarising this equation around the steady state of perpetual development, we get

$$-\varepsilon\frac{\Delta n_t}{n_d} - \left[\frac{\varepsilon\,(1-\tau)\,\nu(e_t/h_t) + (e_t/h_t)^2}{[(1-\tau)\,\nu + (e_t/h_t)]^2}\right]\Delta\,(e_t/h_t) = \frac{\Delta h_t}{h_t} - \frac{\Delta c_t}{c_t}. \tag{26}$$

Then, combining (5) and (6), and proceeding in the same way as before, we get

$$\frac{\Delta c_t}{c_t} = \begin{array}{c} -\frac{(1-\tau)\nu + (e_t/h_t)}{(1-\tau)(T-\nu n_d) - n_d(e_t/h_t)}\Delta n_t + \frac{\Delta h_t}{h_t} \\ -\frac{n_d(e_t/h_t)}{(1-\tau)(T-\nu n_d) - n_d(e_t/h_t)}\frac{\Delta(e_t/h_t)}{(e_t/h_t)} \end{array}. \tag{27}$$

Finally, linearisation of (3) yields

$$\frac{\Delta h_{t+1}}{h_{t+1}} - \frac{\Delta h_t}{h_t} = \frac{\Delta\,(e_t/h_t)}{(e_t/h_t)}, \tag{28}$$

and linearisation of (10) yields

$$\sigma\left(\frac{\Delta c_{t+1}}{c_{t+1}} - \frac{\Delta c_t}{c_t}\right) = -\varepsilon\frac{\Delta n_t}{n_d} - \frac{v}{1-vn}\Delta n_{t+1}. \tag{29}$$

Equations (26), (27), (28) and (29) is a 4×4 system in deviation from the reference paths for the number of children, n_t, relative investments to human capital accumulation,

e_t/h_t, consumption, c_t, and human capital, h_t. Now, the strategy is to reduce this system to a 2×2 system in deviation from the reference paths for h_t and e_t/h_t. To do it, we use (26) and (27) to eliminate $\Delta c_t/c_t$ and Δn_t. We obtain

$$\Delta n_t = -M\Delta\left(e_t/h_t\right),$$

at each instant, with

$$\Gamma = \frac{\frac{\varepsilon(1-\tau)\nu(e_t/h_t)+(e_t/h_t)^2}{[(1-\tau)\nu+(e_t/h_t)]^2} + \frac{n_d}{(1-\tau)(T-\nu n_d)-n_d(e_t/h_t)}}{\frac{\varepsilon}{n_d} + \frac{(1-\tau)\nu+(e_t/h_t)}{(1-\tau)(T-\nu n_d)-n_d(e_t/h_t)}} > 0,$$

and

$$\frac{\Delta c_t}{c_t} = N\Delta\left(e_t/h_t\right) + \frac{\Delta h_t}{h_t},$$

with

$$\Upsilon = \frac{\varepsilon\left(1-\tau\right)\nu(e_t/h_t) + (e_t/h_t)^2}{\left[(1-\tau)\,\nu + (e_t/h_t)\right]^2} - \frac{\varepsilon M}{n_d} < 0,$$

as long as

$$\left[\frac{\varepsilon\left(\sigma-\varepsilon\right)+\left(1-\sigma\right)}{\varepsilon\left(1-\varepsilon\right)}\right]\left[\frac{\left(1-\tau\right)\nu\left(1-\sigma\right)}{\left(\sigma-\varepsilon\right)}\right] < 1.$$

This latter condition is assumed to be verified to ensure a negative relation between consumption and investments in education (see Section 2).

Plugging these results in (29), we obtain

$$\Delta\left(e_{t+1}/h_{t+1}\right) = \Omega\Delta\left(e_t/h_t\right),$$

with

$$\Omega = \frac{\frac{\varepsilon M}{n_d} - \frac{\sigma}{(e_t/h_t)} + \sigma N}{\sigma N - \frac{vM}{1-vn_d}},$$

which, combined with equation (29) leads to the system (19).

5.2.2 Illustration of the great transition through a simple numerical example

In this part, we run a simple numerical simulation to show how the abatement policy can serve as an instrument to switch an economy from the Malthusian poverty trap to a state of perpetual economic development. It is important to keep in mind, however, that the numerical exercise performed here only provides a rough assessment of the mechanisms at work. It is only used to support of the basic economic intuition given in the main text.

To calibrate the model, we use similar benchmark parameter values as BMT (1990). Regarding the level of the abatement policy and parameters linked to the pollution technology, we follow Pautrel (2008, 2009); in particular, as observed from the data, we set the share of resources to abatement technologies around 2-5 percent. Table 1 summarizes the benchmark value of parameters.

Table 1: Benchmark parameter values

Description	Parameter	Benchmark value
Time endowment	T	1.3
Elasticity of environmental quality	χ	1.3
Impact of environmental quality on education	ω	0.05
Fixed cost of good of bringing up a child	f	0.28
Fixed cost of time of bringing up a child	ν	0.15
Elasticity of altruism	ε	0.25
Degree of altruism	α	0.4
Productivity in education	ϕ	4.4
Elasticity of substitution in the utility	σ	0.5
Innate skills	h_0	1
Abatement policy level	τ	0.03 0.05

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