Economic Growth, Environment, Health and Well-being

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Abstract

Our paper presents a two-period overlapping generations model that incorporates environmental and health-related issues. Through defensive expenditures, represented here by healthcare and abatement expenditures, the agent can mitigate the negative effect of a bad environment on his utility. A first stage focuses on a simple production function with no technological externality. We find that a steady state exists and is stable for a positive stock of capital and a positive stock of pollution. The dynamics to reach that equilibrium might either be monotonic or induce an overshooting scenario, depending on the initial condition of environmental quality. A second stage focuses on a model of endogenous growth, where the production function exhibits a technological externality of previous period stock of capital. We find that endogenous growth is possible under certain condition and that it will be coupled to further environmental degradation. A poverty trap might also be encountered for economies starting with a low initial stock of capital.

1 Introduction

Over the last decades, the question of the sustainability of economic growth as well as the link between economic growth and well-being have been extensively debated (see a.o. Jackson, 2009 or Victor, 2008). However, those debates have remained largely ignored by traditional endogenous growth model. These issues can in fact be hardly discussed in a standard endogenous growth framework, which often neglects environmental constraints and hypothesizes de facto an always positive link between income growth and agents' well-being. In those models, an everlasting economic material growth seems possible and it is almost unavoidably coupled with continuous welfare improvements.

The question of the sustainability of economic growth or of the relationship between economic growth and the environment is a topic that has been largely discussed in the last decades, either empirically or theoretically. Dasgupta and Heal (1974) and Solow (1974) were among the first ones to introduce the environment in a theoretical model. They argued that, given the perfect substituability between natural capital and man-made input (whether physical or human capital), long run growth was possible even when a natural resource was at stake. Others followed and developed more sophisticated environmental constraints (among others Beltratti, Chichilnisky and Heal in Goldin and Winters, 1995, that introduced a regeneration process for the natural capital), but the validity of such models were still highly criticized by environmental and ecological economists, notably for the perfect substitution hypothesis (Daly, 1997).

On an empirical basis, the link between economic growth and environmental quality is still strongly discussed by many authors. Grossman and Krueger (1991), for example, introduced the concept of Environmental Kuznets Curve (EKC) that states that, once the economies are sufficiently developed, they will cease to focus only on material accumulation and they will start to take care of the environment. We might obtain an inverted U-shaped curve (the EKC) for the concentration (or the emission) of some pollutants regarding the GDP level at which it has been observed. This concept has been heavily criticized on its methodological standpoint or on the nature of the pollutants under study (among others Stern, 2004). Stating that economic development is a solution to reduce our impact on the environment is therefore strongly debated by many authors and the decoupling of economic growth with environmental degradation as a whole is still far from being obvious.

On the other hand, the positive link between GDP growth and happiness has been questionned several times (a.o. Easterlin, 1995). In particular, Leipert (1989) developed the idea that economic growth constraints the agents to devote a part of their income to defensive expenditures, which are means to "eliminate, mitigate, neutralize, or anticipate and avoid damages and deterioration that the economic process of industrial societies has caused to living, working, and environmental conditions". In traditional endogenous growth models, defensive expenditures are usually limited to abatement activities that mitigate the effect of pollution. But economic growth and its environmental aspects induce much more defensive expenditures that should be introduced in growth models, such as health care, a necessity to compensate the impact of a more stressed way of living or a deteriorated environment. For instance, Finkelstein, Luttmer and Notowidigdo (2011) showed that the marginal utility of consumption was decreasing with the health status of the agent.

Health has already been incorporated in some models (a. o. Chakraborty, 2004) as a determinant of the agents' longevity. In those models, the agent does not determine his own health status since it only depends on the state of the environment and on public expenditure in healthcare. The aim of our research is to extend this analysis by letting the agent choose his own level of healthcare to offset the negative impact of the environment on his utility. The agents have therefore two possible defensive expenditures to mitigate the effect of a bad environmental quality : abatement activities and healthcare.

The first section will present the model in a typical OLG framework with a Cobb-Douglas production function. Section two will then analyse the steady states of the model, as well as their stability, while section three looks at the dynamics of this economy before reaching the steady states. Finally, the last section will look at a model of endogenous growth where the stock of the capital of the previous period exhibits a positive technological externality in the actual production function.

2 The model

The setup of our model is relatively similar to the one proposed in John and Pecchenino (1994) for computational and comparative purposes. We analyse an overlapping generations model where agents live for two periods and we consider no population growth, such that each agent born in period 1 gives birth to another one in period 2. We also normalize this population to unity.

Instead of looking at environmental quality, we here analyse its opposite, the pollution stock P_t, which is set equal to zero when no human activity occurs and grows when economical production takes place. We also suppose that the environment has the ability to regenerate itself over part of the damages encountered by human activity each period. Chevé (2000) analysed the desirable properties of a pollution regeneration function, such as allowing it to be increasing or decreasing relative to the actual pollution stock, but we chose to stick to a standard constant rate of decay b for computational purpose. The analysis of a more sophisticated regeneration function in our setup might be the scope of future research. The pollution stock P_t is therefore a function of its previous state P_{t-1} minus the part of it that has been regenerated (or assimilated by the environment) over the period. It is also positively affected by the agents' consumption of the previous period c_{t-1} but negatively correlated to their spendings in pollution abatement expenditures m_{t-1}, according to an additively separable pollution function. We can therefore write the following equation for the pollution stock :

$$P_{t+1} = (1-b)\, P_t + \beta\, c_t - \gamma\, m_t$$

where $0 < b < 1$, $0 < \beta < 1$ and $0 < \gamma < 1$

Agents live for two period. As in some existing OLG formulations, they work during the first period and only consume during their second period. In the first period, they receive a wage w_t that they can either save for next period (s_t) or spend in pollution abatement m_t. In the second period, what they saved previously is returned with some interest and can be spent in consumption c_{t+1} or in health expenditures h_{t+1}. The constraints of the agent over the two periods can therefore be summarized as follows :

$$w_t = s_t + m_t$$

$$(1 + r_{t+1})\, s_t = c_{t+1} + h_{t+1}$$

In period t, each agent born in that period maximizes his utility function that has the following form :

$$U_t = B(S_{t+1})\, u(c_{t+1})$$

where S_{t+1} is the agent's health status and c_{t+1} his consumption when old. We assume $u(c_{t+1})$ obeys the traditionnal constraints on utility functions, i.e. it is twice continuously differentiable, strictly increasing and concave ($u'(c)>0$, $u''(c)<0$ and $\lim_{c\to 0} u'(c) = +\infty$). Based upon the results of Finkelstein, Luttmer and Notowidigdo (2011), we assume that bad health decreases utility, so we choose to assume a function $B(S_{t+1})$ that obeys a S-shape between 0 and 1 under the following formulation :

$$B(S_{t+1}) = \frac{S_{t+1}}{(1 + S_{t+1})}$$

We include our new kind of negative expenditures in the utility function of the agents through this health status. Defensive expenditures (in this case, healthcare expenditures) are made to counteract the negative effect of a bad environment. Therefore, the agent's health status is determined by both the pollution stock P_{t+1} that acts negatively on the function S_{t+1} and the healthcare expenditures h_{t+1} that offset this negative impact on his utility. The agent's health function can then be written as :

$$S(P_{t+1},\, h_{t+1}) = \frac{h_{t+1}^{\varphi}}{P_{t+1}^{\chi}}$$

where $0<\varphi<1$ and $0<\chi<1$ are parameters that determine how strong the health status is affected by healthcare expenditures and pollution. As in Palivos and Varvarigos(2010), we assume that one unit spent in healthcare service has a larger impact on the health status of the agent than the negative effect of one unit spent in consumption (i.e. $\chi \leq \varphi$). This setting of our utility function answers at best the issues developed in Finkelstein, Luttmer and Notowidigdo (2011).

Our representative firm operates in a perfectly competitive market and maximise its profit. We assume that it uses a production function of the form $Y_t = \psi(K_{t-1})F(K_t, N_t)$. As in most models, we assume $F(K_t, N_t)$ exhibits constant returns to scale. Therefore, and since our population is normalized to one, we can write output per worker in the form $y_t = \psi(k_{t-1})f(k_t)$ where k_t represents the capital per worker. We assume the usual function properties for $f(k_t)$, i.e. $f(0) = 0$, $f'(k_t) > 0$, $f''(k_t) \leq 0$ and $kf''(k_t) + f'(k_t) > 0$. As in John and Pecchenino (1994), we also suppose that our production function might exhibit endogenous growth through the technological externality $\psi(k_{t-1})$ of last period's capital ($\psi'(k_{t-1}) \geq 0$). We don't impose any condition on its second derivative for the moment, so $\psi(k_{t-1})$ might be either convex or concave. Since it depends on the stock of capital that has been accumulated in the previous period, it is perceived as a constant to the representative agent and production still yields constant returns.

Our representative agent born in period t maximizes his expected lifetime utility

$$U_t = B(S_{t+1})\, u(c_{t+1})$$

by choosing c_{t+1}, m_t and s_t subject to the following constraints :

$$w_t = s_t + m_t \tag{1}$$

$$(1 + r_{t+1})\, s_t = c_{t+1} + h_{t+1} \tag{2}$$

$$P_{t+1} = (1-b)\, P_t + \beta\, c_t - \gamma\, m_t \tag{3}$$

$$c_{t+1},\, m_t,\, s_t \geq 0$$

3 Optimality conditions and equilibrium without technological externality

This section analyses the equilibrium when no technological externality occurs, so when $\psi(k_{t-1})$ is set equal to 1 for all k. Section 5 will then analyse what happens in a model of endogenous growth, when $\psi(k_{t-1}) \neq 1$.

The equilibrium in our model is the sequence $\{w_t, s_t, m_t, k_t, P_t, h_{t+1}, c_{t+1}, r_{t+1}\}$ such that agents maximise U_t subject to the constraints (1) to (3) ; firms maximise profits ; market clears ; and $\{k_1, P_1\}$ are given. As the firms maximize profits, we have the following first order conditions for both the wage and the interest rate :

$$r_{t+1} = \boldsymbol{f}'(k_{t+1}) - \delta$$

$$w_t = f(k_t) - k_t\, \boldsymbol{f}'(k_t)$$

From the agent's maximization problem, we can derive an expression that defines healthcare expenditures as a function of the stock of pollution and the stock of capital (through the interest rate) as well as the first-order condition linking consumption, healthcare expenditures, pollution and capital :

$$h_{t+1} = \frac{\varphi\, P_{t+1}(1+\, r_{t+1})}{\gamma\chi}$$

$$\frac{\boldsymbol{u}'_c}{u(c_{t+1})} = \frac{P_{t+1}^{\chi-1}\gamma\chi}{(1+\, r_{t+1})(\, P_{t+1}^{\chi} +\, h_{t+1}^{\varphi})}$$

Using those dynamical equations, we can illustrate the situation at the steady state $(\bar{k},\, \bar{P})$ in an P- k space by rewriting our environmental constraint, which gives the following law of motion for the pollution at its steady state (SSE)

$$\bar{P} = \frac{\gamma\chi}{\varphi\beta\,(1+\bar{r}) + \gamma\chi\, b}\,(\bar{k}\boldsymbol{f}'(\bar{k})(\beta+\gamma) - \gamma\, f(\bar{k}) + \bar{k}\,(\beta(1-\delta)+\gamma))$$

We will use the well-known constant inter-temporal elasticity of substitution (CIES) utility function in order to express the first-order condition exclusively in terms of $\bar{P}$ and $\bar{k}$. It has the form

$$u(c_{t+1}) = \frac{c_{t+1}^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}}$$

and it usually imposes $\sigma > 0$ (and $\sigma \neq 1$, otherwise we obtain a logarithmic utility function where $u(c_{t+1}) = ln(c_{t+1})$) so that the hypothesis exposed previously on the utility function is satisfied. Since our utility function does also depend on the health status of the agent, another condition on σ has to be imposed in our model in order to have a positive marginal rate of substitution between marginal utility of consumption and marginal utility of health. Since

$$U_t = \frac{S}{1+S}\frac{c_{t+1}^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}}$$

the substitution between the marginal utility of consumption and the marginal utility of health can be written as

$$\frac{\boldsymbol{u}'_c}{\boldsymbol{u}'_S} = \frac{\sigma}{\sigma-1}\frac{S(1+S)}{c}$$

Therefore, relative to the value of σ, the marginal rate of substitution between the two marginal utilities can be summarized as follows :

- $\frac{\boldsymbol{u}'_c}{\boldsymbol{u}'_S} < 0$ if $\sigma < 1$
- $\frac{\boldsymbol{u}'_c}{\boldsymbol{u}'_S} \to +\infty$ if $\sigma = 1$
- $\frac{\boldsymbol{u}'_c}{\boldsymbol{u}'_S} > 0$ if $\sigma > 1$

Since we assume a positive substituability between consumption and the health status of the agent in the utility function, we need $\sigma > 1$, where $\sigma = 1$, which is equivalent to a logarithmic utility function in c_t, is our uttermost case. The first order condition of the utility maximization problem can finally be rewritten at its steady state (FOC) as

$$\varphi + \frac{\sigma-1}{\sigma} + \bar{P}^{\varphi-\chi}(\frac{\varphi(1+\bar{r})}{\gamma\chi})^{\chi}(\frac{\sigma-1}{\sigma}) - \frac{\bar{k}\gamma\chi}{\bar{P}} = 0$$

where $\sigma > 1$. Using the implicit function theorem, it can be prooved that there this equation defines a positive relationship between P and k. We will therefore always have a growing function in a P- k space that we can simplify as

$$\bar{P} = \Phi(\bar{k})$$

The two equations (SSE and FOC) are illustrated in figure 1 for a Cobb-Douglas production function (i.e. $y_t = Ak_t^{\alpha}$). For computational purposes, we illustrate in this figure our uttermost case where σ is set equal to 1, which is the same as a logarithmic utility function for consumption. This allows us to greatly simplify our FOC equation so that $\bar{P}$ now becomes linear in $\bar{k}$. We also calibrate all other parameters with standard values that are listed below.

$$\begin{array}{ccc} \beta = 0.4 & b = 0.3 & \delta = 1 \\ \gamma = 0.2 & \varphi = 0.7 & \chi = 0.3 \\ \alpha = 0.3 & A = 20 & \sigma = 1 \end{array}$$

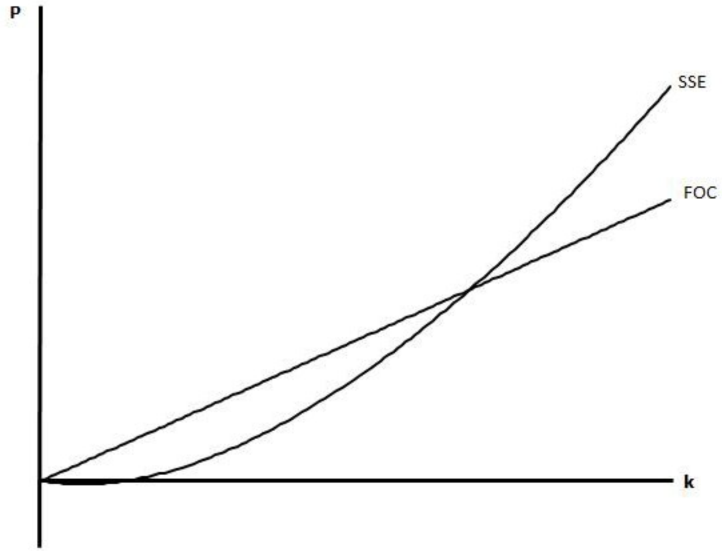

Figure 1 – Interior equilibrium for SSE-FOC conditions

The economy is at its steady state where the two curves intersect. As we can see, the equilibrium can only arise for a positive stock of pollution, given the FOC line is always above 0 in P (in the case of a logarithmic utility function). This result is quite different than the equilibrium situation observed by John and Pecchenino (1994). In their paper, the steady state may occur for a positive capital stock AND a positive environmental quality, meaning that economic activity, through abatement expenditures, might provide an environment that is cleaner than in the absence of any economic production.

We can show that this equilibrium is always stable as long as the SSE curve crosses the FOC line from below, given the assumption $\chi<\varphi$ holds. If we incorporate (1) and (2) in (3) and linearize this equation of pollution accumulation, we obtain

$$(k_{t+1} - \bar{k}) = \left[\frac{(1-b)\boldsymbol{\Phi'} - \beta\boldsymbol{h'} + \beta(1-\delta) + \beta\boldsymbol{f''}k + \beta\boldsymbol{f'} + \gamma k\boldsymbol{f''}}{\boldsymbol{\Phi'} - \gamma}\right](k_t - \bar{k})$$

If we now derive our SSE function (for computational purposes, we keep our health function simply as $h(k)$), we obtain that

$$\boldsymbol{SSE'} = \frac{[\beta(1-\delta) + \beta\boldsymbol{f''}k + \beta\boldsymbol{f'} - \beta\boldsymbol{h'} + \gamma k\boldsymbol{f''} + \gamma]}{b}$$

Therefore, our linearized function of pollution accumulation can be simplified as

$$(k_{t+1} - \bar{k}) = \left[\frac{(1-b)\boldsymbol{\Phi'} + b\boldsymbol{SSE'} - \gamma}{\boldsymbol{\Phi'} - \gamma} \right] (k_t - \bar{k})$$

This equilibrium will be stable if and only if

$$\frac{\boldsymbol{SSE'} - \boldsymbol{\Phi'}}{\boldsymbol{\Phi'} - \gamma} < 0$$

As long as $\boldsymbol{\Phi'} > \gamma$, we know that our steady state is stable if the SSE curve crosses the FOC curve from below. The condition $\boldsymbol{\Phi'} > \gamma$ might even disappear if we look at the particular case of a logarithmic utility function, so when $\sigma = 1$. In this case, the FOC equation becomes linear and can be simplified as

$$\bar{P} = \Phi(\bar{k}) = \frac{\bar{k}\gamma\chi}{\varphi}$$

The condition $\boldsymbol{\Phi'} > \gamma$ is now satisfied, as long as our hypothesis regarding χ and φ (i.e. $\chi \leq \varphi$) holds. We can therefore state that the equilibrium illustrated in figure 1 is stable under a reasonable hypothesis. Outside the logarithmic case, this steady state will only be stable if and only if $\boldsymbol{\Phi'} > \gamma$, which is not a too restrictive condition since the parameter γ should be relatively small.

4 Dynamics

The choice of an overlapping generations model was made due to its intergenerational perspectives. We will now look at the dynamics of our model to see how the variables behave before attaining their steady states. This section will look at two different scenarios : The first one focuses on an economy that starts with a low level of capital coupled with a low level of environmental degradation whilst the second one explores the case of another that starts with the same level of capital but with a slightly higher initial stock of pollution. We will see how such a small difference in the initial condition on the stock of pollution might induce a totally different dynamic path to attain the same equilibrium.

4.1 scenario 1

Our first scenario studies how an economy with low initial capital stock and an environment that is relatively clean grows to attain the steady state that has been detailled in section 3. We also set the initial condition on defensive expenditures to zero.The calibration is similar to the one used previously, but we choose here not to focus on our uttermost case of a logarithmic utility function. That choice was made previously for computational purposes, but we don't need it anymore and we choose to illustrate a scenario where the substitution of marginal utility between consumption and health status is larger than one, but is not as high as infinity (which is the case when σ is set to 1, as exposed previously). We therefore set $\sigma = 1.5$ to obtain a reasonable substitution between the two variables. The dynamics for $k_t, y_t, c_t, B_t, P_t, h_t, m_t$ and U_t are illustrated in figure 2. Note that, graphically, what we call "the first period" is represented by period two in the simulation since all variables (excepted the predetermined ones) start at zero. The initial values of the predetermined variables (k and P) are thus the initial condition for the simulation of the entire model.

As we can see in this figure, the growth of all the variables to reach their steady states is monotonic. They all grow rapidly during their two first periods (especially during the first one) and, by the fourth period, they've nearly all reached their steady state values. We can also observe that the economic growth affects the environmental quality (the stock of pollution rises)

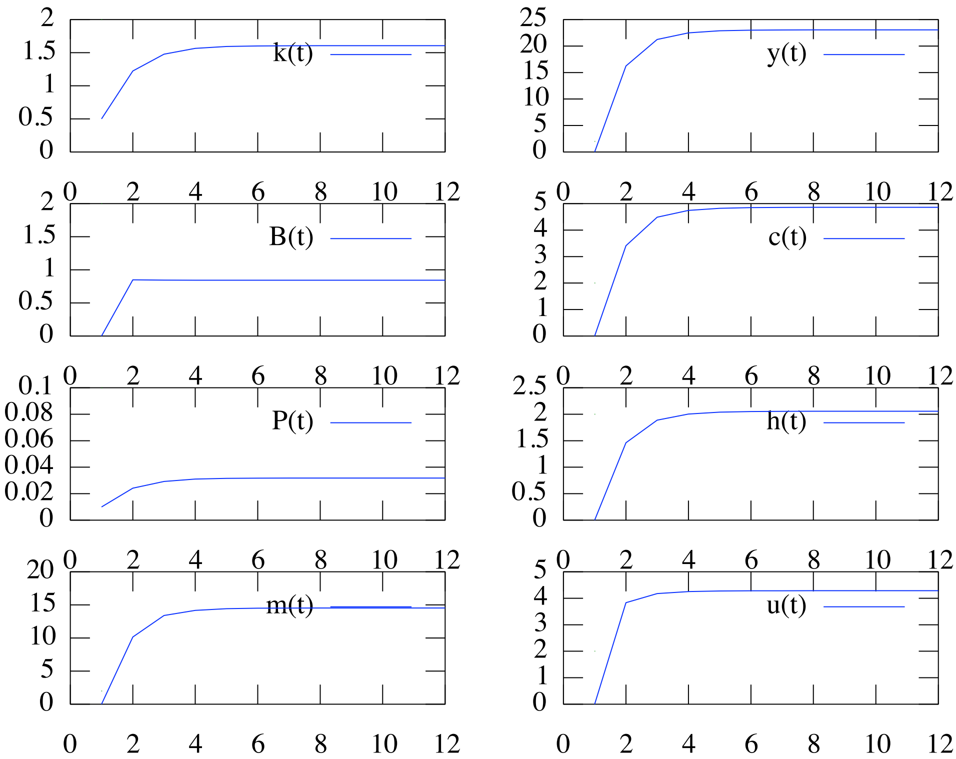

FIGURE 2 – Dynamics for $k_t, y_t, B_t, c_t, P_t, h_t, m_t$ and U_t with a low initial stock of capital and pollution

that behaves roughly according to the same pattern, even though the growth of the pollution stock is much lower (in percentage) than the growth of the production, or even than the growth of consumption. We can also see that the agents choose to invest in defensive expenditures (both abatement and healthcare expenditures) as soon as the simulation starts. The agents seem to anticipate their effect on the environment for the following periods and therefore choose defensive expenditures to counteract the anticipated impact of pollution on their utility. Those defensive expenditures are quite high (abatement expenditures at its steady state is nearly as high as three times the consumption, while healthcare is close to half the consumption) and represent a high share of total production. Finally, one can also point out that health is quite an issue for the agents since it reaches its steady state directly after the first period (variable B in figure 1) and it is close to its maximum value ($B = 1$ meaning that the health status of the agent is perfect and that utility now only depends on consumption). That's why the pattern of utility is roughly similar to the consumption behaviour.

4.2 scenario 2

Our second scenario explores the behaviour of an economy that starts with the same level of capital as the first scenario, but with an environment that is slightly more degradated. The difference between the two initial condition in the pollution stock is not quite high compared to its steady state value : in the first scenario, pollution started at about a third of its steady state value, while it starts at about a half of its equilibrium level now. The initial value of this second scenario is only 50 percent higher but, as we will see, it reveals a completely different growth path for all variables. Besides those initial conditions, the calibration of our parameters remains exactly the same. The dynamics for $k_t, y_t, c_t, B_t, P_t, h_t, m_t$ and U_t are illustrated in figure 3.

As we can see in figure 3, the behaviour of our variables is now completely different with this

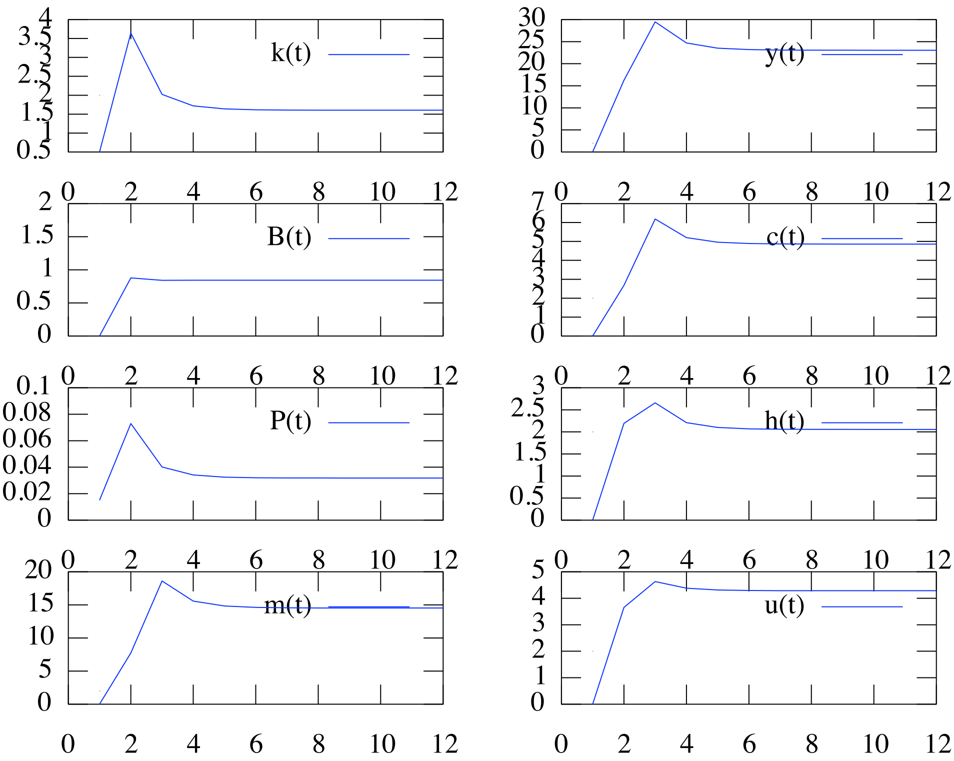

FIGURE 3 – Dynamics for $k_t, y_t, B_t, c_t, P_t, h_t, m_t$ and U_t with a low initial capital stock but a relatively high initial pollution stock

new initial stock of pollution. We can observe in this simulation a kind of overshooting, where agents tend to overaccumulate in a first stage before the economy collapses to finally reach its steady state.

The behaviour of the agents along this path can be summarized as follows. In the first period, the old agents have a low consumption given their initially low capital stock. On the other hand, the young agents have a stronger incentive to save and accumulate capital for the next period to increase their consumption possibilities than to invest in abatement expenditures since the environment is not much of a problem for the moment. Therefore, they reach period two with a quite high capital stock (thus a high production as well) that allows the old to consume much more than their ancestors (though the increase in consumption is lower than in sceanrio 1). Nevertheless, they will also need to invest much more in healthcare since the environment has been severely damaged due to the lack of expenditures in abatement. However, their utility keeps increasing thanks to better material conditions. For the young ones, the situation is quite different : Now that the environment has been severely damaged by the old agents, they will need to focus much more on abatement expenditures, which forces them to lower their savings. Therefore, their production and consumption in the third period (when they are old) is reduced compared to the situation of their ancestors. They cannot sustain such a high production/consumption as before, the economy collapses. The production of their parents was too high to be sustained by the environment, which led to an overshooting in capital accumulation. Besides their consumption, they also have to reduce their healthcare expenditures for two reasons : the environment is less damaged (since they had to highly increase abatement in the previous period) and they have less income. Their health status therefore slightly decreases. The effects of both decreases in consumption and health status finally lowers their utility relative to the previous generation. For the young ones now, the environment is not as much of an issue as for their ancestors, so they may now decrease their abatement efforts and increase their saving rate, even though capital accumulation is still lower due to the relatively smaller size of the actual economy. The following generations will then observe a progressive regeneration of the environment, but a relative impoverishment due to a decline in capital accumulation. What is interesting in this scenario is that the observed breakdown of the economy is not due to physical limits of the environment or any kind of irreversibility of the environmental degradations, but to the agents' choice that depends uniquely on their utility, through the health functions

This overshooting scenario largely depends on the calibration of the parameters. For instance, φ plays a large role since it represents the incentive to choose the curative option (healthcare expenditures) instead of the preventive one (abatement expenditures). By choosing h_{t+1} instead of m_t to mitigate the impact of the pollution on your utility, you also choose to invest more of your wage for the next period, so it contributes to capital accumulation. If we change the calibration of that parameter (let's say that $\varphi = 0.5$ for example), both initial conditions of scenario 1 and 2 lead to monotonic growth of all variables to their steady states. We won't observe an overshooting anymore in the second situation because the healthcare solution becomes less interesting to the agents (the marginal efficiency of healthcare expenditures has been reduced) in order to balance the effect of pollution. But if we also increase the initial stock of pollution sufficiently high, it is possible to find another overshooting scenario.

As we have seen with the two scenarios, the two economies finally converge to the same steady state at the end through different paths. One grows monotically to its equilibrium while the second one has to go through an overshooting situation (overaccumulation of capital that induces too much pressure on the environment) before collapsing and reaching its steady state. The only difference between the two being their initial state of the environment. We see that they behave differently even though we don't impose any irreversibility of environmental degradation, which might be an important issue in many cases, mainly in overshooting situation, when the regeneration of the environment might be affected. Incorporating a more sophisticated regeneration scheme for the environment (as well as a more sophisticated environmental degradation function) would probably enlarge the scope of our research. For example, Chevé (2000) analyses different regeneration functions that depend on the actual state of the environment and uses a pollution function where degradation and abatement are not separable anymore.

5 Endogenous growth

This section will look at the optimality conditions and the equilibrium of our model when technological externality occurs, i.e. when $\psi(k_{t-1}) \neq 1$. As explained earlier, endogenous growth is made possible in our model through the technological externality of last period's capital $\psi(k_{t-1})$ that is included in the production function ($y_t = \psi(k_{t-1}) f(k_t)$). Section 3 analyses the equilibrium that is reached when no technological externality occurs ($\psi(k_{t-1}) = 1$), we will now see what happens when this assumption is relaxed.

The setup of the model remains roughly the same, with the same budget constraints over the two periods for the agent and the same pollution accumulation function. For the agents, nothing really changes since this externality depends on previous perdio's capital stock, so it is perceived as a constant for them. What changes is the profit-maximizing conditions for the firms. Since the factor $\psi(k_{t-1})$ is different from one, the interest rate and the wages are fixed by the following equations :

$$r_{t+1} = \psi(k_t)\, \boldsymbol{f}'(k_{t+1}) - \delta$$
$$w_t = \psi(k_{t-1})\, f(k_t) - k_t \psi(k_{t-1}) \boldsymbol{f}'(k_t)$$

This has also an impact on c_{t+1} and h_{t+1} since they both depend on $(1 + r_{t+1})$. The SSE and the FOC condition are now defined as :

$$\bar{P} = \frac{\gamma\chi}{\varphi\beta\left(1+\psi(\bar{k})\boldsymbol{f}'(\bar{k})-\delta\right)+\gamma\chi\, b}\left(\bar{k}\psi(\bar{k})\boldsymbol{f}'(\bar{k})(\beta+\gamma)-\gamma\psi(\bar{k})\, f(\bar{k})+\bar{k}\left(\beta(1-\delta)+\gamma\right)\right)$$

$$\varphi+\frac{\sigma-1}{\sigma}+\bar{P}^{\varphi-\chi}\left(\frac{\varphi(1+\psi(\bar{k})\boldsymbol{f}'(\bar{k})-\delta)}{\gamma\chi}\right)^{\chi}\left(\frac{\sigma-1}{\sigma}\right)-\frac{\bar{k}\gamma\chi}{\bar{P}}=0$$

$\psi(\bar{k})$ is a positive function of k, but it might either be concave or convex. If we state that it is a concave function of k, it won't affect our results very much and the situation will remain roughly the same as the one illustrated in figure 1. Besides, if we assume $\psi(\bar{k})$ to be a convex function of k (i.e. $\boldsymbol{\psi}'(k)>0$ and $\boldsymbol{\psi}''(k)>0$), the situation is slightly different and endogenous growth now becomes a possibility. This situation is illustrated in figure 4. Again, for computational purposes, we decide to show the situation of a logarithmic utility function ($\sigma=1$), so our FOC condition becomes a linear combination of k in P. All other parameters are calibrated as before.

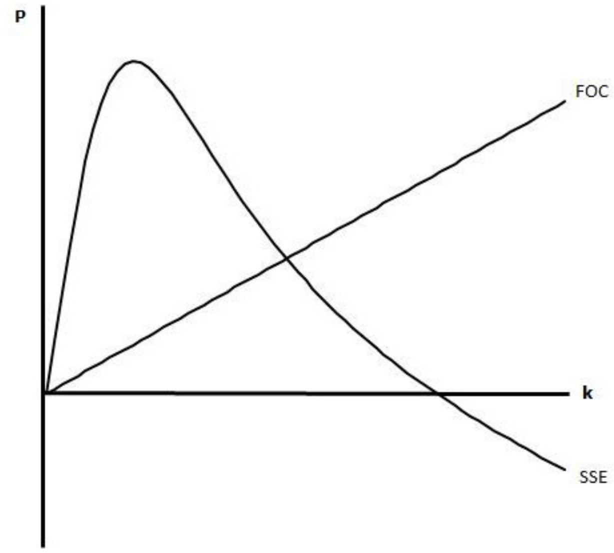

FIGURE 4 – Interior equilibrium for SSE-FOC conditions with endogenous growth

As we can see in figure 4, we now have two steady states. Since the stability condition is not affected by a technological externality different from 1, we still have that an equilibrium is stable if and only if the SSE curve crosses the FOC line from below. Therefore, we have one stable and one unstable steady state. The stable one is at 0 (if $\sigma \neq 1$, the equilibrium won't be situated at 0 but at a low capital/low pollution level) and the unstable one for a positive capital and pollution stock. In the simplest model without any technological externality, we also had technically two possible steady states in the logarithmic situation, a stable and an unstable one. The difference with this new situation resides in the poverty trap at $k=0$ and $P=0$: it was unstable in section 3 and it is now stable. Therefore, in section 3, no economy will ever reach such an equilibrium since they all start with a positive initial stock of capital, any economy will then converge to the same steady state. In the scenario with technological externality, however, since the steady state ($k=0$ and $P=0$) is now stable, it will attract to it all the economies that start with a sufficiently low level of initial capital (they will be stuck into the poverty trap in the long run) while all other countries that start with a sufficiently high initial capital stock will experience sustained growth. In the logarithmic case, since the balance growth path is situated along the FOC line, this sustained growth will be coupled to further environmental deterioration. This is a huge difference regarding the John and Pecchenino (1994) paper where sustained growth takes place with environmental improvement for economies that start with a high enough initial capital stock.

6 Conclusion

The relationship between economic growth and the state of the environment has been largely debated throughout the last decades, empirically as well as theoretically. As empirical studies tend to usually stress out, even though we can observe an improvement for some environmental indicators, the decoupling of environmental quality and economic growth is not a stylized fact so far and environmental quality usually deteriorates with economic activity. On the other hand, theoretical analysis tend to state that sustained growth coupled to environmental improvements is possible, or that growth may be sustainable.

We constructed a two-period overlapping generations model where agents suffer illness from bad environmental quality. To offset this inconvenience, they can invest in defensive expenditures, either in abatement or healthcare (the preventive versus the curative option). This setup allows us to find a steady state where both the capital stock and the pollution stock are positive. When endogenous growth is introduced in our model, it means that sustained growth is possible, but only linked to further environmental degradation. The dynamics of our model also renders a kind of overshooting scenario possible. Depending on the initial condition on the stock of pollution, agents may tend to overaccumulate capital regarding what is efficient, which leads to a collapse of the economic system in following periods. Our setup therefore excludes any form of sustainability in a decentralized economy.

Our setup relies upon quite restrictive hypothesis and restrictions for computational and comparative purposes. Further extensions should be introduced in many directions. First of all, our pollution accumulation function might be improved and may become much more sophisticated. Imposing a non-additive separability between the negative impact of consumption and the positive impact of abatement might be more realistic, as well as stating that economic activity as a whole deteriorates the environment instead of just the agent's consumption. Besides, the environment's regeneration function is probably not represented at best by a constant regeneration factor. A regeneration that depends on the stock of pollution might be much more realistic (Chevé, 2000). Secondly, the hypothesis made on the overlapping generations setup itself may be changed. Stating that consumption and healthcare expenditures only takes place in the second period while agents only work during the first one is also quite restrictive and may be relaxed in later studies. Finally, a better sensitivity analysis on the relevance of the calibration of the parameters should be made to know how the steady state and/or the dynamics are affected by a slight change in a parameter's value.

7 Bibliography

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