Pollution perception

An inquiry into intergenerational equity *

Ingmar SCHUMACHER[†], Benteng ZOU[‡]

July 2005

Abstract

In this article we extend the recent literature on overlapping generations with a pollution sector by allowing generations to have a certain pollution perception with regards to the stock of pollution. Pollution perception, assumed to be part of the generations' preferences, can be either a concern for the flow of pollution only, or for the stock, or anything in between. We analyse the different steady states for their implications on intergenerational equity.

Our main result is that if generations are only partly concerned with the actual stock of pollution, then periodic cycling will occur. We use the concept of Intergenerational Moral Intuition to analyse this periodic cycling. Our main policy conclusion is that decision makers who would like to achieve intergenerational equitable outcomes must either use the maximin criterion or take decisions spanning several generations in order to avoid the period cycling effect.

JEL Classification: Q20, I31.

*The authors would like to thank all the participants at the *Rencontre de l'environnement* in Paris for their helpful comments as well as Stéphane Lambrecht. All remaining errors are ours. The first author acknowledges financial support from the Chair Lhoist Berghmans in Environmental Economics and Management in combination with the CLIMNEG II programme financed by the Belgium Office for Scientific, Technical and Cultural Affairs. The second author acknowledges financial support from DFG (EBIM, under GRK1134/1), and from L'ACI (ME0014).

†CORE, Université catholique de Louvain, 34 Voie du Roman Pays, 1348 Louvain-la-Neuve, Belgium. E-mail: schumacher@core.ucl.ac.be.

‡Institute of Mathematical Economics, Bielefeld University, Postfach 100131, 33501, Bielefeld, Germany. E-mail: bzou@wiwi.uni-bielefeld.de.

1 Introduction

This article analyses pollution perception in an overlapping generations framework à la John and Pecchenino (1994) and specifically Seegmuller and Verchère (2005). We extend the literature by allowing generations to perceive the utility derived from pollution to differ from the actual stock of pollution. We interpret this partial concern for pollution stock as coming from the preferences of the generations. In the extreme case the utility will be a function of the changes in pollution only.

This appears to be a rather important property of models which seems to have been neglected in the literature up to now. The factor we introduce has similar properties as the habit factor in consumption, which has seen some recent research by e.g. Wendner (2002). The qualitative results we obtain are however very different.

The idea for the importance of introducing the pollution perception factor can be demonstrated with a simple example. A generation, born at time $t = 0$, will be born with an existing level of pollution equal to P_0. However, this generation will not know the world differently. For them the existing pollution stock will be the natural level of the environment. So the only effect of pollution that they might feel is the change in the pollution stock during the time of their existence, as given by $P_1 - hP_0$. We generalise this idea by allowing the generations to be concerned with either the stock of pollution ($h = 0$), or the change in pollution ($h = 1$), or anything in between($0 < h < 1$).

It seems that an obvious problem in this context is intergenerational equity. If the newborn generations perceive the existing level of pollution as the natural one (e.g. if $h = 1$) then this decouples utility from pollution accumulation. Hence one could imagine that generations allow pollution to grow forever. For $0 < h < 1$ one could imagine that pollution tends to a rather high steady state. Thus it seems very easy that potential pollution thresholds could be crossed. However, we are able to show that even without the existence of pollution thresholds this pollution perception can lead to serious concerns of intergenerational inequality. For this we use the concept of Intergenerational Moral Intuition, which is able to pinpoint the source of the intergenerational inequality. In fact, in this article we are only going to be concerned with this second intergenerational inequality.

The paper is organised as follows. Section 2 introduces the basic features of the model and derives the intertemporal equilibrium. Section 3 describes the dynamics. Section 4 reviews the prior results within the theory of intergenerational equity.

2 The Model

We consider a perfectly competitive overlapping generations economy. We allow for perfect foresight and discrete time with an indeterminate horizon, $t = 0, 1, 2....$ For simplicity we assume that population is constant and each generation consists of a single representative individual. At each date a generation lives for two periods, young and old. Furthermore, the young generations supply their labour inelastically and decide whether to save or invest (in abatement), and the old generations obtain utility from consuming their savings. In addition, we assume that the old generations feel the effects of pollution as a disutility, but perceive pollution differently for the various reasons as laid out in the introduction.

2.1 The Pollution Accumulation

Pollution is assumed to accumulate as described by the following equation

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

where $b \in (0, 1)$ is the rate of pollution absorption, $\beta(> 0)$ is a parameters of consumption externality, representing the rate of pollution emissions from a unit of consumption, and $\gamma(> 0)$ represents the strength of the abatement effort, A_t, on pollution. Hence, the stock of tomorrow's pollution is partially depending on today's pollution stock and is being increased by consumption and reduced by abatement. Notice that we do not assume irreversibilities here.

Furthermore we choose the pollution accumulation in preference for the environmental accumulation function à la John and Pecchenino (1994) because we feel uncomfortable with the assumption that the initial level of the environment must be above the natural level. John and Pecchenino (1994) had to introduce this assumption in order to obtain a concave utility function.

2.2 The Generations

Agents derive utility over consumption and pollution in period $t + 1$ only. Their utility function is of the form

$$U(c_{t+1}, P_{t+1}, P_t) = \ln c_{t+1} - \alpha \ln(P_{t+1} - hP_t), \tag{2}$$

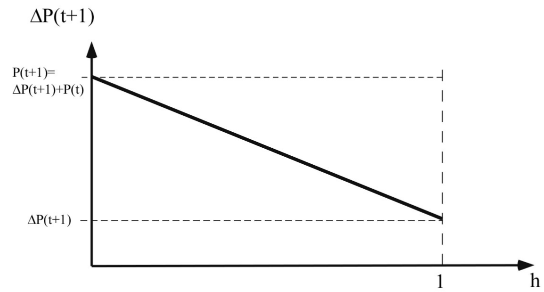

Figure 1: Pollution perception for different values of the parameter h

where c_{t+1} refers to (per capita) consumption in period $t+1$, and P_{t+1} and P_t refer to the stock of pollution in periods $t+1$ and t respectively[1]. $0 < \alpha < 1$ measures the relative preference of the generations for pollution over consumption.

Thus, we extend the literature by allowing generations to perceive (either partly, $h \in (0,1)$, or fully, $h = 1$, or not at all, $h = 0$) the pollution stocks in different ways. We interpret this perception as a concern for either the stock or the flow of pollution, or anything in between. Figure 1 demonstrates how the perception of pollution changes given different levels of the parameter h. For $h = 0$, generations perceive only the stock of pollution, for $h = 1$ they are only concerned with the flow, and for $0 < h < 1$ they are partly concerned with either.

Generations then maximise their utility with respect to savings and subject to their budget constraints which are given by

$$w_t - A_t = s_t, \tag{3}$$

$$(1 + r_{t+1})s_t = c_{t+1}, \tag{4}$$

[1]For any P_t and P_{t+1} there $\exists \hat{h}$ such that $P_{t+1} > \hat{h}P_t$, $\forall t$. Throughout the paper we assume that $h \leq \hat{h}$. We utilise this utility function in order to obtain simple and explicit solutions. Furthermore it is the only one which fits our assumptions. In addition, for $0 < P_{t+1} - hP_t < 1$, the effect of pollution perception is able to increase utility.

and the pollution accumulation equation (1). Here, w, A, s and r refer to the wages obtained, the abatement effort, the savings carried forward to the next period and the interest obtained on the savings, respectively. The first order condition from the generation's maximisation problem is

$$\frac{1}{s_t} = \frac{\alpha\gamma}{P_{t+1} - hP_t}. \tag{5}$$

The first order condition allows us to find the maximum of utility as the utility function is strictly concave with respect to savings, our variable of choice. We assume that the abatement effort is a result of a collective decision process by each generation.

2.3 The Firms

The firms produce with a constant returns to scale technology, $y = f(k)L$, where we normalise the labour supply to $L = 1$. We furthermore assume the standard conditions $f'(k) > 0$ and $f''(k) < 0$. Then firms maximize profits in a competitive market that clears, such that

$$f'(k_{t+1}) - \delta = r_{t+1}, \tag{6}$$

$$f(k_t) - f'(k_t)k_t = w_t, \tag{7}$$

$$s_t = k_{t+1}. \tag{8}$$

We moreover use the Cobb-Douglas output function to specify the production technology, with $f(k) = k^m$, where $m \in (0,1)$ is the capital share. Finally, and without loss of generality, we assume full depreciation, $\delta = 1$, during the course of one generation. Empirical evidence suggests this captures reality appropriately.

2.4 The Intertemporal Equilibrium

We first define the intertemporal equilibrium of this economy.

Intertemporal equilibrium: The intertemporal equilibrium of the above depicted economy is a sequence $\{k_t, P_t\}_{t=0}^{\infty}$ with given initial conditions $\{k_0, P_0\}$ which satisfies the two equations that rule the dynamics, (9) and (10).

By combining the first order condition with the market clearing condition, the output function, as well as the budget constraints and the pollution equation, we obtain

$$k_{t+1} = -\frac{1-b-h}{\gamma(1-\alpha)}P_t - \frac{m\beta + m\gamma - \gamma}{\gamma(1-\alpha)}k_t^m. \tag{9}$$

and

$$P_{t+1} = \frac{h + b\alpha - \alpha}{1 - \alpha} P_t - \frac{(m\beta + m\gamma - \gamma)\alpha}{(1 - \alpha)} k_t^m. \tag{10}$$

By taking $k_t = \overline{k}$ and $P_t = \overline{P}$, we derive the steady states of this economy. There exist two steady states, one is trivial with $\{\overline{k}, \overline{P}\} = (0, 0)$. The other steady state is given by

$$\overline{k} = \left(\frac{(1 - h)(m\beta + m\gamma - \gamma)}{\gamma(b\alpha + h - 1)} \right)^{\frac{1}{1-m}}, \tag{11}$$

for $m\beta + m\gamma - \gamma \neq 0$ and $b\alpha + h - 1 \neq 0$, where $k > 0$ provided that $m\beta + m\gamma - \gamma$ and $b\alpha + h - 1$ have the same sign, as well as

$$\overline{P} = \frac{\alpha\gamma}{1 - h} \left(\frac{(1 - h)(m\beta + m\gamma - \gamma)}{\gamma(b\alpha + h - 1)} \right)^{\frac{1}{1-m}}. \tag{12}$$

Given the above reasoning, we shall from now on impose the following condition.

Assumption 1 We assume $m\beta + m\gamma - \gamma < 0$[2]. We furthermore impose that $h + \alpha b - 1 < 0$.

This assumption is consistent with a wide range of parameters for m, β and γ and is required for the existence of positive steady states. We furthermore take the case of long-lasting pollutants like climate change or nuclear waste, such that b is very small. This allows to focus our analysis on an extensive range for the parameter of concern, h.

The effect of pollution perception on the steady state can be discovered by taking the derivative of (11) and (12) with respect to h. After rearranging we obtain

$$\frac{\partial \overline{k}}{\partial h} = -\frac{b\alpha\overline{k}}{(1 - h)(1 - m)(b\alpha + h - 1)}. \tag{13}$$

Based on our Assumption 1, the steady state capital stock increases with increases the pollution perception parameter, h. Obviously, if generations perceive the stock of pollution to be lower than it actually is, they will fell less concerned about it and thus produce more and abate less.

[2] This assumption is equivalent to $\beta < \gamma \ \frac{1}{m} - 1$. In general, the capital share is around $m = 1/3$, which leads to β being less than twice the value of γ. In other words, we allow that it takes less effort to pollute than to clean up.

By similar calculation for (12) we obtain

$$\frac{\partial \overline{P}}{\partial h} = \frac{\overline{P}}{(1-h)(1-m)}\left[-m - \frac{1-h}{b\alpha + h - 1}\right]. \tag{14}$$

Hence pollution perception h will always increase the steady state stock of pollution[3]. Intuitively, if generations are less concerned with the actual stock of pollution, they will be willing to trade-off a higher stock of pollution for a higher capital stock.

3 The Dynamics

By linearising equations (9) and (10) around the non-trivial steady state we obtain the dynamics around the steady state. Proposition 1 summarises our results. These are given with respect to the various assumptions that we priorly imposed.

Proposition 1 *Suppose that Assumption 1 holds.*

(i) The non-trivial steady state $(\overline{k}, \overline{P})$ is asymptotically stable in the sense of Lyapunov, if and only if either of the following conditions holds

$$(1)\ \ 0 < \alpha < \frac{(1+m)}{2-b(1-m)}, \ \text{ and } \ 0 \le h < 1 - b\alpha$$

or

$$(2)\ \ \frac{(1+m)}{2-b(1-m)} < \alpha < 1 \ \text{ and } \ \frac{\alpha(2-b(1-m))-(1+m)}{1-m} < h < 1 - b\alpha. \tag{15}$$

The convergence towards the asymptotic steady state exhibits a spiral motion.

(ii) The non-trivial steady state $(\overline{k}, \overline{P})$ is instable, if and only if the following conditions are satisfied

$$\frac{(1+m)}{2-b(1-m)} < \alpha < 1, \ \text{ and } \ 0 \le h < \frac{\alpha(2-b(1-m))-(1+m)}{1-m}. \tag{16}$$

(iii) The system generates a Flip bifurcation if the subsequent conditions hold

$$\frac{(1+m)}{2-b(1-m)} < \alpha \le 1, \ \text{ and } \ 0 < h = \frac{\alpha(2-b(1-m))-(1+m)}{1-m}. \tag{17}$$

[3] A sufficient condition for this is given by our assumption that $b \in (0,1)$ and that $\alpha < 1$.

Finally, a sufficient but not necessary condition for positive abatement is $\alpha \leq \frac{m\beta}{\gamma - m\gamma}$.

Proof 1 Assume $0 < \alpha < 1$ and $0 < h < 1 - b\alpha$. We are going to analyse the system for its various dynamics by linearising the equations that describe the dynamics around their non-trivial steady state. In the further analysis we are going to take the known parameters b, m, γ, β as fixed, but allow the uncertain parameters α and h to vary. So, linearizing equations (9) and (10) around the non-trivial steady state $(\overline{k}, \overline{P})$, gives the following Jacobian matrix

$$\begin{aligned} J(\overline{k}, \overline{P}) &= \begin{pmatrix} -\dfrac{m(mb + m\gamma - \gamma)}{\gamma(1-\alpha)}\overline{k}^{m-1} & -\dfrac{1-h-b}{\gamma(1-\alpha)} \\ -\dfrac{\alpha m(mb + m\gamma - \gamma)}{1-\alpha}\overline{k}^{m-1} & \dfrac{h + b\alpha - \alpha}{(1-\alpha)} \end{pmatrix} \\ &= \begin{pmatrix} -\dfrac{m(b\alpha + h - 1)}{(1-h)(1-\alpha)} & -\dfrac{1-h-b}{\gamma(1-\alpha)} \\ -\dfrac{\alpha m\gamma(b\alpha + h - 1)}{(1-h)(1-\alpha)} & \dfrac{h + b\alpha - \alpha}{(1-\alpha)} \end{pmatrix}, \end{aligned} \tag{18}$$

where the last equality is obtained by substituting (11) into the first matrix.

Suppose the eigenvalues of the Jacobian matrix of the system given by the equations (9) and (10) are λ_j, $j = 1, 2$. The steady state $(\overline{k}, \overline{P})$ is asymptotically stable if and only if for any $j = 1, 2$ the norm of the eigenvalues is $|\lambda_j| < 1$. The characteristic function of the Jacobian matrix is

$$(1-h)(1-\alpha)\lambda^2 - [(1-h)(h+b\alpha-\alpha) - m(h+b\alpha-1)]\lambda + mh(h+b\alpha-1) = 0. \tag{19}$$

Therefore, the solutions of the characteristic function are given by

$$\lambda_{1,2} = \frac{[(1-h)(h + b\alpha - \alpha) - m(h + b\alpha - 1)] \mp \sqrt{\Delta}}{2(1-h)(1-\alpha)}, \tag{20}$$

where

$$\Delta = [(1-h)(h+b\alpha-\alpha) - m(h+b\alpha-1)]^2 - 4(1-h)(1-\alpha)mh(h+b\alpha-1) > 0,$$

due to the fact that $0 < \alpha < 1$ and $0 < h < 1 - b\alpha$. Hence in this case, the two eigenvalues are real, with one being positive and the other being negative. A positive and negative eigenvalue imply spiral movements of the system. Denote $\lambda_1 < 0$ and $\lambda_2 > 0$. Therefore, the steady state is asymptotically stable if and only if

$$-1 < \lambda_1 < 0, \quad \text{and} \quad 0 < \lambda_2 < 1.$$

Step 1. We prove that $\lambda_2 < 1$, which is equivalent to showing that

$$\sqrt{\Delta} < 2(1-h)(1-\alpha) - [(1-h)(h+b\alpha-\alpha) - m(h+b\alpha-1)].$$

Taking squares on both side and using the definition of Δ, after rearranging the terms, we have that

$$(1-m)h^2 + (1-m)(2-b\alpha)h + (1-m)(1-b\alpha) > 0,$$

which is a second order polynomial with positive coefficients. We can check that given the parameter conditions, the above is always true for any $0 < h$, hence for $0 < h < 1 - b\alpha$.

Step 2. We prove that $-1 < \lambda_1$. Similarly to above we obtain, after rearranging the terms that $-1 < \lambda_1$ if and only if

$$h > \frac{\alpha(2-b(1-m)) - (1+m)}{1-m},$$

which is always positive, provided that

$$\alpha > \frac{1+m}{2-b(1-m)}.$$

If

$$0 < \alpha \leq \frac{1+m}{2-b(1-m)},$$

take

$$h > 0.$$

We also can prove that for any $0 < \alpha < 1$

$$\frac{\alpha(2-b(1-m)) - (1+m)}{1-m} < 1 - b\alpha.$$

Conclusively, we have that for $j = 1, 2, |\lambda_j| < 1$, if and only if the conditions as given by the equations (15) hold.
The case for $h = 0$ can be treated as follows. In the case of $h = 0$, the first order condition can be rewritten as

$$P_{t+1} = \alpha\gamma k_{t+1}. \tag{21}$$

Substituting equation (21) and equation (21) iterated backwards into the pollution emission equation (1), then rearranging terms, gives

$$k_{t+1} = -\frac{\alpha(1-b)}{1-\alpha}k_t + \frac{\gamma - m\beta - m\gamma}{\gamma(1-\alpha)}k_t^m. \tag{22}$$

Rewriting Equation (1) gives

$$P_{t+1} = (1-b)P_t + (m\beta + m\gamma - \gamma)k_t^m + \gamma k_{t+1}^m. \tag{23}$$

Then the linearized system around its steady state is

$$\begin{pmatrix} k_{t+1} \\ P_{t+1} \end{pmatrix} = J_0(\overline{k_0}, \overline{P_0}) \begin{pmatrix} k_t \\ P_t \end{pmatrix} + \begin{pmatrix} \dfrac{(1-b\alpha)(1-m)}{1-\alpha}\overline{k_0} \\ \dfrac{\alpha\gamma(1-b\alpha)(1-m)}{1-\alpha}\overline{k_0} \end{pmatrix}, \tag{24}$$

where the Jacobian is

$$J_0(\overline{k_0}, \overline{P_0}) = \begin{pmatrix} \dfrac{b\alpha(1-m) + (m-\alpha)}{1-\alpha} & 0 \\ -\alpha\gamma\dfrac{1-b-m(1-b\alpha)}{1-\alpha} & 1-b \end{pmatrix}. \tag{25}$$

The two eigenvalues of the above system are positive and given by $\lambda_3 = 1-b(<1)$ and $\lambda_4 = \frac{b\alpha(1-m)+(m-\alpha)}{1-\alpha}$. Hence the steady state is asymptotically stable if and only if $|\lambda_4| < 1$, which is equivalent to

$$\frac{1+m}{2-b(1-m)} < \alpha < 1.$$

Thus the steady state is instable if and only if $0 < \alpha < \frac{1+m}{2-b(1-m)}$. Furthermore, if $\alpha = \frac{1+m}{2-b(1-m)}$, a Flip bifurcation occurs.

The condition on positive abatement can be obtained as follows: As $A_t = w_t - s_t$ and $s_t = k_{t+1}$, we can then substitute the solutions $w_t = f(k) - f'(k)k$ as well as the dynamical equation for k_{t+1}, as given by equation (9). Hence $A_t = (1-m)k_t^m + \frac{1-b-h}{\gamma(1-\alpha)}P_t + \frac{m\beta+m\gamma-\gamma}{\gamma(1-\alpha)}k_t^m$. The coefficient on pollution is always positive, so a sufficient condition for positive abatement is $0 \leq (1-m) + \frac{m\beta+m\gamma-\gamma}{\gamma(1-\alpha)}$, which implies that $\gamma \leq \frac{m\beta}{\alpha(1-m)}$. ■

Figure 2 summarises the results of proposition 1 for ease of demonstration in a simple graph for the standard case of $m = 1/3$ and assuming a slow natural improvement in pollution with $b = 0.1$ (e.g. for climate change).

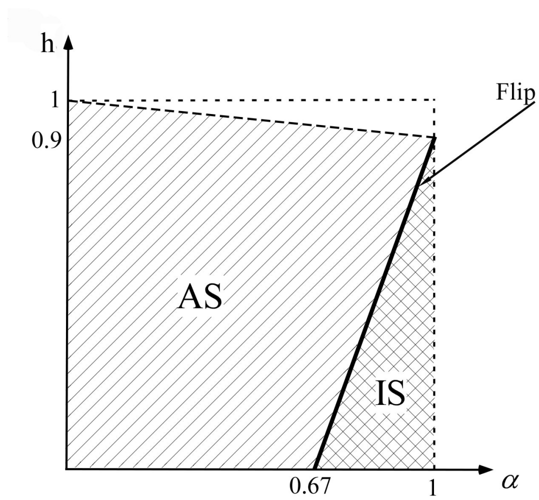

Figure 2: Regions of stability and instability for combinations of h and α

The hatched area (labelled AS) refers to the combination of h and α where the model leads to asymptotic stable dynamics, whereas the cross-hatched area (labelled IS) refers to the parameter combination that leads to instability. The thick dark line shows the combinations of h and α which lead to Flip bifurcations.

Then Figure 3 depicts the dynamics and steady state equations for certain, general values of the parameters[4], such that the steady state is asymptotically stable.

As our system generates one positive and one negative eigenvalue, this periodic cycling appears for any steady state. Furthermore, the closer we get to the combination of parameters leading to bifurcations, the stronger the periodic cycling effect.

4 Welfare Analysis and Intergenerational Equity

Overlapping generation models, even most continuous time growth models, augmented with an environmental sector (e.g. John and Pecchenino, 1994) possess clear dynamics. Utility either increases or decreases over time given

[4]The chosen values are as follows: $b = 0.1$, $h = 0.6$, $\gamma = 0.2$, $\alpha = 0.75$, $m = 0.3$, $\beta = 0.35$.

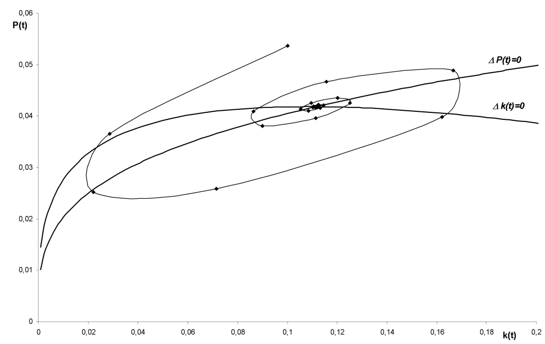

Figure 3: Dynamics under partial concern (for $0 \leq h < 1 - b\alpha$)

an optimal choice of consumption and abatement. Some models have the capacity to generate nonlinear dynamics, especially those models which obtain Environmental Kuznets Curve relationships (e.g. Stokey, 1998). Only very few models actually create non-monotonic behaviour in form of cycles and bifurcations (Bréchet and Lambrecht, 2004; Seegmuller and Verchère, 2004).

In the case of Bréchet and Lambrecht (2004), these bifurcations or cyclical behaviour are a result of the choice of a specific resource function, and therefore these dynamics don't derive directly from the inside of the model. Furthermore, they provide no attempt in trying to explain these cyclical dynamics within welfare analysis. Seegmuller and Verchère (2004) develop a similar model as we do, but with a much less general utility function (they use $U = c_{t+1} - P_{t+1}^2$) and, most importantly, without a pollution perception factor, h. In effect, their cyclical dynamics (they find a flip bifurcation) arise only for specific cases of parameter combinations at one specific point.

The interest in non-monotonic behaviour derives from an intergenerational equity point of view. If some generations possess the capacity to reduce future generation's utility in relation to their own, then most intergenerational equity theories demand policy makers to act upon this behaviour (e.g. egalitarianism). The following proposition summarises the motion of utility on the optimal path.

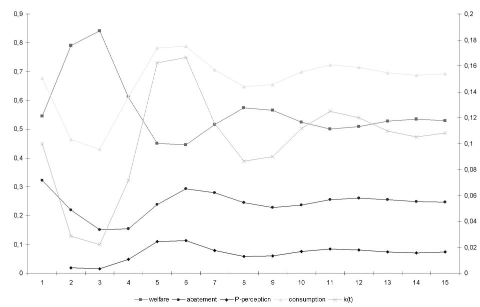

Figure 4: Changes in welfare, abatement, pollution perception, consumption and capital on the optimal path

Proposition 2 *The level of utility on the optimal path is a function of the optimal capital stock and thus follows the periodic cycling movement of capital. In particular, the utility level is either pro-cyclical (if $m > \alpha$) or counter-cyclical (if $m < \alpha$) depending on the relative importance of pollution in generating utility.*

Proof 1 For the proof we utilise the utility function of each generation. We have that utility is equal to $u(\cdot) = \ln(c_{t+1}) - \alpha \ln(P_{t+1} - hP_t)$ and we substitute $c_{t+1} = (1 + r_{t+1})s_t$, which equals mk_{t+1}^m, and we substitute the FOC. Thus we get $\ln(mk_{t+1}^m) - \alpha \ln(\alpha\gamma k_{t+1}) = (m - \alpha)\ln(k_{t+1}) + \ln(\frac{m}{(\alpha\gamma)^\alpha})$. Hence, utility on the optimal path is only a function of the capital stock. If $m < \alpha$ then utility is counter-cyclical, and for $m > \alpha$ utility will be pro-cyclical. ■

Figure 4 describes the changes in utility for the general parameter choices that we also use for generating Figure 3. The assumptions imply that $h + b\alpha - \alpha < 0$ and $m < \alpha$. It is easy to observe that utility has a counter-cyclical relationship with capital stock, but a pro-cyclical relationship with pollution. The reason for this is that, for $m < \alpha$, pollution is important enough to superimpose its effect on utility. Generations will thus face different levels of utility depending on when they are born. However, no generation can choose at which point in time it will exist. But each generation will prefer to be born with the expectation of at least the same utility level as its predecessor. The dynamic path that we obtain does not allow this to happen all the time. As the conditions for periodic cycling in an economy described by our model are extremely broad and happen for all parameter configurations (taking the known parameters m, b, γ, β fixed), it is necessary to see where the intergenerational inequality comes from.

We shall analyse our result of periodic cycling towards steady state with the aid of a concept called *Intergenerational Moral Intuition*, as developed by Schumacher (2005). This concept is based on three simple, straight forward axioms.

Axiom 1: If agents want to do something good[5] for consecutive generations, they should be allowed to.

Axiom 2: If agents' actions induce an adverse outcome[6] on any of its subsequent generations, they should be prevented from doing so.

Axiom 3: Axiom 2 always has priority over Axiom 1.

We can easily identify that Axiom 2 is violated. Under our assumption, pollution is more important for utility than consumption, as $m < \alpha$ (We could as well impose $m > \alpha$, which only reverses the arguments). Hence, generation $t = \tau$ will reduce pollution by producing and consuming less, and thereby increases its own utility. However, this behaviour cannot continue if capital and pollution are not to go to zero. This thus imposes sacrifices on generation $t = \tau + 1$. The $\tau + 1$ generation must give up more of its utility in order to increase the capital stock again[7]. Hence the violation of Axiom 2.

On the other hand we notice that Axiom 1 is violated, too. The reason for this periodic cycling is because some generations feel the need to clean the environment, which allows the future generation to produce more. But this then leads to a violation of Axiom 2 due to the period cycling. By Axiom 3, the behaviour of the first generation leading to the periodic cycling is thus not allowed. Thus, without considering long-term planning (spanning several generations), the only means to avoid this intergenerational inequality is by keeping capital and thus pollution constant. This is the only way

[5]Although loosely defined, this can be interpreted as (for example) increasing future's utility via reducing pollution.

[6]An adverse outcome can be interpreted as violating a basic sustainability requirement, as captured by $\frac{du}{dt} \geq 0$, $\forall t$. See Pezzey (1997) for a discussion of this kind of constraint in optimal growth models.

[7]This result always holds given that $m < \alpha$.

to satisfy the axioms imposed by the Intergenerational Moral Intuition and is equivalent to the maximin outcome as imposed by Egalitarianism.

Our conclusion for policy taking is thus as follows. Considering periods of up to one generation is not enough in order to foresee intergenerational injustice. Our model predicts periodic cycling for the whole range of the uncertain parameters h and α. Thus, if a policy maker would like to satisfy the axioms of Intergenerational Moral Intuition, then this analysis calls either for the implementation of the strict maximin criterion or for time-frames for decision-taking of several generations in order to acknowledge and thus prevent period cycling via appropriate intergenerational transfers.

References

1. Bréchet, T. and Lambrecht, S. (2004) *Puzzling over sustainability: an equilibrium analysis*, CORE Discussion Paper 2005/1.

2. John, A. and Pecchenino, R. (1994) *An overlapping generations model of growth and the environment*, The Economic Journal, 104, p. 1393-1410.

3. Pezzey, J. 1997, "Sustainability constraints, versus "optimality" versus intertemporal concern, and axioms versus data", Land Economics 73, No. 4, p. 448-466.

4. Seegmuller, T. and Verchère, A. (2004) *Pollution as a source of endogenous fluctuations and periodic welfare inequality in OLG economies* , Economics Letters 84, p. 363-369.

5. Schumacher, I. (2005) *Reviewing Social Discounting within Intergenerational Moral Intuition*, Environmental Economics and Management Memorandum,

6. Stokey, N. (1998) *Are There Limits to Growth?*, International Economic Review 39, No.1, p. 1-31.

7. Wendner, R. (2002) *Capital Accumulation and Habit Formation*, Economics Bulletin 4, No. 7, p. 1-10.