Optimal pollution abatement with endogenous time preferences*

Sugata Ghosh and Nigar Hashimzade†

Department of Economics and Finance, Brunel University London

February 23, 2022

Abstract

We investigate an optimal allocation of public expenditures between pollution abatement and public infrastructure in an endogenous growth model where the time preferences depend on the quality of the environment. The growth-maximising policy achieves higher welfare than the environmental quality-maximising policy when the total factor productivity (TFP) and/or the efficiency of abatement technology are relatively low. The opposite holds when the TFP and/or abatement efficiency are relatively high. In the context of growth-environment trade-off, our results provide rationale for the more advanced economies focussing their policies on the environment and for the developing economies on boosting economic growth.

Key words: endogenous discounting; endogenous growth; pollution; environmental Kuznets curve

JEL classification numbers: H23; O44; Q56

1 Introduction

It is widely perceived that higher economic growth leads to higher pollution, but the environmental degradation due to that can be reversed beyond some point if national incomes are high

*Preliminary and incomplete. Please do not circulate without permission.

†Corresponding author: nigar.hashimzade@brunel.ac.uk

enough to allow a certain proportion of the resources to be spent on replenishing the environment. This Environmental Kuznets Curve (EKC) hypothesis of Grossman and Krueger (1995) leads to the question about when it is appropriate for a country to spend on pollution abatement to reverse environmental decay, and how much of its resources should be spent on that. It is important also to understand whether such an objective on the part of a benevolent government is at variance with other objectives, such as the maximisation of welfare of its citizens or maximisation of the growth rate of its economy. In this paper, we attempt to answer such important questions.

Our paper is based on an overlapping-generations (OLG) model with endogenous growth driven by public capital input in production and endogenous time preferences. The agents' consumption causes pollution leading to deterioration of the environment. Private agents ignore the detrimental effect of their consumpion on the environment. The environmental degradation can be offset by pollution abatement. In the model both the pollution abatement facilities and the productive public capital are funded by the tax on producers. The central feature of our model is that the agents' time preferences are determined by the quality of the environment. Specifically, we assume that the time discount factor is positively related to the quality of the environment. The idea behind this assumption is that better environment could eventually lead to better health and higher longevity and thus to a stronger long-term orientation among subsequent generations. Thus, the weight the private agents place on the future outcomes could be expected to grow as environmental quality improves (see the discussion in Pittel, 2002; Lines, 2005; Yanase, 2011; Vella et al., 2015; Chu et al., 2016, among others). There is also evidence in economic experiments that individuals who value the importance of natural resources tend to be more patient (Viscusi et al., 2008).

In this setting we investigate the optimal policy of a benevolent government which decides how to allocate tax revenue between pollution abatement facilities and productive capital expenditures. The government recognises the negative effect of private consumption on the environmental quality and in choosing the optimal allocation of public funds it internalises the environmental externality ignored by the private agents. We characterise this policy along the balanced growth path and simulate the numerical values for optimal allocation of public expenditures in a calibrated model. We compare the outcomes under three different government objectives: environmental quality, economic growth, and social welfare in a calibrated model.

We find that the welfare is higher under the environmental objective when the TFP and/or efficiency of abatement are sufficiently high. Conversely, higher welfare is achieved when the government pursues economic growth if the TFP and/or efficiency of abatement are low. Moreover, for the TFP and/or abatement efficiency below a threshold level the social welfare is maximised when the entire tax revenue in the productive public capital and nothing is spent on pollution abatement. Our results are supportive of the view that the onus of investing resources to combat pollution should be on developed countries, with high productivity and better abatement technologies, whereas developing countries should be directing their efforts to boosting long-run economic growth.

The road-map of the paper from here on is as follows: in Section 2 the model is developed, and the role of the private and public sectors and of the environment are discussed in detail. The decentralised equilibrium is characterised in Section 3. In Section 4 the optimal environmental policy of the government is characterised and analysed. In Section 5 the model is solved numerically, and the implications of the main results are outlined. Section 6 discusses the contribution of this paper to the literature and the limitations of the model. Section 7 concludes the paper.

2 The model

Consider a two-period deterministic OLG economy with identical cohorts and constant population. Without loss of generality we normalise the size of a cohort to unity. An agent born at the beginning of period t ($t = 0, 1, 2, \ldots$) works when young, gives birth to one offpsring, and retires when old in period $t+1$. There is an 'initial old' agent at time $t = 0$. The agents derive utility from consumption. Consumption generates pollution which worsens the environment, and lower environmental quality reduces the weight on the utility of consumption in the future. The government taxes the producers and spends the revenues on the productive public capital and pollution abatement.

2.1 Production sector

The production sector consists of a large number of competitive firms producing a uniform physical good that can be costlessly converted into a consumption good or invested in physical capital. The firms buy labour and physical capital in perfectly competitive markets and use them as inputs in production. The evolution of the physical capital is described by

$$K_{t+1} = (1 - \delta_K) K_t + I_t, \tag{1}$$

where I_t is private investment in period t and δ_K is the depreciation rate.

The production technology has constant returns to scale in private inputs, and so the production sector can be described by a representative firm. In every period $t = 0, 1, 2, \ldots$ the representative firm maximises profits, taking the prices of inputs and output as given. We assume that the production function is Cobb-Douglas in labour and private capital, and is augmented by a non-rival stock of public capital, or public infrastructure, as in Barro (1990):

$$Y_t = AK_t^{\alpha} L_t^{1-\alpha} K_{Gt}^{1-\alpha}. \tag{2}$$

Here, Y_t is the output, K_t is the stock of private capital in period t, L_t is labour input, K_{Gt} is the stock of public infrastructure, and A is the TFP. The producers pay tax at rate τ_t per unit of output. Thus, the after-tax profits in period t are given by

$$\pi_t = [1 - \tau_t] Y_t - w_t L_t - (r_t + \delta_K) K_t. \tag{3}$$

w_t is the wage rate, and r_t is the interest rate.

The first-order conditions for profit maximisation equate the prices of factor inputs to their marginal products:

$$r_t + \delta_K = [1 - \tau] \alpha A \left[\frac{k_{Gt} L_t}{k_t} \right]^{1-\alpha}, \tag{4}$$

$$w_t = [1 - \tau] [1 - \alpha] A k_{Gt} \left[\frac{k_{Gt} L_t}{k_t} \right]^{-\alpha}, \tag{5}$$

where $k_t \equiv \frac{K_t}{Y_t}$ and $k_{Gt} \equiv \frac{K_{Gt}}{Y_t}$ denote the capital to output ratios for private and public capital, respectively.

2.2 Consumers

All young agents are endowed with one unit of labour each and own equal shares in the firms when young. A young agent works, consumes and saves for retirement. Savings are invested in the capital market. When old, an agent retires and consumes savings and the interest earned.

There is no bequests. The period budget constraints,

$$c_t^y + s_t = w_t + \pi_t, \tag{6}$$

$$c_{t+1}^o = (1 + r_{t+1}) s_t \tag{7}$$

can be combined into a lifetime budget constraint,

$$c_t^y + \frac{c_{t+1}^o}{1 + r_{t+1}} = w_t + \pi_t, \tag{8}$$

where c_t^y and c_{t+1}^o are consumption levels in the young and in the old age, respectively, and s_t are the savings of the young.

The preferences of an agent born in period t are described by the utility function of the form

$$U\left(c_t^y, \ln c_{t+1}^o\right) = \ln c_t^y + \beta(N_t) \ln c_{t+1}^o, \tag{9}$$

where N_t is the environmental quality in period t, and $\beta(\cdot)$ is the time discount factor, such that

$$\beta(\cdot) \in (0, 1), \beta'(\cdot) \geq 0, \beta''(\cdot) \leq 0. \tag{10}$$

The properties of the time preferences described in (10) mean that an individual discounts future consumption when old more, the lower is the environmental quality experienced when young. This could be interpreted as poor environment reducing longevity, as in Jouvet et al. (2010), or causing deterioration of health, thus reducing the enjoyment of consumption. Conversely, better environmental quality experienced when young increases the weight attached to the utility of consumption when old.

An agent born in period t chooses the lifetime consumption profile to maximise utility (9) subject to the budget constraint (8), taking the wage rate, the interest rate, and the environmental quality as given. The consumption levels maximise the Lagrangean,

$$\max_{\left\{c_t^y, c_{t+1}^o\right\}} \mathcal{L} = \ln c_t^y + \beta(N_t) \ln c_{t+1}^o + \lambda_t \left[w_t + \pi_t - c_t^y - \frac{c_{t+1}^o}{1 + r_{t+1}}\right] \tag{11}$$

where $\lambda_t \geq 0$ is the Lagrange multiplier. The first-order conditions for an interior solution are given by

$$\frac{\partial \mathcal{L}}{\partial c_t^y} = \frac{1}{c_t^y} - \lambda_t = 0, \tag{12}$$

$$\frac{\partial \mathcal{L}}{\partial c_{t+1}^o} = \frac{\beta(N_t)}{c_{t+1}^o} - \frac{\lambda_t}{1 + r_{t+1}} = 0. \tag{13}$$

Combined with the budget constraint, this gives

$$c_t^y = \frac{w_t + \pi_t}{1 + \beta(N_t)}, \tag{14}$$

$$c_{t+1}^o = \frac{\beta(N_t)}{1 + \beta(N_t)} [1 + r_{t+1}] [w_t + \pi_t] \tag{15}$$

2.3 Public sector

In every period, the government collects taxes from the producers and divides the revenues between the investment in public infrastructure and the environmental expenditures. The government runs balanced budget in every period. We assume that the government can credibly commit to its policies. To concentrate the analysis on the environmental policy, we assume that the tax rate is determined outside the model and focus on the share of tax revenues invested in the environmental programme, $b_t \in [0, 1]$ as the policy variable. (Thus, the share of revenues invested in public infrastructure is $1 - b_t$.).

Let T_t denote tax revenue collected in period t, and let G_t and E_t denote the government spending on public infrastructure and on the environmental in period t, respectively. The balanced budget constraint can be written as

$$G_t = (1 - b_t) T_t, \tag{16}$$

$$E_t = b_t T_t. \tag{17}$$

The public capital stock then evolves according to

$$K_{G,t+1} = (1 - \delta_K) K_{Gt} + G_t, \tag{18}$$

where δ_K is the depreciation rate, for simplicity assumed to be the same as the one for the private capital.

2.4 Environment

Consumption activities in the economy pollute the environment, and the public environmental programme reduces the level of pollution. Pollution via consumption is a realistic assumption, as various types of pollution are by-products of consumption activities. The domestic use of carbon-based fuels leads to significant air pollution. Household wastes and municipal sewage, when dumped into waterways, lead to widespread water pollution. Use of various electronic appliances leads to radiation and sound pollution. In this paper we abstract from the pollution caused by production activities; both assumptions are widely used in the literature.

We assume that the pollution abatement facilities make use of the public infrastructure, as in Andreoni and Levinson (2001). To this end, one can cite examples of investment in green infrastructure projects, such as the efficient management of stormwater and provision of green spaces in urban areas, which can supplement the direct benefits from abatement. Formally, the stock of public capital serves as an input in the pollution reduction technology. Denoting the level of pollution in period t by P_t, we then have $P_t = P_t\left(C_t, E_t, K_{Gt}\right)$, with $\frac{\partial P_t}{\partial C_t} > 0$, $\frac{\partial P_t}{\partial E_t} < 0$ and $\frac{\partial P_t}{\partial K_{Gt}} < 0$, where

$$C_t = c_t^y + c_t^o$$

is the aggregate consumption in period t. We further assume that the effectiveness of the public environmental programme, measured by the pollution reduction per unit of environmental expenditure, $\left|\frac{\partial P_t}{\partial E_t}\right|$, is positively related to the level of public infrastructure: $\frac{\partial}{\partial K_{Gt}}\left|\frac{\partial P_t}{\partial E_t}\right| > 0$, or $\frac{\partial}{\partial K_{Gt}}\frac{\partial P_t}{\partial E_t} < 0$.

Let $\overline{N}$ denote the 'natural' quality of the environment, in the absense of polluting activities and environmental efforts, and let D_t denote the destruction of environmental quality by pollution. We assume that the evolution of environmental quality is described by

$$N_{t+1} - N_t = \delta_N\left(\overline{N} - N_t\right) - D_t. \tag{19}$$

Here $\delta_N \in (0, 1)$ can be interpreted as the rate of adjustment of environmental quality to its natural level. The degradation of environment is faster, the larger is the flow of pollution relative to the aggregate output, $D_t = D\left(\frac{P_t}{Y_t}\right)$, with $D'(\cdot) > 0$.

For analytical tractability we further assume that D_t and P_t are given by

$$D_t = \frac{P_t}{Y_t}, \tag{20}$$

and

$$P_t = \sigma C_t - \psi K_{Gt}^{1-\gamma} E_t^{\gamma}, \tag{21}$$

where $\sigma > 0$ measures the 'dirtiness' of consumption and $\psi > 0$ measures the productivity of the public environmental protection programme.

3 Equilibrium

Definition 1 *Given the sequence of the tax rates and the allocation of public expenditures,* $\{\tau_t, b_t\}_{t=0}^{\infty}$*, the initial environmental quality,* N_0*, the initial stock of private and public capital,* $\{K_0, K_{G0}\}$*, and the consumption of the initial old agent,* c_0^o*, a temporal equilibrium in the economy is the sequence* $\left\{c_t^y, c_{t+1}^0, K_{t+1}, K_{G,t+1}, N_{t+1}; w_t, r_{t+1}\right\}_{t=0}^{\infty}$ *which solves equations (1) (4), (5), (14) – (21), along with the market clearing conditions,* $I_t = s_t$ *and* $L_t = 1$*.*

We are interested in the long-run outcomes for welfare, growth and environment in the economy and, therefore, will focus analysis on the balanced growth path (BGP) equilibrium.

Definition 2 *A temporal equilibrium in which*

$$\begin{aligned} \frac{c_{t+1}^y}{c_t^y} &= \frac{c_{t+1}^o}{c_t^o} = \frac{K_{t+1}}{K_t} = \frac{K_{G,t+1}}{K_{Gt}} = \frac{w_{t+1}}{w_t} = 1 + g, \\ N_{t+1} &= N_t, r_{t+1} = r_t \end{aligned}$$

for all $t = 0, 1, 2, \ldots$ *is said to be the balanced growth path (BGP) equilibrium.*

In the BGP equilibrium the policy variables are constant, $\tau_t = \tau$ and $b_t = b$ for all $t = 0, 1, 2, \ldots$.

It is straightforward to show[1] that the environmental quality in the the BGP equilibrium is given by

$$N = \overline{N} - \frac{\sigma}{\delta_N} [1 - \tau] \frac{1 + \alpha\beta(N)}{1 + \beta(N)} + \frac{\psi\tau(1-b)^{1-\gamma} b^{\gamma}}{\delta_N [g + \delta_K]^{1-\gamma}}, \tag{22}$$

and the growth rate is given by

$$g = A [1 - \alpha]^{\alpha} \left[\frac{\beta(N)}{1 + \beta(N)}\right]^{\alpha} [1 - \tau]^{\alpha} [(1 - b)\tau]^{1-\alpha} - \delta_K. \tag{23}$$

In the subsequent analysis we assume that the model parameters are such that the BGP equilibrium exists.

4 Optimal environmental policy

The optimal policy in the BGP equilibrium is reduced to the choice of $b \in [0, 1]$. We consider three different objectives of the government in the choice of b: environmental quality, economic growth, and social welfare.

[1] The details of all derivations can be provided upon request.

For analytical tractability, from now on we assume that the discount factor is a monotonically increasing linear function of the environmental quality:

$$\beta(N) = \beta_0 + \kappa N,\ \ \beta_0 > 0,\ \ \kappa > 0,$$

and focus on the range of model parameters and the initial values of the capital stock such that $\beta(N) \in (0,1)$.

Environmental quality

Let b_N^* denote the value of b that maximises the environmental quality. One can show that b_N^* is given by

$$b_N^* = \frac{\gamma}{[\gamma + \alpha[1-\gamma]]} \tag{24}$$

he solution for b_N^* is always in the interior, $b_N^* \in (0,1)$, and $\frac{\partial b_N^*}{\partial \alpha} < 0$, $\frac{\partial b_N^*}{\partial \gamma} > 0$, as long as $\gamma > 0$. That is, the proportion of public spending on environmental protection aimed at maximising the environmental quality is higher, the more important is environmental protection in the pollution abatement (the higher is γ) and the more important is public infrastructure in the output production (the higher is $1-\alpha$). Thus, $b_N^* \to 0$ when $\gamma \to 0$: nothing should be invested in the environmental protection programme if it does not contribute to the pollution abatement, and, conversely, $b_N^* \to 1$ when $\gamma \to 1$. Similarly, $b_N^* \to \gamma$ when $\alpha \to 1$: when public infrastructure only contributes to the pollution abatement, the optimal proportion of revenue spent on environmental protection equals the share of the public capital in the pollution abatement technology, and $b_N^* \to 1$ when $\alpha \to 0$: the environmental quality in this case is maximised when all public spending goes into the environmental protection programme.

Economic growth

Let b_g^* denote the value of b that maximises the growth rate. It is straightforward to show that the solutions for b_g^* satisfies

$$b_g^* = \gamma\left[1 + \frac{1-\alpha}{\alpha}\frac{\beta(N)}{\beta'(N)}\frac{[1+\beta(N)]^2 - \frac{\sigma}{\delta_N}[1-\tau](1-\alpha)\beta'(N)}{[1+\beta(N)]\left[N-\overline{N}\right] + \frac{\sigma}{\delta_N}[1-\tau][1+\alpha\beta(N)]}\right]^{-1}, \tag{25}$$

Note that equation (25) defines b_g^* implicitly, since N is the solution of (22)-(23) at $b = b_g^*$. In contrast to b_N^*,, which is always in the interior, b_g^* can be either in the interior or equal to zero, depending on the model parameters. In particular, $b_g^* \to 0$ as $\beta'(N) \to 0$: if the time preferences are not affected by the environment, the growth rate is maximised when the public funds are invested entirely in the productive infrastructure and nothing is spent on the environmental policies.

Social welfare

We define the social welfare as the infinite discounted sum of consumer utilities across generations and assume that the social discount factor (time preference between generations) is equal to the private discount factor (time preference between young and old age):

$$W = \sum_{t=0}^{\infty} \prod_{i=0}^{t} \beta(N_t) \left[\ln c_t^y + \ln c_t^o\right]. \tag{26}$$

The welfare-maximising optimal share of tax revenue is the second-best policy, which respects the individual optimising decisions of the private agents and, at the same time, takes into account the environmental externality in the time discount factor.

In the BGP equilibrium expression (26) takes the form

$$\begin{aligned} W \quad = \quad & \ln\alpha - \frac{1-\beta(N)-2\alpha}{1-\beta(N)}\ln(1-\alpha) + \frac{2}{1-\beta(N)}\ln(AK_0) \\ & + \frac{2\alpha}{1-\beta(N)}\ln(1-\tau) + \frac{2(1-\alpha)}{1-\beta(N)}\ln((1-b)\tau) \\ & + \frac{1-\beta(N)-2\alpha}{1-\beta(N)}\ln(1+\beta(N)) - \frac{2(1-\alpha)-\beta(N)}{1-\beta(N)}\ln(\beta(N)) \\ & + \frac{\beta(N)}{1-\beta(N)}\ln(1+r) + \frac{[1+\beta(N)]\beta(N)}{[1-\beta(N)]^2}\ln(1+g) \end{aligned}$$

where

$$r = \frac{1+\beta(N)}{\beta(N)}\frac{\alpha(g+\delta_K)}{1-\alpha} - \delta_K$$

and N and g are given by (23) and (22). See Appendix for details.

It is straightforward to show that without environmental externality in time preferences, i.e. $\beta(N) = \beta = Const.$, the social welfare defined above is maximised at $b = 0$, that is, welfare-maximising policy coincides with the growth-maximising policy. Intuitively, without environmental externality the quality of environment is irrelevant for the economic outcomes, and so no resources should be allocated to environmental programme. Furthermore, if the government also chooses the tax rate, the welfare-maximising tax rate in this case is $\tau = 1 - \alpha$.

This is consistent with the standard results of the Barro-type endogenous growth model: since the growth is driven by the productive public capital, the optimal tax is equal to the share of public capital in production.

In the presence of environmental externality there is no closed-form solution for b that maximises W, and so we resort to a numerical solution in a calibrated model.

5 Calibration

To illustrate the effect of allocation of tax revenue between public input in production and public input in pollution abatement we calibrate the model following Gomme and Rupert (2007) and Jouvet et al. (2010), assuming, as in the latter, that one period in a two-period OLG model corresponds to 40 years. Our benchmark parametrisation is the following: $\beta_0 = 0.3$; $\kappa = 0.12$; $\overline{N} = 1$; $\tau = 0.35$; $\alpha = 0.36$; $\sigma = 0.1$; $\delta_N = 0.9$; $\psi = 1$; $\gamma = 0.25$; $A = 15$; $K_0 = 10$; $\delta K = 0.99$. For the BGP equilibrium these parameter values imply the annual discount factor at about 0.98, the annual growth rate at about 3.3%, the annual interest rate at about 4.8%, the annual depreciation rate of physical capital at about 0.11, and the investment-output ratio at about 13%, which is consistent with the commonly used calibration of macroeconomic models as outlined in Gomme and Rupert (2007). In this calibration the welfare is maximised at $b = 0.017$. That is, in the optimal BGP equilibrium about 1.7% of the government spending (equal to tax revenue) is invested in the pollution abatement. This is matched to the UK government spending of £14.5 billion on environmental protection in 2018, accounting for 1.7% of all UK government expenditure.[2]

Figures 1 – 4 illustrate how the optimal share b of public funds invested in abatement, and the corresponding long-run values of environmental quality, N, growth rate, g, and social welfare, W, depend on the TFP (A) and the pollution abatement productivity (ψ). The solid, the dashed, and the dotted lines correspond to three different objectives of the government: namely, maximal welfare (—), maximal growth (- -), and maximal environmental quality ($\cdots$), respectively.

[2] https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/environmentalprotectionexpenditureuk/2018

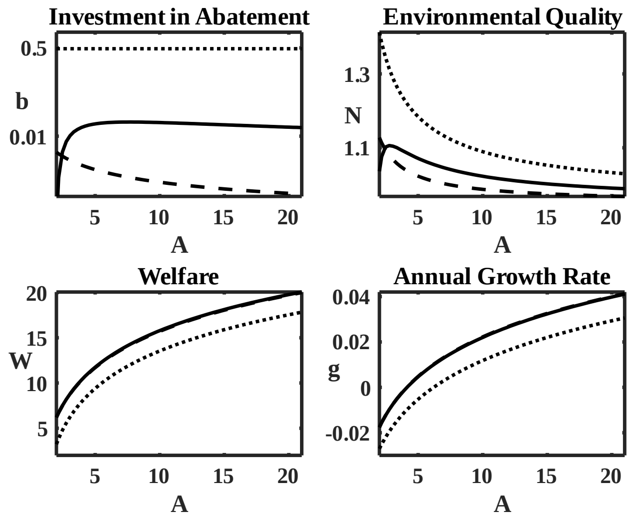

Figure 1: The effect of TFP (A) on the optimal investment in abatement (top left; logarithmic scale for b) and the long-run environmental quality (top right), annual growth rate (bottom right), and social welfare (bottom left), for three alternative policy objectives: maximal welfare (solid lines), maximal environmental quality (dotted lines), and maximal growth rate (dashed lines); $\psi = 1$.

As one would expect, the optimal investment in abatement is the highest under the environmental objective and the lowest under the growth objective, with the welfare-maximising share being in between. As shown above in (24), under the environmental objective the optimal share of investment in abatement depends only on α and γ, and in our benchmark parametrisation it is equal to 0.5. This is shown as a horizontal dotted line in the top left panel in both figures. With fixed ψ and varying A (Figs. 1 and 2), under two other objectives the abatement share is significantly lower, and, except for a very narrow range of low values of the TFP, the welfare-maximising abatement share is higher than the growth-maximising one. (Note that in all figures the scale for b is logarithmic.)The long-run levels of environmental quality under the three objectives follow the same ranking. Interestingly, the welfare levels and the growth rate are very close under welfare maximisation and under growth maximisation (the solid line and the dashed line are almost indistinguishable) and are higher than under the environmental objective.

Fig. 2 illustrates the effect of A on the long-run outcomes in the case with $\psi = 10$ and with all other parameters as in the benchmark calibration. Now the ranking of welfare levels under

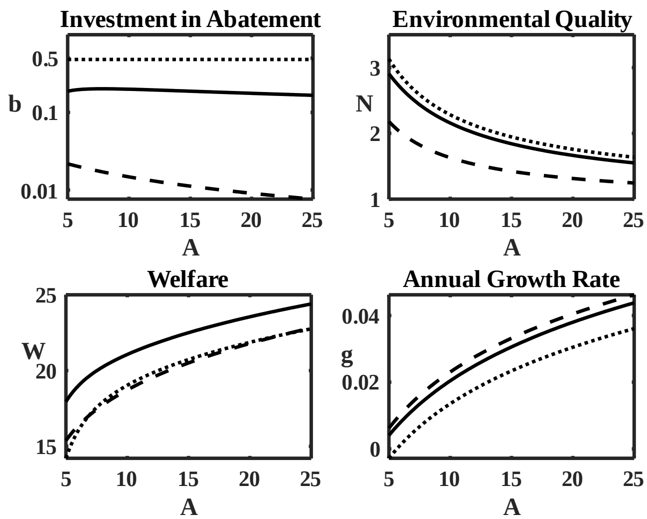

Figure 2: The effect of TFP (A) on the optimal investment in abatement (top left; logarithmic scale for b) and the long-run environmental quality (top right), annual growth rate (bottom right), and social welfare (bottom left), for three alternative policy objectives: maximal welfare (solid lines), maximal environmental quality (dotted lines), and maximal growth rate (dashed lines); $\psi = 10$.

the growth objective and under the environmental objective is non-monotone. For the lower values of the TFP the welfare is higher when the growth rate is maximised, and the converse is true for the higher values of the TFP. Thus, when the productivity of abatement technology is low ($\psi = 1$), the growth maximisation always delivers higher welfare than the environmental quality maximisation. However, when the productivity of abatement technology is sufficiently high ($\psi = 10$), the welfare is higher under growth maximisation when the TFP is low and it is higher under the environmental quality maximisation when the TFP is high.

With fixed A and varying ψ (Fig. 3), the ranking of the environmental quality levels and the growth rates under the three objectives follows the same trade-off pattern: the environmental quality is the highest (the lowest) and the growth rate is the lowest (the highest) under the environmental (growth) objective, whereas under the social welfare objective both take intermediate values. The welfare is, of course, the highest under the social welfare objective, but, as in the previous case, the relative ranking under two other objectives is non-monotone. When ψ, the productivity of the pollution abatement technology, is low, the growth-centred policy leads to

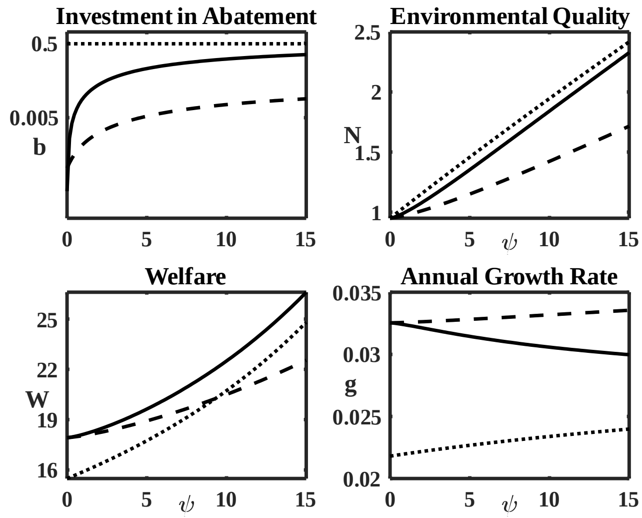

Figure 3: The effect of pollution abatement efficiency (ψ) on the optimal investment in abatement (top left; logarithmic scale for b) and the long-run environmental quality (top right), annual growth rate (bottom right), and social welfare (bottom left), for three alternative policy objectives: maximal welfare (solid lines), maximal environmental quality (dotted lines), and maximal growth rate (dashed lines).

the higher level of welfare than the environment-centred policy. This changes above the threshold level of ψ: under sufficiently high productivity of abatement technology environment-centred policy delivers higher welfare than the growth-centred policy.

It is not unreasonable to assume that in more advanced economies both the TFP and the efficiency of pollution abatement technologies are higher. This situation is illustrated in Fig. 4, for which we set $\psi = \frac{2}{3}A$. We see the same pattern: for a range of lower productivities in both the goods sector and the pollution abatement sector, the growth-maximising objective delivers higher social welfare. When the productivities are sufficiently high, the environmental objective leads to higher welfare.

These results suggests a rationale for the growth-environment trade-off. An advanced economy, with more efficient pollution abatement technologies, is better off if the policies focus on improving the environment, whereas a developing economy, with weaker abatement technologies, is better off if it ploughs resources in the economic growth. Moreover, if there is an increase in productivity of abatement in the latter, – for example, the country imports better equipment

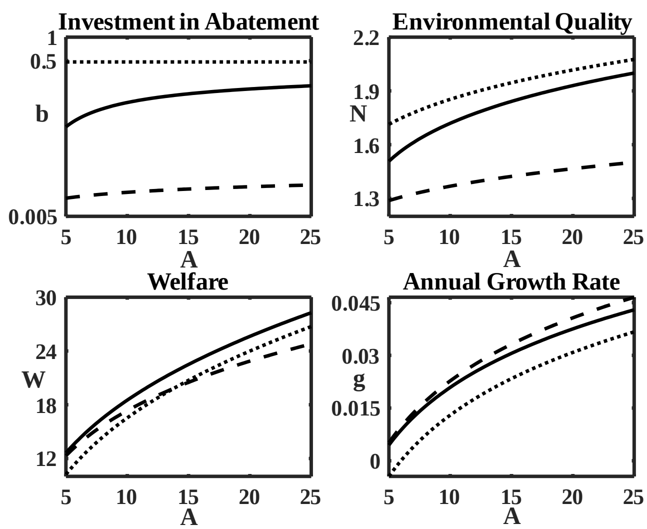

Figure 4: The effect of simultaneous change in TFP (A) and abatement technology productivity (ψ) on the optimal investment in abatement (top left) and long-run environmental quality (top right), annual growth rate (bottom right), and social welfare (bottom right), for three alternative policy objectives: maximal welfare (solid lines), maximal environmental quality (dotted lines), and maximal growth rate (dashed lines); $\psi = \frac{2}{3}A$.

or gains access to a better technology, – it will benefit from switching from the growth objective to the environmental objective.

6 Discussion

The contribution of our paper to the literature on environmental externalities and growth analysis is in that we demonstrate that the effect of pollution and environment degradation on time preferences may explain why the economic growth objective takes priority over the environmental considerations for countries where productivity is low and pollution abatement technologies are not very efficient. Accounting for the possible endogeneity and dynamics of time preferences is especially important for the evaluation of long-term projects, such as the projects aiming to reduce global warming and mitigate climate change (Freeman et al. 2015), which necessarily involves consideration of the welfare of generations in the distant future.

The crucial assumption in our model is the positive effect of the environmental quality on the time discount factor, reflecting stronger concern for the future. Galor and Ozak (2016) offered an 'agricultural' explanation of the link between the environment and farsightedness from a historical perspective alongside economic development. They theorise that a positive shock to the crop yield and the associated experience of higher return to agricultural investment could lead to a higher long-term orientation among the descendants of individuals who resided in such geographical regions in the contemporary period. In our model the effect is not linked to an increase in production or return to investment, but, instead, can be interpreted as an improvement in living condition, health and longevity, similar to Jouvet et al. (2010).[3] While Jouvet at al. (2010) use the assumption of the endogenous time preferences to analyse optimal taxation of income and health spending, our paper is close in spirit to Dioikitopoulos et al. (2020), and Goenka et al. (2020), who analysed the dynamic equilibrium effects of environmental policies when the negative externality of pollution is only through its effect on time preferences.[4]

In this paper we do not attempt to compute the first-best policy; the focus, instead, is on the

[3] Jouviet et al. (2010) present an overview of empirical evidence of the links between environmental quality and mortality risk.

[4] The consequences of the effect of environmental quality on time preferences were also studied, for example, in Le Kama and Schubert (2007) and Chu et al. (2016), but in these and some other works, in addition to time preferences, pollution was also assumed to affect directly the instantaneous utility and/or output.

welfare outcomes of the government pursuing different objectives, such as the economic growth or the environmental quality, or a measure of social welfare. To make the analysis tractable, we assume an exogenously fixed tax rate and define the optimal policy as the allocation of government expenditures between production sector and pollution abatement that achieves the given objective. Dioikitopoulos et al. (2020) analysed the long-run equilibria in an infinitely-lived representative agent model with a similar environmental policy, but assuming that both the tax rate and the proportions of revenues allocated between abatement and production are exogenously fixed. They show that this economy can exhibit multiple equilibria and an 'environmental and economic poverty trap'. Interestingly, their model predicts that an increase in TFP may lead to lower environmental quality and growth in the long run, if the rate of time preferences is sufficiently sensitive to the environmental quality. Goenka et al. (2020) analysed second-best pollution tax policy when pollution is generated by production, assuming that longevity, or the probability to survive into the second period (effectively, the discount factor), is decreasing in pollution and increasing in income. These counteracting effects of production on discount factor lead to multiplicity of equilibria in their model. First, the authors show that two long-run steady states can exist when the TFP is high enough, for an exogenously fixed rate of income tax used to fund pollution abatement. Next, they derive the sequence of second-best state-contingent taxes, assuming that the planner maximises the weighted sum of lifetime utilities of the current and all future generations, with the exogenously given geometrically declining weights. They showed that this economy can exhibit multiple interior steady-state equilibria and a poverty trap equilibrium, with or without abatement, depending, in particular, on the initial capital stock. Thus, the optimal abatement tax is zero when capital stock is below a threshold level and is weakly increasing above the threshold, suggesting that "...*economies that are close to or just emerging from a poverty trap might impose zero or low levels of environmental protection but eventually this will rise along the growth path.*" (Goenka et al. 2020, p. 13). This policy implication is qualitatively similar to the one suggested by our results, although our analysis in this paper is restricted to an interior long-run equilibrium that is independent of the initial conditions, and we do not consider transitional dynamics. The threshold between zero and positive pollution abatement in our framework is determined by the level of technologies rather than the level of endowments.

7 Conclusion

The motivation for this paper stems from the concept of the Environmental Kuznets Curve (EKC): as an economy grows, it pollutes the environment, but beyond a point enough resources can be generated to reverse environmental degradation. This leads to the important question of how much a benevolent government in a growing economy ought to spend on protecting the environment vis-à-vis its other objectives, such as maximising economic growth or maximising social welfare. This is precisely what we aimed to investigate in this paper, in a dynamic framework where pollution is generated by private consumption activities and the government decides on allocation of tax revenues between pollution abatement and investment in public capital infrastructure.

A distinctive feature of our model is the channel of the interaction between environmental degradation and the economy. We assume that the environment affects individual time preferences. This is different from the commonly used in the literature assumptions of the direct effect of pollution on utility or production. The assumption of endogenous time preferences reflects the observation that, as the quality of environment improves, so does health and longevity, and hence long-term orientation in the individual economic decisions. The agents ignore the negative externality from their consumption on the environment, and their myopic over-consumption and under-saving leads to lower environmental quality, lower economic growth, and lower welfare.

In this setting we calculated the long-run optimal allocation of public funds between production sector and pollution abatement. We found that, depending on the efficiency of the abatement technology and the TFP in the production sector, higher social welfare can be achieved either when the government's objective is to maximise economic growth or when the objective is to maximise environmental quality. Specifically, it is possible that in an economy with lower TFP and/or lower abatement efficiency, growth-maximising objective delivers higher welfare. This is reversed when TFP and/or abatement efficiency are sufficiently high: higher social welfare is achieved under the environmental objective.

Our results have important policy implications. Firstly, the model predictions give support to the reluctance of less developed countries to focus on environmental objective, as the efforts on enhancing economic growth may be socially more beneficial. Secondly, we show that even at the relatively low productivity in the real output sector, the environmental objective can lead to a higher welfare than the growth objective, provided that the efficiency of pollution abatement technology is sufficiently high. This suggests that developed countries could incentivise the environmental policy efforts of the less developed countries by sharing with them advanced abatement technologies. While these results were obtained in a calibrated model, it would be interesting to investigate the relationship among the TFP, the productivity of pollution abatement technology, and environmental quality from an empirical standpoint based on our theory. These aspects are in the agenda for the future work.

References

Andreoni J. and Levinson, A. (2001). The simple analytics of the environmental Kuznets curve. *Journal of Public Economics*, 80, 269 – 286.

Barro, Robert J. (1990). Government spending in a simple model of endogeneous growth. Journal of Political Economy 98 (5), S103 – S125.

Chu, H., Lai, C-C., and Liao, C-H. (2016). A note on environment-dependent time preferences, *Macroeconomics Dynamics*, 20(6), 1652 – 1667.

Dioikitopoulos E. V., Ghosh S., Karydas C., and Vella, E. (2020). Roads to prosperity without environmental poverty: The role of impatience. *Economic Letters*, 186 (1), Article 108870.

Freeman, M. C., Groom, B., Panopoulou, E., & Pantelidis, T. (2015). Declining discount rates and the Fisher Effect: Inflated past, discounted future?. *Journal of Environmental Economics and Management*, 73, 32 – 49.

Galor O., and Ozak, O. (2016). The agricultural origins of time preference. *American Economic Review*, 106(10), 3064 – 3103.

Grossman, G. M. and Krueger, A. B. (1995). Economic growth and the environment. *Quarterly Journal of Economics*, 110, 353 – 377.

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

Lines, M. (2005). Intertemporal equilibrium dynamics with a pollution externality. *Journal of Economic Behavior and Organization*, 56, 349 – 364.

Pittel, K. (2002). *Sustainability and Endogenous Growth.* Cheltenham, UK: Edward Elgar.

Vella, E., Dioikitopoulos, E. V. and Kalyvitis, S. (2015). Green spending reforms, growth and

welfare with endogenous subjective discounting. *Macroeconomic Dynamics*, 19, 1240 – 1260.

Viscusi, W. Kip, Huber, J. and Bell, J. (2008). Estimating discount rates for environmental

quality from utility-based choice experiments. *Journal of Risk and Uncertainty,* 37 (2), 199 – 220.

Yanase, A. (2011). Impatience, pollution and indeterminacy. *Journal of Economic Dynamics and Control*, 35, 1789 – 1799.