ARC Project: Sustainability

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Abstract

This project puts together philosophers from the Hoover Chair and economists from IRES in order to make progresses on the notion of sustainability and its implications. We aim at exploiting the methodological complementarities between the two groups. We plan to work on three specific subjects: the meaning of sustainability, sustainability and population dynamics, and sustainability and firms policy.

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Introduction

Together with the rise of ecological ideas, there is a growing concern about the long-term sustainability of the so-called Western economic regime among scientists and opinion leaders. This concern has been recently formulated by the famous question 'Are we consuming too much?' raised by a group of economists led by Nobel price Kenneth Arrow (2004). The question is indeed increasingly legitimate: while per capita consumption in the West has sharply increased in the last century, natural resources have been largely depleted and pollution has steadily gone up leading to a sizeable ecological cost, which can hardly be omitted by economists and politicians. In such a context, the foundations of the Western economic model and the associated economic theory benchmarks call for a thorough revisiting. New keywords appear to be sustainability and sustainable development. As originally defined by the Brundtland Commission (1987), development is sustainable if '[it] meets the needs of the present without compromising the ability of future generations to meet their own needs'. While this definition seems pretty clear, at least in immediate terms of intergenerational justice, it turns out to be quite hard to incorporate in the corpus of economic theory in a rigorous way. Even the most direct welfarist translation of this definition (as implemented for example by Arrow and others, 2004) involve a number of difficult conceptual and methodological problems, which largely remain open questions to this date. In particular, the demographic and technological determinants of sustainable development are still debated by an increasingly growing literature taking both the normative and positive avenues. Our proposal is integrally in line with this fundamental debate.

Roughly speaking, sustainability involves two types of issues.On the one hand, sustainability insists on the importance of perpetuity, of not jeopardizing the capacity of the Earth or of humankind to go ahead with existing. On the other hand, it embodies a concern as to the intergenerational path to be followed by our societies: is our consumption such that future generations will be able to have the same level of consumption as well? Are we going to transfer them a planet in a worst state? Is growth in whichever of its forms sustainable at all? In short, there are two ideas: "could we make sure that x continues and if yes, how?" and "are we being fair towards each of the coming generations?". The project addresses both types of questions.

1. The normative issues are broadly addressed along the proposal. First, the first part of the project is entirely devoted to discuss sustainability as a theory of intergenerational justice, much beyond the simple slogan of the Brundtland Commission. Second, we question the framework of optimal economic growth theory (with a constant social time discount rate), based on optimal control programs à la Pontryagin, and propose to evaluate an alternative framework relying on viability theory, which in particular does not make use of social discounting, and allows to naturally incorporate in the analysis all types of sustainability criteria to fulfill. Third, we extensively study the demographic determinants of sustainability. From the normative point of view, what's an optimal population size? Could it be the

case that population extinction at finite time is first-best? The latter question will be examined in connection with the issue of optimal depletion of natural resources. Fourth, for a given population size, what's an optimal composition of population? We will look at three different dimensions of heterogeneity: skill, gender, cultural group. We then ask the following questions: would a world where the skilled would not have children any more be sustainable? or a world with a severe imbalance in the number of men compared to women? or a situation in which different cultural groups having different fertility levels compete in getting more resources? Policy recommendations (notably optimal education policies) are extracted accordingly.

2. The project also addresses a wide variety of positive questions, in interaction with the normative tasks undertaken. In particular, part of the project is to be devoted to investigate the quantitative implications of heterogenity along the dimensions outlined above. This includes the analysis of differential fertility as an engine of natural selection, a debate recently enhanced by Clark's work (2007) on medieval England, and the impact of social (or cultural) norms on economic, social and demographic dynamics, and therefore on long-term sustainability of a society.

3. The last block of the project focuses on the central economic agent in the economic growth process, firms. In this part, we tackle two kinds of issues. Significant normative issues arise regarding short-termism. We can assume however that in a large number of cases, sustainability concerns are arguably inconsistent with immediate profit maximization objectives, and with any other form of short-termism. We shall study the determinants of short-termism at the firm level and propose appropriate organizational measures to fight it. The second aspect treated is the contribution of firms to sustainability as the main engine of technological progress. This aspect is fundamental in the ongoing sustainability literature starting with Arrow et al. (2004), and can hardly be avoided in any sustainability appraisal. The project is intended to bring out new contributions to the technological debate around sustainability by deeply characterizing the set of modernization strategies the firms can implement in response to resource scarcity and/or regulation required for sustainable growth (including environmental regulation).

1 Sustainability

1.1 Sustainability as a theory of justice

There is a whole set of questions that we are still unable to answer when it comes to philosophical theories of intergenerational justice. And some of these questions have remained unanswered - or at least didn't receive an answer that is firm enough - because philosophers have not tried to enter into a dialogue with economists. Nor did economists address all the questions that philosophers could put to them. In other words, philosophers need to have the modesty to go and ask for the help of economists to address some of the questions for which they don't have the tools. And economists also need to accept to engage in some issues that might not be standard in their discipline. Let us point at a few of these questions:

1. **Can the benefits of cooperation be mutually beneficial at the intergenerationnal level?**

   Some theories of intergenerational justice give special importance to the possibility of mutual advantage. For they claim that justice should be derived from rationality in the rational choice sense, i.e. understanding rationality as self-interest. An author like David Gauthier (1986) has thus rightly pointed at the importance of generational overlap for theories of justice that would try to be based on the idea of mutual advantage. And in fact, generational overlap is also relevant to other theories of justice. But to come back to our question, we need to engage into a more systematic analysis to find out (a) whether it is true that mutual advantage is not possible in the intergenerational context (think for example about the slogan: posterity cannot do anything for us) and (b) what should follow from it for a defender of mutual advantage theories of justice. For the first one of these two question, we need someone with a good command of game theory to analyze the problem with and without overlap, looking at whether ascending and descending benefits and threats are or not possible and under which forms. This is a work that has not been done systematically enough so far. To our knowledge, there are only two papers devoted to this issue in the philosophical literature (Heath, 1997; Arrhenius, 1999).

2. **Towards a sequential theory of intergenerational justice**

   There is a variety of theories of intergenerational justice. And Brundtland's version of it, as it appears from her definition of sustainable development, is certainly not the only option here. Besides the mutual advantage-based one above, we can mention three of such theories. An aggregative theory will aim at calling for the maximization of intergenerational welfare, i.e. making sure that the cake of welfare, taken over the present and future generations is as large as possible. A distributive theory will care about the distribution of welfare (or any other metrics) among the generations. It will not care about the size of the cake, but about how it is sliced. Then we have a commutative theory of justice that takes the form here of a theory of indirect reciprocity. We look at what (piece of) cake we received from the previous generation and we expect each generation to transfer to the next one a (piece of) cake of at least the same size. This theory can be regarded not only as commutative, but also as sequential, the exact connections between the two being unclear at this stage.

   What we don't understand well yet is the set of properties of a sequential theory of intergenerational justice, once compared with a theory of distributive justice. To understand this, we would probably have to build a model of a sequential theory of justice within one generation, to see what it would look like, which problems it would help addressing and which difficulties it would raise. A sequential theory may for example help addressing the difficulties that an aggregative theory faces with respect to infinity/indefinity. In other words, how do we allocate the cake to maximize intergenerational welfare if we don't know how many guests we have around the table? And a sequential theory may also answer in a specific way to the difficulties that a distributive theory faces in case of non-compliance. In other words, how are my obligations affected (if at all) if someone else does not comply with his own? (think about world poverty: if my neighbour never does anything to alleviate world poverty, does it reduce, increase or leave unaffected my own obligations?). We suspect that for this question, someone with both a background in philosophy and in economics could do a great job at analyzing the nature of this approach.

3. **Intergenerational justice with descending altruism**

   Theories of justice tend not to rely on the idea of altruism. One of the reason is that altruism understood as generosity would give us too vague indications as to what to expect from each of us. And generosity might also violate the idea of impartiality, since we may be more generous to some people than to some other ones. So, the reasons underlying attempts at elaborating theories of justice without relying on the idea of altruism need not be justified by the mere idea that it would be naive to expect people to act out of altruism (actually, it is not naive as we may argue that a lot of us actually do act out of altruism).

   The intergenerational context confronts us with an especially vivid form of altruism, i.e. the one of parents towards their children. A philosopher like Rawls has relied on this at one point in his work (1971). And economists such as Arrow (1973), Dasgupta (1974), Ray (1987) or Asheim (1988) have looked at this, pointing at problems of time-inconsistency if we combine Rawlsian maximin with such descending altruism. The question ahead of us is thus the following: is it impossible to produce a theory of intergenerational justice that would realistically take into account the existence of descending altruism. In particular, are there ways of reducing the time-inconsistency identified by economists? Is time-inconsistency necessarily to be seen as a source of unfairness? And does descending altruism have features that make it special when compared with other forms of altruism?

4. **Intergenerational maximin and growth**

   The last dimension on which research involving close collaboration between philosophers and economists is needed is the question of the compatibility of intergenerational justice and growth. Axel Gosseries has started investigating this in a paper with Gaspart (2007). However, we are far from fully understanding the variety of possible ways in which and the precise extent to which intergenerational maximin and growth as we standardly understand it could be made compatible with each other.

1.2 Sustainability Vs Pontryagin optimality

A prominent part of economic growth theory is based on the neoclassical growth model, which relies on the maximization of an inter-temporal (or intergenerational) welfare function. The basic optimization apparatus used is optimal control as pioneered by Pontryagin. Importantly enough, inter-temporal optimization in traditional growth theory relies on a time discounted social welfare function, which, giving more weight to present generations, has no reason to satisfy long-term sustainability criteria. To this end, several strategies have been followed so far. Chichilnisky (1993) added a long-term outcome term to the traditional inter-temporal optimization of utility. This alteration enables the identification of a green golden rule in the extreme case where utility is reduced to this long-term outcome term, but, in the general case of a convex combination of this term with inter-temporal utility, there is no guarantee of the existence of an optimal sustainable path (Beltratti, Chichilnisky, and Heal, 1994). Other authors have departed form the constant social discount rate assumption inherent in the neoclassical model by assuming that the discount rate is endogenous (depending on consumption or the capital stock, as reviewed by Le Kama and Schubert, 2007).

In both frameworks, inter-temporal optimization remains the criterion of inter-generational resource allocation. In this project, we examine an alternative framework, much closer to the spirit of Arrow et al. (2004). These authors formalized sustainability in line with the Brundtland Commission (1987), requiring that inter-temporal social welfare $V(t)$ would not decrease over time t. Arrow et al. emphasized that this criterion "does not identify a unique consumption path: the criterion could in principle be met by many consumption paths" (: 150), and that "in defining sustainable development, there is no presumption that the consumption path being followed is in the sense of maximizing V" (: 150). Clearly enough, the set-up advocated by these authors need not be compatible with inter-temporal optimality in the sense of optimal control, say Pontryagin optimality.

So far no criterion has been made operational. In this project, we wish to show the deep link between sustainability as defined by the Brundtland Commission and viability theory, a theory pioneered by Nagumo as soon as 1942 and developed by Aubin (1991, 1997) and Aubin et al (forthcoming). In viability theory, one result is the existence and the computation of the largest set, called the viability kernel, possibly empty, containing all initial states from which there exists at least one trajectory along which some qualitative or quantitative property –represented by a set of constraints– is satisfied until a given, possibly infinite, time horizon. We shall study to which extent this theory is useful to study Brundtland stability and to disentangle its economic and demographic determinants. We also wish to identify the nexus between Pontryagin optimality and sustainability as captured by viability theory. The viability kernel contains not only the states through which a given criterion can be optimized *while satisfying the constraints*, but it also allows one to identify sub-optimal trajectories (which satisfy the constraints all the same) under a given dynamic.We shall exploit this feature of the theory to characterize in some benchmark cases the link between viability and Pontryagin optimality.

Early applications to economics are in Aubin (1997), Bonneuil and Boarini (2004) and Marco and Romaniello (2006). The relationship between viability and optimality in the sense of optimal control, say Pontryagin optimality, has been studied in abstract settings. This relationship makes sense in the proposal conducted by Arrow et al. (2004). Viability theory supplies the bridge between sustainability and Pontryagin optimality. Cannarsa and Frankowska (1991) showed that, for the Mayer problem, the epigraph of the value function is the viability kernel of an extended control system. We shall use similar arguments to clarify the nexus between Brundtland sustainability and Pontryagin optimality in standard growth models.

The benchmark

For the sake of clarity, we start focussing on the well-known Ramsey growth model originated in the seminal work of Frank Ramsey (1928) (Barro and Sala-i-Martin, 1995, Chapter 2). By mostly relying on the well-known literature on optimal paths of the latter model, we establish several links between viability and optimality in the sense of Pontryagin.

The Ramsey model concerns a planner (either an individual or a government) whose objective is to maximize the present value of future utility gains $w(c(t))e^{-\rho t}$ as a positive function of consumption per capita $c(t)$ at time t and depending on a subjective rate of "time preference" ρ, where $0 < \rho < 1$, over an infinite time horizon and continuous time:

$$\begin{array}{l} \max_{c(.)} \int_0^\infty w(c(\tau))e^{-\rho\tau}\, d\tau \\ \text{subject to} \\ k'(t) = f(k(t)) - (n+\delta)k(t) - c(t) \end{array} \tag{1}$$

where "now" is time 0, n denotes the population growth rate, δ the depreciation rate of capital, $k(t)$ the capital per worker, $k(0) > 0$ is given. $w(.)$ is a strictly increasing and concave utility function, and the production function $f(.)$ is also taken standard, strictly increasing and concave. Constraints on the variables are:

$$k \geq 0,\ c \geq 0\,. \tag{2}$$

The optimal paths corresponding to the Ramsey model have been characterized in the economic literature. As mentioned in the introduction, Chichilnisky (1993) has criticized the discounting objective function, arguing that in many circumstances it fails to guarantee subsistence levels for future generations, because properties of long-term equilibria fail to exist. For the sake of simplicity, we start with the viability idea of "non-starvation", that is obtaining minimal consumption for all generations. The former viewpoint of inter-temporal utility optimization is superseded by feasibility from today until the given time horizon, a concept which is formally represented by the dynamics under viability constraints:

$$\left\{ \begin{array}{rrcl} (i) & k'(t) & = & f(k(t)) - (n+\delta)k(t) - c(t) \\ (ii) & c'(t) & = & u(t) \in U := [u^\flat, u^\sharp] \end{array} \right. \tag{3}$$

where U is a closed set of admissible consumption changes, which are time-dependent. The constraints are:

$$\begin{cases} k(t) & \geq & 0 \\ c(t) & \geq & \underline{c} \end{cases} \tag{4}$$

defining a set K of constraints, where $\underline{c}$ is a given consumption threshold, here taken as constant, but which can be changed into a time-dependent function. It ensures that people will not starve. Instead of inter-temporal optimization, the program {(3),(4)} now requires that its solution satisfies the qualitative property (4) at any time. This is not a trivial problem.

The viability problem {(3),(4)} has two state variables $k(t)$ and $c(t)$, a fact which is in apparent contradiction with the optimal control problem (1). The original control variable $c(t)$ is handled as a state variable, but no $c(0)$ value is imposed. While an optimal control technique seeks the optimal value of $c(0)$, viability is concerned with the initial conditions $(k(0), c(0))$ from which there exists a solution to the system (3) that remains in the constraints (4) over a given time horizon, here infinite.

Another novelty with respect to the original optimal control is the appearance of the control $u(t)$, formalizing any admissible change in consumption, which ultimately allows us to write a state equation for $c(t)$. At any given point in time, there might be an infinity of admissible changes, namely changes in consumption compatible with the viability constraints (4). An optimal path in the sense of Pontryagin which is also viable will correspond to a path for the control $u(t)$.

Extensions: Brundtland sustainability

Arrow et al (2004) identify social welfare with "the present discounted value of the flow of utility from consumption from the present to infinity, discounted using the constant rate [ρ] (> 0)" (: 149). In line with the Brundtland commission, they take "sustainability to mean that inter-temporal social welfare must not decrease over time," . Social welfare at time θ is:

$$V(\theta) = \int_{\theta}^{\infty} w(c(\tau))e^{-\rho(\tau-\theta)}\, d\tau \tag{5}$$

the differential of which is:

$$V'(\theta) = -w(c(\theta)) + \rho V(\theta) \tag{6}$$

and the Brundtland condition of sustainability can be stated as:

$$V'(\theta) \geq 0 \tag{7}$$

As $V'(\theta) = -w(c(\theta)) + \rho V(\theta)$, the Brundtland condition of sustainability is equivalent to:

$$V(\theta) \geq \frac{w(c(\theta))}{\rho} \tag{8}$$

If V could vary a priori anywhere in $I\!R^{+}$, the problem would turn into the search of the viability kernel in the 3-dimensional state-space (k, c, V). However, not any $V \geq 0$

can be taken as an initial condition. $V(0)$ must be such that there exists at least one trajectory $x(.)$ such that

$$V(0) = \int_0^\infty w(c(\tau))e^{-\rho(\tau-\theta)}\, d\tau \tag{9}$$

exists. This is the reason why we introduce the auxiliary variable y, and with it, the time variable t involved in y:

$$\left\{\begin{array}{rrcl} (i) & k'(t) & = & f(k(t)) - (n+\delta)k(t) - c(t) \\ (ii) & c'(t) & = & u(t) \\ (iii) & t' & = & 1 \\ (iv) & V'(t) & = & -w(c(t)) + \rho V(t) \\ (v) & y'(t) & = & -w(c(t))e^{-\rho t} \end{array}\right. \tag{10}$$

Satisfying the Brundtland condition amounts that (k, c, t, V, y) remains in the closed set defined, in particular, by the constraint (8) until reaching the target $y = 0$ at the time horizon.

Tasks

The main tasks are:

1. Study analytically the relationship between viability and Pontryagin optimality in the case of the simple requirement of non-starvation.
2. Compute the viability kernels under non-starvation and/or Brundtland sustainability, and identify the economic and demographic determinants of non-emptiness of these kernels and their volume.
3. Repeat the previous task for other problems involving more realistic demographics and natural resources (with the corresponding environmental regulation as additional viability constraints).

For the last two tasks, the approach is computational. We use an algorithm developed by Bonneuil (2006) who addressed the computation of viable states and of the viability kernel in large state dimension based on stochastic optimization. The idea is to minimize the distance to the set of constraints of solutions stemming from a given state, and to assess the viability status of this state whether or not the minimization of the distance leads to at least one trajectory remaining in the set of constraints. The search for viable states is also obtained by the minimization of a distance to the set of constraints, so that the procedure relies on a double stochastic optimization: one with the initial state under examination fixed, so as to decide whether it is viable or not, and one where this initial state is varied. We shall use this algorithm in our computational work later on.

2 Sustainability and Population

Demographic choices are clearly relevant to sustainability. Strangely enough, in the public debate, we talk a lot about reducing consumption per capita, shifting to less energy intensive modes of production or to modes of energy production that are less carbon-intensive. Yet, the issue of population size, while present when it comes to health care and pensions, is not really high on the agenda at the moment when it comes to environmental issues.

2.1 Optimal population size: Normative issues

Considering both the philosophical and the economic perspectives on demographic issues in relation with sustainability, there are two types of issues that definitely need more research. The first set of issues has to do with optimal population size. The second set of issues does not take population size as the object of choice, but rather takes it as given and asks how various theories of intergenerational justice should look at it. The project is intended to contribute to both topics.

Optimal population size

On the philosophical side, the work of Derek Parfit (1984) (or the later one of Arrhenius, 2000) has raised a serious challenge as to the very possibility of meaningfully answering the question of optimal population size. If you ask yourself whether it is better to have 100 or 150 people in the coming generation, you need to ask yourself "better for whom?". And as soon as you ask yourself this question, you face what philosophers refer to as "person-affecting" morality issues. In other words, if you consider that something can only be better if it is at least better for one person, then we are in trouble because the larger population includes people who would not exist if we were to go for the "100 people" scenario. And for these people, you cannot use the word "better" since the alternative for them is not to exist at all. If you consider, in contrast, that states of affairs can be assessed independently of whether they are better for at least one person or not, then we are in trouble with understanding what we aim at when we expect people to act fairly. This project is intended to provide new insights on this side.

In order to make prescriptions for optimal policy when population is endogenous, we need to define a social welfare function. Unfortunately, the standard approach does not carry over to situations where the number of agents is a choice variable. When comparing two allocations with different population sizes, one has to take a stand on how to value the utility of people who are alive in one allocation but not in the other. Implicitly it amounts to make assumptions on the utility of not being born. To illustrate the difficulties involved in this step, consider two well-known examples of criteria that have been proposed: average utilitarianism and total utilitarianism. In average utilitarianism, the objective is to maximize the average utility of everyone who is alive. Implicit in this criterion is that the utility of not being born is equal to the average utility of those who are alive. To see why this is so, two allocations, one in which two people are born with a utility of two each, and one where in addition to the two people with utility two a third person exists with utility equal to one. According to average utilitarianism, the first allocation is to be preferred, since average utility is higher. But no one who is alive in the first allocation is worse off in the second, we merely added a third person with utility equal to one. If we prefer the first allocation, implicitly we are therefore stating that the third person is better off not being born. Clearly, this appears arbitrary.

Let us no consider total utilitarianism (Dasgupta 1969), where the objective is to maximize total utility in the economy. Under total utilitarianism, in our previous example the second allocation is to be preferred; it always improves welfare to add people with positive utility, as long as nobody already existing is made worse off. Implicitly, therefore, we are now assuming that the utility of not being born is exactly zero. But notice that assigning a utility of zero to unborn people is just as arbitrary as any other real number. Total utilitarianism is part of a more general class of welfare criteria known as critical-level utilitarianism, see Blackorby, Bossert and Donaldson (2005). With this criterion adding a person is worthwhile if his/her utility exceeds a critical level, which happens to be zero in total utilitarianism. Utility functions are defined only up to positive transformations, so it is not clear what exactly is meant by zero utility. With total utilitarianism, setting the utility of the unborn is therefore a key step in defining the welfare criterion, but it is not clear how that should be done.

The central difficulty is that the utility of not being born cannot be determined by introspection, which is employed by utilitarianism to rank the various situations, given that everyone currently alive will not make the experience of never being born. Is it, then, simply impossible to find a basis on which a plausible welfare criterion can be based? There exists a view of the world under which the utility of the unborn can be assessed even by people who are currently alive. The key is to find an interpretation where being alive and not unborn are not mutually exclusive, but merely different states which are experienced by one and the same being over time. Such a view of the world does exist and is in fact quite common. What is required is a world with a fixed supply of souls, who get reincarnated from time to time in different human bodies. For such a soul, determining population does not amount to a drastic "to be or not to be" question; instead, a smaller world population merely amounts to a longer wait to the next incarnation.

The objective of our research is to look at whether such an approach could be used and what it really means. As far as the usability of the approach is concerned, we will have to show that it leads to more robust conclusions about optimal population than the existing criteria. In terms of meaning, we will have to convince that, although we do not necessarily believe in reincarnation as a right description of the world, it can be used to build a meaningful criterion. We intend to develop the following argument: The soul takes into account the utility of all her future lives. It is as if a household would take care of random future beings. This view is called in the literature generalized altruism, going back to the notions of love of mankind or universal benevolence implying that we desire the happiness of all innocent and sensible beings, embracing the immensity of the universe, present and future.

Population change and intergenerational justice

Gosseries (in press) has recently explored the demo-sensitivity of one family of theories, i.e. theories of reciprocity. A more systematic work should be done however to understand whether and to what extent other theories can come up with versions that are demo-sensitive or not. A theory is demo-sensitive if differences between the population size of two succeeding generations affect the content of what we owe to the next generation. Imagine that we reproduce in such a way that the population of the next generation is the double of ours. Does it mean that we should transfer them twice as many resources as what we inherited from the previous generation? Conversely, if we reduce the population by half through adopting extremely low reproduction rates, does it follow that we can destroy half of what we inherited from the previous generation and only transfer to the next one half of it? These are not just theoretical questions and they also arise in the pension case for example. For the problem of social security from the intergenerational perspective is primarily due to fluctuations in population levels that require an answer - at the normative level - as to how such population changes should affect the level of benefit and the level of contribution of succeeding generations.

2.2 Population extinction: the role of natural resources

There is a very clear interaction between natural resources and population dynamics. Faced with the uncertainties surrounding the future of earth climate and environment, scientists have tried to understand how several past societies failed to find a stable development path, with a sustainable balance between resources, production and population. Typical examples of these failure are the collapse of the classical Maya civilization in the ninth century (Demarest 2004) and the dramatic decline of the Easter Island society (Flenley and Bahn 2003). An even more extreme example is the complete extinction of the Viking's colonies of Greenland (Diamond 2005, chapters 6, 7 and 8). The question raised by this literature is twofold. First, it provides explanations for these scenarii. Second, it wonders to what extend these examples from the past can be used as a metaphor of today's global problems.

The literature on decline and collapse has one point in common. The collapse always result from a suboptimal outcome. Two explanations dominate the field. Either some myopic behavior is assumed - people being unable to foresee all the consequences of their action. Or there is a coordination failure. When there are strategic complementarities between agents, achieving the first best outcome requires coordinating the individuals actions. In the absence of coordination device, non-cooperative behavior may lead to a collapse. In the context of Easter Island, De la Croix and Dottori (2008) analyze the conditions under which a collapse effectively occurs in a world where clan's bargaining power depends on its threat level when fighting a war. The biggest group has the highest probability of winning. In the quest for greater bargaining power, each clan's optimal size depends on that of the other clan, and a population race follows. This race may exhaust the natural resources and lead to the ultimate collapse of the society.

In the present economic literature it has never been imagined that a collapse could be an optimal outcome. Still we can at least imagine a situation where, confronted with a limited resource, a society prefers to take a maximum pleasure today and then become extinct, rather than living at a low standard for an infinite time. In other words, could a finite extinction date be optimal? This is the essential question we address in this part of the project. The intended contributions are twofold. First, we enlarge the literature on collapse so as to include first best outcomes. Second, we aim to derive conditions under which an optimal collapse occur, rather than an infinitely lived society.

Beyond the modeling of decline scenarios, our research question echoes two different literature. One is in theoretical biology. For example, Shastri and Diwekar (2006) aim at achieving a sustainable ecosystem through manipulations of the population dynamics of the species in an ecosystem. In particular they show how to avoid the extinction of a given species with different control options, the profiles for which are derived using the optimal control theory. Whittle and Horwood (1995) develop policy recommendations for optimal resource management under the treat of extinction of the resource. They maximize expected total future yields and show that if extinction of the resource is possible then the exploitation rate should be almost zero. They do not discuss much the role of discounting, but admit that discounting has the effect of making the contingency of extinction seem so remote as to be irrelevant. The other one is the classical literature on optimal size of population introduced in the preceding section (Blackorby, Bossert, and Donaldson, 2005).

Various criteria have been proposed to deal with the question of optimal population. In some cases, the corresponding maximum will turn to be the corner solution of zero population. Such solutions are generally discarded by the literature as being uninteresting and irrelevant. However, as soon as we consider a dynamic problem, such solutions could become interesting again, since they reflect the possibility, and even the optimality, of extinction. There is however no social choice paper dealing with this question, at least to our knowledge.

Before considering the interaction between resource and population dynamics, we recast the standard static optimal population problem in a dynamic framework. This will allow us to considerably enrich and generalize the usual analysis, as well as pave the way for the more intricate problem with endogenous resources. In a second step, we will consider an economy which has a stock of renewable natural resource. This resource is essential for production. Its depletion rate depends on the level of population. Having many people in the economy is enjoyable but it depletes the resource faster. The central question is under what conditions it is optimal to completely deplete the resource in finite time.

2.3 Composition of population, sustainability and policy

In all species, when available resources are more abundant, reproduction increases. This was also true for the human species before the industrial revolution. This relationship has changed in the recent past. During the last two centuries, as economies grew richer, people had fewer children. This phenomenon is known as the demographic transition (see Chesnais (1992) for a comprehensive empirical characterization and Cervellati and Sunde (2005) for a model matching these facts with both endogenous fertility and mortality). Now, both within and across countries, the rich and the educated have less children than the poor and the unskilled (Skirbekk (2008) carries out a meta-analysis of the large empirical literature in demography on the correlation between education and fertility using 902 samples reported in 136 different published research papers. The results show a strong and stable pattern of differential fertility, with lower fertility of individuals with higher educational background.). Demographers and economists largely disagree on the reasons of this reversal. Demographers stress the access to contraception technology and to knowledge as one important factor underlying these changes. Economists, on the contrary, do not believe that a significant part of observed fertility is involuntary, and would not have materialized if contraception was available. They insist on incentives faced by parents to have many or fewer children.

Economists have developed different models where the number of children flows as a result of households optimization problem. One school of thought models children as a way to save resources for the future and to obtain some support when old. This is the old-age support hypothesis. A second one studies the interplay between fertility and children mortality, stressing that lower mortality reduces the need for high fertility in order to obtain the same number of children reaching adulthood. Another one emphasizes that parents face a trade-off between having many children and spending large resources on the health and education on each of them. This approach is particularly successful to explain fertility differences as a function of the social class of the parents. Educated parents, for whom time is highly valuable on the labor market, will optimally choose to have few children but spend more resources on their education and health (de la Croix and Doepke, 2003).

These models have predictions on how the size and the composition of population are going to change in the future through their interaction with the economic and natural environment. Population dynamics are key for the development of poor countries and the future of the Earth. In this part of the project we acknowledge that not only the level but also the composition of population is key for determining sustainability. We will look at three different dimensions of heterogeneity: skill, gender, and cultural group. Indeed, would a world where the skilled would not have children any more be sustainable? or a world with a severe imbalance in the number of men compared to women? or a situation in which different cultural groups having different fertility levels compete in getting more resources?

1. **Skill heterogeneity**

   Both within and across countries, the rich and the educated have less children than the poor and the unskilled. Recently, a new trend has appeared in the literature: differential fertility as an engine of natural selection. In his history of the world, Clark (2007) argues that, in medieval England, rich households had more surviving children than the rest; the children of the rich also appeared to become rich and had higher-than-average reproductive success; the attitudes that accounted for their economic success were transmitted to their descendants, proliferated, and were responsible for the industrial revolution. The situation is now reversed. Better-educated individuals produce few children while less-educated individuals produce many children and all individuals invest too little in the education of their children (Fan and Stark 2008). If this is true, it has strong implications for the future. The fact that the most creative and gifted persons have fewer children inverses the logic above.

This selection mechanism story has been strongly criticized, notably by Samuel Bowles (2007) in his Science article: Parents transmit personality traits to their children, and there is good evidence that genetic transmission is involved for some social behaviors. However, the correlations between parental and offspring measures of personality are strikingly low. John Loehlin's survey of 859 such correlations found a mean value of 0.13. Thus whether genetic or cultural, parental influence on descendent preferences is quickly dissipated across the generations, which makes Clark's story unlikely.

We would like to come into this important debate first with the tools of quantitative theory. The main question to be addressed is which persistence do we need between parental and offspring characteristics in to obtain the dynamics advocated by Clark. More precisely one can start from Galor and Michalopoulos (2008), who propose a formal model of evolution and selection to explain the industrial revolution, remove the assumption of perfect correlation between parents and offsprings and study the corresponding population dynamics. Which mechanisms are likely able to generate such a persistence and which are not is the next question to address. Then, we can use the model to simulate various outcomes for the future, depending on the mechanisms of transmissions in place.

One important variable to consider is the future distribution of income. When differential fertility is at play, there is a tendency for the poor to increase in number of individuals, but also to have a smaller and smaller share of total income. Education and/or population policy can partly correct this, at least if one is concerned with inequality. A joint paper between two promoters of this project (de la Croix and Gosseries 2009) has considered that issue with en emphasis on the short-run. Developing this work further to look at the interaction between income distribution and sustainability in the long run is on the agenda of this project.

2. **Gender differences**

   The second line along population composition matters is the one of the gender imbalance. This imbalance is highly visible in parts of Asia because of female infanticide and/or abortion (the so-called missing daughter); here also population dynamics may have devastating long-run effects but, despite many descriptive studies, the theoretical consequences of such imbalance remains largely unexplored.

Data show that in these countries there is a strong imbalance in the gender ratio of children in favor of boys. This imbalance has consequences for the future marriage market, fertility and population dynamics. Once presenting our paper about tradable procreation rights (De la Croix and Gosseries, 2008), it was suggested to develop a framework in which we would have differentiated entitlements as a function of the gender of the child. It would be similar to having different family allowances for boys and girls. The properties of such a scheme, its ability to counteract the current gender bias in Asia, and its ethical limits would be the subject of this research, with a strong need for interactions between philosophers and economists.

3. **Cultural differences** [this part of the project is directly related to post-doc candidate Thomas Baudin]

   From a contemporary point of view, there exist persistent disparities between fertility behaviors within European population. For instance, the English and French populations are expected to increase up to 2050 while populations of Spain, Germany and Italy will decrease. In his green paper entitled "Confronting demographic change: a new solidarity between the Generations", the European Commission shows the great importance of this question. It particularly asks the central question "What value do we attach to children?". We will argue in this section that these features are beyond the scope of the standard models of fertility because they are closely related to the interaction between cultural and economic conditions.

   This part of the project will put the interaction between culture and economic variables at the heart of the explanation to the long run evolution of economies. Doing so consists in rehabilitating and improving the old Synthesis Model of fertility proposed by Easterlin (1978). In this model, agents are utility maximizers as in the usual Beckerian approach but social norms are included as a determinant of parental utility. Preferences determine individual demands for commodities and children while social norms determine preferences. Birdsall (1988) underlines that "...In the long run, these norms may change in response to economic factors, but they are viewed as changing slowly enough so that for individual couples within a given society they can be considered as exogenous to fertility". This section aims at making endogenous the long run evolution of social norms by exploring the black box linking economic behaviors and the dynamics of social norms. This new model will allow investigate the impact of initial cultural and economic differences on the long run evolution and sustainability of population and on current population problems. It will also improve the explanation of early demographic transition in Europe by allowing, for instance, the consideration of the role of Catholicism, Socialism, etc. It will also enable us to propose an explanation to the persistence of differences in fertility behaviors between closed populations.

   Apps and Rees (2004) argue that public policies consisting in providing day nurseries and reducing the cost of child care by sitters decrease the child rearing time of parents (and especially women) and in turn, incite households to have more children and women to increase their labor supply. One question can be addressed in this framework: why this policy is not largely implemented in all European countries? Why political choices and voting are not unanimous to implement these policies? Why such policies do not recover the same efficiency in every country? These issues are related to the question raised by the European Commission's Green Paper: "What value do we attach to children?". We aim at investigating this question and the reasons why all countries does not value their children in exactly the same way which creates differences in their demographic dynamics and policies. To reach our goal three questions have to be addressed: How to endogenously determine a social norm in a tractable way? How social norms are transmitted through generations? How do cultural and economic differences co-evolve?

The easiest way to determine a social norm for a variable x is to define it as its average value E(x) into the group during preceding periods. Then, for an initial exogenous social norm, all subsequent norms will be determined by rational choices of agents belonging to this group. This method has been suggested, for instance, by Palivos (2001). As individual choices will be determined by economic conditions at the date of choice and the agent's utility (influenced by the group's norm), the evolution of norms will be endogenous and shaped by the economic environment. The transmission of social norms asks the question of cultural transmission from parents and society to children. Here, a culture is defined by the set of social norms followed by members of the same group. Simply supposing a perfect vertical transmission from parents to children would restrict the model to an evolutionary framework, in other words, no social and cultural mobility would exist.

The mechanism of socialization à la Bisin and Verdier (2001) will constitute a central building block of the project. Indeed, the vertical transmission will not be automatically successful. Parents will engage resources to transmit their culture to their children because they are characterized by an imperfect empathy meaning they prefer children like them. This will allow the persistence of non efficient cultures and to obtain some long lasting effect of disappeared cultures. The last building block of the project consists in understanding the mechanism at the heart of the co evolution of culture and economic conditions. This part will crucially be inspired by De la Croix and Doepke's framework (2003). Indeed, the parental trade-off between quality and quantity will determine their children future incomes given their future cultural choices. The framework of De la Croix and Doepke allows to simply model the quality-quantity trade-off in a framework where differential wealth and preferences matters for long run dynamics.

3 Firms and Sustainable Development

3.1 The problem of short-termism

One dimension that needs to be addressed to operationalize the idea of sustainability is to make sure that the time horizon of various actors be appropriate. One of us (AG) realized two years ago, when organizing a workshop on short-termism, how little literature there is on this (See however: Laverty, 1996; Black and Fraser, 2002). It raises essentially three types of issues. The first one is whether having a long-term perspective is always fairer than having a short-term one. The answer to this question is not obvious. And it requires both a proper understanding of what " being long-termist " can possibly mean, as well as a close examination of whether it can be compatible with intergenerational impartiality. And one aspect is for example whether impatience and descending altruism (see Section 2.1) both generate the same forms of time inconsistencies.

There is then a second question which consists in identifying the factors that render a given actor more or less short-termist. We cannot hope to generate incentives towards long-termism if we don't properly understand the factors that influence our time horizon. The problem arises for politicians. But it also arises in firms. For example, how does the seniority of workers (hence, the evolution towards more short-term contracts) as well as the degree of turnover among shareholders affect their temporal horizon? Under which conditions, if at all, do we tend to observe effects of contagion such that as soon as one actor is more short-termist, he pushes the other ones to become so as well (a form of temporal leveling down) ? Also, why do we observe so many short termist actors if we can also predict on other grounds that the more patient you are, the richer you will become?

These are just a few examples of factors that could influence the time horizon of actors. Once a proper diagnosis of such determinants will be available, we will then be able to propose precise measures. For example, should we subject the right to vote of shareholders to a minimum seniority of their shares? Should we call for a different periodicity of activity reports in firms? What is the price to pay in extending political mandates in parliaments and governments? Would that effectively modify the politicians' time horizon for the better, without any excessive price to pay in terms of accountability? Are there alternative ways to accommodate in a better manner the accountability requirement and the need to avoid excessive short-termism?

3.2 The choice of sustainable technologies

A crucial issue repeatedly addressed in the ongoing debate on sustainable development is the possibility for the economies to keep on growing while confronted to physical limits and legal constraints such like those related to the limited availability or regenerative capacity of natural resources (fossil energy, fish, forest, etc.), to economic and ecological regulation (emission quotas, harvesting quotas, etc.) or to financial resource constraints at the firm or national economy level. One of the common ideas turns out to be that such a growth possibility is certainly widely open if the economies are able to maintain a permanent stream of innovations, assuring long-term technological progress (see Arrow et al., 2004, for a comprehensive view of sustainability). An excellent illustration of the problems we aim to study in this project is the case of the chlor-alkali industry in Japan 1960-2000. We summarize it hereafter.

The case of the chlor-alkali industry in Japan

This case is documented in Yarime (2007). The chlor-alkali industry produces chlorine and caustic soda through electrolysis. Because it involves electrolysis, it is one of the major energy consumers in the Japanese industry. In this context, a major concern of the firms operating in this industry is to develop innovative techniques in order to reduce energy consumption. Of course, the R&D activities conducted to this end were not all dictated by environmental constraints or rising resource prices. This was certainly not the case in the 60s, for example. On the other hand, the technological context of such an industry is highly interesting for the study of energy-saving innovation processes.

To this context, one has to add a sensitive environmental issue, linked to the electrolysis technique used, which has motivated an increasingly severe environmental regulation from the late 60s. Indeed, at that time, the electrolytic process employed was a mercury process, thus based on a highly toxic substance. It was relatively quickly established that the mercury released by the chlor-alkali industry to the neighboring seas was the cause of the so-called Minimata disease, which caused about 700 victims in that time. The Japanese authorities started ruling against chlor-alkali industry from the mid-60s, stipulating among others quantitative limits to control the levels of mercury released to environment. In 1974, the Japanese authorities took a step further against the industry and require the conversion of as many mercury plants as possible to the unique alternative at that time, the made-in-USA diaphragm electrolytic process, by the end of 1975.

Now, comes the most interesting part of the story. Because the alternative diaphragm process was clearly disadvantageous in terms of energy consumption compared to the mercury process, and given the period of rapidly increasing energy prices (recall the anti-mercury process regulation was taken during the first oil crisis), both producers and authorities quickly discovered the urgent need to develop an alternative electrolytic process, less energy-consuming than the diaphragm process and less polluting than the mercury process. This motivated a massive R&D effort in developing a third electrolytic process, the ion exchange membrane process, and the suspension of the conversion program (to the diaphragm process technology) by May 1977. As mentioned by Yarime (2007), although the idea of using ion exchange membranes had been known by many years at that time, a significant R&D effort was needed to develop ion exchange membranes adapted to the chlor-alkali industry, and the number of patent applications by Japanese firms increased markedly after the mid-70s and until the early 80s in this field. In 1998, about 90% of the Japanese chlor-alkali plants used the ion exchange membrane process.

In terms of economic theory, the previous case can be connected to two hot topics: the relationship between resource scarcity and innovation, and the relationship between regulation and economic behavior. Scarcer resources are increasingly expensive, and this should in a way affect the behavior of consumers and firms, and end up shaping the direction of technological progress. A related fundamental hypothesis, popularized by Hicks (1932), is the so-called induced-innovation hypothesis. According to Hicks, the change of relative prices of production inputs stimulates innovation, an innovation of a particular type, directed to save the production factor that becomes relatively expensive. In the context of the energy consumption debate, this hypothesis simply stipulates that in periods of rapidly rising energy prices (relative to other inputs), economic agents will find it more profitable to develop alternative technologies, that is, energy-saving technologies. However, in their well-known work, Newell, Jaffee and Stavins (1999) concluded that a large portion of efficiency improvements in US manufacturing seems to be autonomous, and therefore not driven by the Hicksian mechanism outlined above.

Just like scarcity, regulation can also be a decisive determinant of technological progress. As an immediate illustration of such a potential nexus, environmental economists use to put forward the so-called Porter hypothesis (Porter, 1991) according to which a carefully designed environmental regulation can increase firm competitiveness by encouraging innovation in environmental technologies. A considerable amount of studies has been devoted to the empirical corroboration of this hypothesis, reaching distinct and contrasted conclusions (see Parto and Herbert-Copley, 2007, for an excellent compilation of case studies).

The benchmark

In this part of the project, we take the firm perspective. Firms are typically affected by several institutional and economic factors, notably by competition, credit constraints and legal constraints which are not only linked to ecological regulation. In the benchmark case, we consider the worst scenario possible in this respect:

1. No market power: the firm is price-taker and prices can rise reflecting scarcity.
2. Liquidity-constraints: the firm cannot incur in a negative cash flow at any date.
3. Quota constraints: we impose a quota constraint on the use of a production input (fossil energy or natural resource like fish as immediate examples), which may feature emission or extraction quotas.

In such a context, how could the firm experience a sustainable growth of profits? Answering this question properly requires accounting for a comprehensive set of modernization instruments that the firm can use in response to the above constraints. At first place, the role of innovation and technology adoption at the firm level is a key. If the firms do effectively respond to the latter constraints and circumstances by doing more R&D and/or adopting better technologies, then the "sustainability problem", stated in the beginning, can be at least partially solved. But firms cannot always push on this command button for many reasons. Two are quite obvious. On one hand, financial constraints "hurt": As mentioned above, this type of constraints is, of course, crucial as long as one is concerned with technological renovation, especially when it is imposed by law. If the firms do not face any type of financial constraints, then they could finance R&D expenditures and/or technology adoption with no limit, which is certainly unrealistic. In the case of the Japanese chlor-alkali industry described in Yarime (2007), financial constraints are even more crucial since the whole industry was required to switch technology in a limited amount of time.

Second, technological complexity often limits technological adoption.: It is very well known that the success of R&D programs depends, among others, on the complexity and sophistication of the technologies to be up-graded. Complexity is therefore a fundamental ingredient of early technology adoption theoriesà la Nelson and Phelps (1964) and of more recent standard growth theory (see for example, Barro and Sala-i-Martin, 1995, chapter 7, or Segerstrom, 2000). Needless to say, the problem of technological sophistication is also a sensitive barrier to technological progress because of limited amount of available skills and hi-tech capital (see Chudnowsky and Lopez, 2007, pp 88-121, for the Argentinean case).

We shall account for it in our modeling. In addition to innovative and/or adoptive R&D, firms may decide to scrap old and definitely non-sustainable technologies with their associated capital goods, and to replace them (or not) with leading technologies and new equipment. If one aims to thoroughly capture the mechanisms of modernization, the latter instruments are crucial to consider. Typically, firms will respond by combining all these instruments and by choosing the optimal timing for each of them. We take this avenue here by considering vintage technologies at the firm level, allowing the firm to innovate, to scrap and to invest.

Tasks

A fundamental objective in the project is the identification of the optimal modernization strategies pursued by firms based on the three instruments listed just above. We shall use vintage capital technologies in line with Malcomson (1975), Benhabib and Rustichini (1991), Boucekkine et al. (1997, 1999, 2004, 2005, 2008a, 2008b) and Hritonenko and Yatsenko (1996, 2005). There are essentially two inputs, capital and a resource subject to quota, which can be fossil energy or any natural resource. Capital goods produced at different dates embody different technologies, the youngest vintages are the most resource-saving. Beside realism, working with vintage capital production functions allows us to capture some key elements of the problem under consideration, which would be lost under the typical assumption of homogenous capital. For instance, facing an emission tax, firms are tempted to downsize. However, in the vintage capital framework where the firm also chooses the optimal age structure of capital, downsizing entails modernization: the oldest and, thus, the least efficient technologies are then removed.

Due to the analytical complexity of vintage models, very few papers rely on such specifications. A noticeable exception is Feichtinger, Hartl, Kort and Veliov (2005) who introduced a proper specification of embodied technological progress underlying the considered vintage capital structure. They concluded that if learning costs are incorporated into the analysis (i.e., running new machines at their full productivity potential takes time), then the magnitude of modernization effect is reduced, and regulation has a markedly negative effect on industry profits.

Our project extends the latter result in two important directions: It endogenizes the optimal lifetime of technologies and associated equipment through endogenous scrapping decision, and it endogenizes the pace of technological progress in the workplace by considering an optimal innovative or adoptive R&D decision (the technological progress is exogenous at the firm level in the previous paper). In such a context, the set of possible modernization strategies is much richer. We aim at identifying the optimal modernization strategies followed by the firms in the benchmark case described above. Is the R&D effort sufficient for such a heavily constrained firm to keep on growing? Which kind of modernization strategy should be preferred by the firm as natural resources become increasingly expensive? In other words, what are the optimal Hicksian mechanisms in this benchmark case? How the results get altered if we depart from the benchmark case (for example by giving firms market power or more financial instruments)?

4 Organization and Budget

Section 1.1 will be led by Axel Gosseries and his team with contributions from David de la Croix as far as intergenerational justice is concerned (cf the book de la Croix and Michel 2002) as well as from Raouf Boucekkine (sequentiality). The work of the post-doc will be jointly supervised by the three promotors. Section 1.2 will be led by Raouf Boucekkine with contributions of everybody on various aspects of sustainability modelling. Section 2.1 will be co-managed by David de la Croix and Axel Gosseries. Section 2.2 is mainly a joint project between Raouf Boucekkine and David de la Croix; the competencies of the first on dynamic analysis will be paired with the competencies of the second on population economics and theories of decline. Section 2.3 will be led by David de la Croix with interventions of Axel Gosseries on the normative aspects of inequality and sustainability. Section 3.1 is mostly managed by Axel Gosseries, and involves the two other promoters to establish bridges between applied philosophy methodology and the economic theory one. Section 3.2 will be mostly conducted by Raouf Boucekkine. All sections also rely on international cooperation, which we do not describe here in detail.

A significant part of the budget is devoted to finance three *doctoral* positions. We do not require more than three because we are confident to benefit from ph students who will bring their own funding with them (for example we have an influx of excellent students from Italian universities who could very often find some Italian fellowships to write a thesis abroad). The project will therefore coordinate Ph.d students around one theme,

	2009 3 months	2010	2011	2012	2013	2014 9 months	Total
Phd student 1	6.909	29.019	30.470	23.995			90.393
Phd student 2	6.909	29.019	30.470	31.993	25.195		123.586
Phd student 3		7.255	30.470	31.993	33.593	25.195	128.506
Post-doc Hoover	9.141	38.392	40.312	42.327	33.333		163.505
Post-doc ECON	18.282	38.392	30.234				86.908
Functioning	6.000	21.200	15.250	15.250	24.150	8.050	89.900
Equipment	10000	4000	4000	10000	4000		32.000
Overhead	2.362	8.164	8.860	7.278	5.814	1.662	34.140
Total	59.604	175.441	190.066	162.836	126.084	34.907	748.938

Table 1: Budget

sustainability, and generate a critical mass in this subject. Training is a top priority of the project.

Concerning the *post-doctoral positions*, let us be very specific. Each year, the Hoover Chair receives many applications from excellent researchers worldwide, but is only able to fund 10 to 12 months using the interests paid on its endowment. It would be highly valuable for the project to select one of these persons who works on a relevant field and offer him/her the possibility to stay two years. We would like to do that two times over the duration of the project. Insofar as the two times two years post-doc fellowships to be allocated to the Hoover Chair is concerned, we aim at finding someone with a strong profile in economics. Axel Gosseries has been working for more than ten years on some of these issues. We are not looking for a pure philosopher who would not be complementary enough with what Axel Gosseries would be able to do by himself. Rather, the idea is to test some of the hypothesis as they arise from the philosophical debate with the tools from economics. For this to be successful, not only do we need to find a post-doc with a strong profile in economics, but we also need to have a joint supervision together with economists. Axel Gosseries knows from past experience that such a joint supervision is absolutely necessary. The chances to find a good candidate are increased by two factors: the reputation of the Hoover post-doc of the Hoover Chair and the reputation of the economics department.

The second post-doctoral position is directly related to one person, Thomas Baudin, who has very useful skills for the project and is willing to come to UC Louvain for two years and work on the population and sustainability workpackage.

The functioning budget will mostly be used to finance the mobility of researchers (in and out) and to organize three workshops and one larger conference in 2013.

Equipment covers computers and software licences (Matlab, Mathematica).

5 References

Apps P. and Rees R. 2004. “Fertility, Taxation and Family Policy”, Scandinavian Journal of Economics, Vol. 106(4), pp 745-763

Arrow, K., 1973., “Rawls Principle of Just Savings”, Swedish Journal of Economics, 75, 323-335

Arrow K., Dasgupta P., Goulder L., Daily G., Ehrlich P., Heal G., Levin S., Mäler K., Schneider S. Starrett, and Walker B. 2004. “Are we consuming too much?”, Journal of Economic Perspectives, 18(3), 147-172.

Arrhenius, G., 1999. “Mutual Advantage Contractarianism and Future Generations”, Theoria, 65, 25-35

Arrhenius, G., 2000. “An Impossibility Theorem for Welfarist Axiologies”, Economics and Philosophy, 16: 247-266

Asheim, G., 1988, “Rawlsian Intergenerational Justice as a Markov-Perfect Equilibrium in a Resource Technology”, The Review of Economic Studies, 55: 469-483

Aubin, J.-P. 1997. *Dynamic Economic Theory: A Viability Approach.* Boston, Basel: Springer-Verlag Birkhäuser.

Aubin J.-P., Bayen, A., Bonneuil, N., Saint-Pierre, P. forthcoming. *Viability, Control, Games.* Boston, Basel: Springer-Verlag Birkhäuser.

Barro, R. and Sala-i-Martin, X. 1995. *Economic Growth.* New York: McGraw-Hill.

Beltrati A., Chichilnisky, G., Heal, G. 1994. “The environment and the long run: a comparison of different criteria”, Ricerche Economiche, 48, 319-340.

Benhabib, J., and Rustichini, A. 1991. “Vintage capital, investment, and growth”, Journal of Economic Theory, 55, 323-339.

Birdsall N. 1988. “Economic Approach to Population Growth”, Handbook of Development Economics Volume 1, Pages 477-542

Bisin A. and Verdier T. 2001. ”The Economics of Cultural Transmission and the Dynamic of Preferences”, Journal of Economic Theory, Vol 97, pp 298-319

Black, A., P. Fraser, 2002, “Stock Market short-termism an international perspective”, J. of Multinational Financial Management, 12, 135-158

Blackorby, C., W. Bossert, and D. Donaldson. 2005. Population Issues in Social Choice Theory, Welfare Economics, and Ethics. Econometric Society Monographs. Cambridge: Cambridge University Press.

Bonneuil, N. 2006. “Computing the viability kernel in large state dimension”, Journal of Mathematical Analysis and Applications, 323, 1444-1454.

Bonneuil N. and Boarini, R. 2004. “Preserving Transfer Benefit for Present and Future Generations”, Mathematical Population Studies, 11(3-4), 181-204.

Boucekkine, R., Hritonenko, N. and Yatsenko,Y. 2008a. “Optimal firm behavior under environmental constraints”, CORE Discussion Paper 2008/24, Université catholique de Louvain, Louvain-la-Neuve, Belgium.

Boucekkine, R., del Rio, F. and Martinez, B. 2008b. “Technological progress, obsolescence and depreciation”, Oxford Economic Papers, forthcoming.

Boucekkine, R., de la Croix, D. and Licandro, O. 2007. “Modelling vintage structures with DDEs: Principles and applications”, Mathematical Population Studies, 11, 151-179.

Boucekkine, R., del Rio, F. and Licandro, O. 2005. “Obsolescence and modernization in the growth process”, Journal of Development Economics, 77, 153-171.

Boucekkine, R., del Rio, F. and Licandro, O. 1999. “Exogenous vs endogenously driven fluctuations in vintage capital growth models”, Journal of Economic Theory, 88, 161-187

Boucekkine, R., Germain, M. and Licandro, O. 1997. “Replacement echoes in the vintage capital growth model”, Journal of Economic Theory, 74, 333-348.

Bowles S., 2007, “Genetically capitalist?”, Science 318.

Cannarsa, P. and Frankowska, H. 1991. “Some characterizations of optimal trajectories in control theory”, SIAM J. of Control and Optimization, 29, 1322-1347.

Cervellati, M., and U. Sunde. 2005. “Human Capital, Life Expectancy, and the Process of Development,” American Economic Review, 95(5), 1653-1672.

Chesnais, J.-C. 1992. The Demographic Transition: Stages, Patterns and Economic Implications. A Longitudinal Study of Sixty-Seven Countries Covering the Period 1720-1984. Clarendon Press, Oxford.

Chichilnisky, G. 1993. “What is sustainable development?”, Paper presented at the 1993 workshop of the Stanford Institute for Theoretical Economics.

Chudnowsky, D. and Lopez, A. 2007. “Environmental management and innovative capabilities in Argentine industry”, in Parto, S., and Herbert-Copley, B. (Eds.), *Industrial Innovation and Environmental Regulation*, Maastricht: The UN University, 81-114.

Clark G., 2007, A Farewell to Alms: a Brief Economic History of the World, Princeton: Princeton University Press.

Dasgupta, P., 1974, “Some Problems Arising from Professor Rawls Conception of Distributive Justice”, Theory and Decision, 4, 325-334

De La Croix D. and Doepke M. 2003. ”Inequality and Growth: Why Differential Fertility Matters?”, The American Economic Review, American Economic Association, vol. 93(4), p 1091-1113

De la Croix, D., and D. Dottori. 2008. “Easter Island collapse: a tale of a population race.” Journal of Economic Growth 13 (1): 2755.

De la Croix D., and A. Gosseries, 2009. “Population Policy Through Tradable Procreation Entitlements”, International Economic Review, forthcoming.

De la Croix D. and Michel P., 2002. A Theory of Economic Growth: Dynamics and Policy in Overlapping Generations, Cambridge: Cambridge University Press.

De Marco, G. and Romaniello, M. 2006. "Dynamics of mixed coalitions under social cohesion constraints", Mathematical Population Studies 13,39-62.

Demarest, A. 2004. Ancient Maya - The rise and fall of a rainforest civilization. Cambridge: Cambridge University Press.

Diamond, J. 2005. Collapse. How societies choose to fail or survive. London: Penguin Books.

Easterlin R.A. 1978 "The economics and sociology of fertility: A synthesis", in: C. Tilley, ed. Historical studies of changing fertility. Princeton, NJ: Princeton University Press.

Feichtinger, G., Hartl, R., Kort, P. and Veliov, V. 2005. "Environmental policy, the Porter hypothesis and the composition of capital: Effects of learning and technological progress"', Journal of Environmental Economics and Management, 50, 434-446.

Flenley, J., and P. Bahn. 2003. The enigmas of Easter Island. Oxford University Press.

Galor O. and S. Michalopoulos, 2008, "The Evolution of Entrepreneurial Spirit and the Process of Development", mimeo, Brown University.

Gauthier, D., 1986, Morals by agreement , Oxford: Clarendon Press

Gaspart, F., Gosseries A. , 2007. "Are Generational Savings Unjust?", Politics, Philosophy and Economics, 6,193-217

Gosseries, A., "Three models of intergenerational reciprocity", in Axel Gosseries and L. Meyer (eds.), Intergenerational Justice , Oxford: Oxford U. Press (in press)

Heath, J., 1997. "Intergenerational Cooperation and Distributive Justice", Canadian J. of Phil., 27(3), 361-376

Hicks, J. 1932. *The Theory of Wages*. London: McMillan.

Hritonenko, N., and Yatsenko, Y. 2005. "Turnpike and optimal trajectories in integral dynamic models with endogenous delay", Journal of Optimization Theory and Applications, 127, 109-127.

Hritonenko, N. and Yatsenko, Y. 1996. *Modeling and Optimization of the Lifetime of Technologies*. Dordrecht: Kluwer Academic Publishers.

Laverty, K., 1996. "Economic "Short-Termism": The Debate, The Unresolved Issues, And The Implications for Management Practice and Research", Academy of Management Review, 21, 825-860

Le Kama, A. and K. Schubert Le Kama, A. 2007. "A Note of the consequences of an endogenous discounting depending on the environmental quality", Macroeconomic Dynamics, 11, 272-289.

Malcomson, J. 1975. “Replacement and the rental value of capital equipment subject to obsolescence”, Journal of Economic Theory, 10, 24-41.

Nagumo, M. 1942. “Über die Lage der integralkurven gewöhnlicher Differentialgleichungen”', Proc. Phys. Math. Soc. Japan, 24, 551-559.

Nelson, R., and Phelps, E. 1966. “Investment in humans, technology diffusion and economic growth”, American Economic Review, 56, 69-75.

Newell, R., Jaffee, A. and Stavins, R. 1999. “The induced innovation hypothesis and resource-saving technological change”', The Quarterly Journal of Economics, 114, 941-975.

Palivos T. 2001. ”Social norms, fertility and economic development”, Journal of Economic Dynamics and Control, Elsevier, vol 25(12), p 1919-1934.

Parto, S., and Herbert-Copley, B. (Eds.) 2007. *Industrial Innovation and Environmental Regulation*. Maastricht: The UN University.

Parfit, D., 1984, Reasons and Persons, Oxford: Clarendon Press, 543 p.

Porter, M. 1991. “America’s green strategy”, Scientific America, 264, 4.

Ramsey, F. 1928. “A Mathematical theory of saving”, Economic Journal, 38, 543-559.

Rawls, J. , 1971. A Theory of Justice , Oxford/New York: Oxford University Press

Ray, D. 1987, “Nonpaternalistic Intergenerational Altruism”, Journal of Economic Theory, 41, 112-132

Shastri, Y., and U. Diwekar. 2006. “Sustainable ecosystem management using optimal control theory: Part 1 (deterministic systems).” Journal of Theoretical Biology 241:506521.

Skirbekk, V. 2008. “Fertility Trends by Social Status,” Demographic Research, 18, 145-180.

Whittle, P. and J. Horwood. 1995. “Population Extinction and Optimal Resource Management.” Philosophical Transactions: Biological Sciences 350:179 188.

Yarime, M. 2007. “Innovation on clean technology through environmental policy: Emergence of the ion exchange membrane process in the Japanese chlor-alkali industry”, in Parto, S., and Herbert-Copley, B. (Eds.), *Industrial Innovation and Environmental Regulation*, Maastricht: The UN University, 176-199.