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Sustainability

Ethical Foundations and Economic Properties

Geir B. Asheim

Sustainability is about intergenerational distribution. So, public policy aimed at sustainable development should strengthen the mechanisms for redistribution from the present to the future.

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Summary findings

Asheim interprets development to be sustainable if it involves a nondecreasing quality of life. He introduces a concept of justice, and shows that a development path must be sustainable to prevent injustice.

He argues, and illustrates through growth models, that altruism alone does not — even in the context of an economically efficient market economy — ensure sustainability. In particular, technologies with complementarity between manmade and natural capital represent cases where sustainability need not result. Thus, policies aimed at economic efficiency, such as internalizing external effects, need not generate sustainable development.

Asheim argues that a positive interest rate is not inconsistent with sustainable development. He also maintains that, even in a perfect market economy, prices may not convey whether investments in manmade capital are sufficient to compensate for the depletion of natural capital. In particular, a non-negative market value of net investment is not sufficient for the present quality of life to be sustainable. Finally, he emphasizes that public policy aimed at sustainable development should strengthen the mechanisms for redistribution from the present to the future.

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SUSTAINABILITY: ETHICAL FOUNDATIONS AND ECONOMIC PROPERTIES*

by

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0. SUMMARY

Sustainability is defined as a *requirement of our generation to manage the resource base such that the average quality of life that we ensure ourselves can potentially be shared by all future generations.* The notion 'quality of life' is meant to include everything that influences the situation in which people live. Hence, the notion includes much more than material consumption. Extending the requirement of sustainability to future generations yields the following definition of sustainable development: *Development is sustainable if it involves a non-decreasing average quality of life.* Furthermore, it places the following requirement on our generation: *Our generation's management of the resource base is sustainable if it constitutes the first part of a feasible sustainable development.* This is the interpretation of sustainability which has been suggested in a number of references.

Sustainability in the above sense is a natural requirement of intergenerational justice because it can be shown that under given conditions that if development is not sustainable there exists another development that increases the total sum of quality of life that can be be shared among the generations and, in addition, shares it in a more egalitarian way. Briefly stated: *To prevent injustice, development must be sustainable.*

Does efficiency ensure sustainability when each generation's welfare – according to its own 'subjective' preferences – depends on its own quality of life and the welfare of the next generation? Equivalently, do bequest motives ensure that a perfect inter-temporal competitive equilibrium leads to sustainability? This question is posed in the presence of three different production technologies. The results are negative for two technologies with heterogeneous capital and a certain degree of complementarity between the stock of manmade capital and the extraction of natural capital. Therefore,

generational conflicts will not necessarily be solved by a perfect market economy. Thus, a requirement for sustainability is a requirement for a more fair intergenerational *distribution*, it is not a simple requirement for an efficient management of natural and environmental resources. By examining models having the realistic feature that capital is heterogeneous, one can conclude that our bequests to future generations cannot be viewed simply as a stock of an aggregated capital good.

If the weight placed on the future in each generation's 'subjective preferences' does not ensure sustainability, then by what 'ethical preferences' (to use a term coined by Harsanyi) should we express our concern for the well being of future generations beyond the subjective concern for our own children? In the context of a well known resource model, it is argued that the Ramsey-criterion (maximizing the undiscounted sum of utilities) and the maximin criterion (maximizing the quality of life of the generation with the lowest quality of life) do not ensure both equity and development. Building on my own work I claim that (a) maximizing the welfare of the worst off generation (defined by their own subjective preferences), and (b) maximizing the welfare of the present generation subject to the constraint that the resulting development not be unjust, are much better alternatives.

It is sometimes argued that sustainable development cannot be realized if the market interest rate is positive. This claim is ill-founded. To the contrary, it can be argued that if the economy follows a development that is reasonably egalitarian, then the market interest rate will be positive, though there may be reasons to assume that the interest rate is decreasing over time.

Hartwick's rule characterizes a certain kind of sustainable development – namely a development where the quality of life is held constant – in a perfect market economy with constant population and a stationary technology: The depletion of

natural capital at any time corresponds in market value to the accumulation of manmade capital. I argue, however, that this cannot be turned into a prescriptive rule: Development need not be sustainable even when market prices for all kinds of capital are available in a constant population, stationary technology economy and the accumulation of manmade capital in market prices more than compensates for the depletion of natural capital. The reason why this does not hold is that the relative price of manmade capital in terms of natural capital in an intertemporal competitive equilibrium depends on the entire future equilibrium path. Hence, present prices themselves may not typically convey the information necessary to determine if the capital and resource management of our generation is sustainable.

Finally, in discussing public policy aimed at sustainable development, I argue that one should seek to strengthen the mechanisms that can be used for redistribution from the present to the future. If development is not sustainable, this is a question of faulty distribution, not faulty prices.

1. Definition of sustainability

The notion of 'sustainable development' was introduced into the political agenda by the World Commission on Environment and Development through its report (WCED, 1987), also called the Brundtland Report. The Report does not give a precise definition of 'sustainable development'. The quotation that is usually taken as a point of departure is the following: "Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, p. 43). The Brundtland Report thus looks at sustainability both as a requirement for intragenerational justice and as a requirement for intergenerational justice. I limit the discussion here by considering sustainability to be a requirement for intergenerational justice; specifically, sustainability requires that our generation not use more than our fair share of the resource base. More precisely, sustainability is defined as a *requirement of our generation to manage the resource base such that the average quality of life that we ensure ourselves can potentially be shared by all future generations.*

The notion 'quality of life' includes everything that influences the situation in which people live. Hence, it includes much more than material consumption. It is intended to capture the importance of health, culture, and nature. There are two important restrictions, though: 'Quality of life' does not include the welfare that people derive from their children's consumption. Likewise, only nature's instrumental value (i.e. recognized value to humans) is included in the 'quality of life', not its intrinsic value (i.e. value in its own right regardless of human experience); i.e., an anthropocentric perspective is taken. The general rationale behind these restrictions is that there is an argument to be made in favor of distinguishing the concept of justice

applied in a society from the forces that are instrumental in attaining it. In the present context this means that it may be desirable to separate the definition of sustainability from the forces that can motivate our generation to act in accordance with the requirement of sustainability.

It is possible that our generation will use the resource base in a way that ensures ourselves a quality of life that cannot be shared by all future generations. In such a case, sustainability requires that we reduce the exploitation of the resource base today.

If the requirement of sustainability as defined above is not extended to later generations, it cannot rule out some later generation using the resource base to ensure *itself* an average quality of life that cannot be shared by *its* successors. It seems, however, odd *not* to let sustainability be a requirement of later generations as well. In particular, it would be unreasonable for our generation to have the welfare of distant generations in mind if we believed that the intermediary generations would not take part in an effort to give these generations their fair share of the resource base. Extending the requirement of sustainability to later generations yields the following definition of sustainable development:

Development is sustainable if it involves a non-decreasing average quality of life.

Furthermore, it places the following requirement on our generation:

Our generation's management of the resource base is sustainable if it constitutes the first part of a feasible sustainable development.

This interpretation of sustainability has been suggested in a number of references.[1]

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[1] The idea of defining sustainability in this way dates at least back to Tietenberg (1984) and seems to have been fairly widely accepted; see, e.g. Repetto (1986), Pezzey (1989), and Mäler (1989). A critical assessment of this interpretation of sustainability is given by Pearce et al. (1989, pp 32 & 49). Hammond (1993) gives an interesting review of references relating to the notion of sustainability.

2. A Normative Foundation for Sustainability

In Asheim (1991) I argue that sustainability in the sense of Section 1 is a natural requirement for intergenerational justice. The following gives a brief account of this normative foundation for sustainability.

Let x_t denote the quality of life that generation t enjoys, and call $(x_t)_{t=0}^{\infty}$ a development describing how the quality of life is distributed among the countable, but infinite, number of generations $t = 0, 1, 2, \ldots$. Say that $(x_t)_{t=0}^{\infty}$ is as just as an alternative development $(x'_t)_{t=0}^{\infty}$ if there exists $\bar{s}$ such that for all $s \geq \bar{s}$,

$\Sigma_{t=0}^{s} x_t \geq \Sigma_{t=0}^{s} x'_t$ ($(x_t)_{t=0}^{\infty}$ catches up with $(x'_t)_{t=0}^{\infty}$ in finite time) and

$(x_t)_{t=0}^{s}$ Lorenz-dominates $(x'_t)_{t=0}^{s}$ ($(x_t)_{t=0}^{\infty}$ is as egalitarian as $(x'_t)_{t=0}^{\infty}$).

Say that the development $(x'_t)_{t=0}^{\infty}$ is *unjust* if there exists an alternative feasible development $(x_t)_{t=0}^{\infty}$ such that $(x_t)_{t=0}^{\infty}$ is as just as $(x'_t)_{t=0}^{\infty}$ but the converse does not hold.

Excluding from a social choice developments that are unjust amounts to a weak ethical restriction: It requires a feasible development to be excluded if there exists another feasible development that increases the total sum to be shared between the generations, and simultaneously, shares it in a more egalitarian way. Still, this weak concept of justice excludes all feasible developments that are not sustainable, given that the underlying technology is productive (implying that waiting is productive). In fact, in a productive technology, a development is not unjust if and only if it is dynamically efficient and non-decreasing.

The central argument necessary for establishing this result is the following: If a feasible development $(x'_t)_{t=0}^{\infty}$ is not non-decreasing – i.e. there exist s' and s'' with $s' < s''$ such that $x'_{s'} > x'_{s''}$ – then there exists an alternative feasible development

$(x_t)_{t=0}^{\infty}$ which is identical to $(x'_t)_{t=0}^{\infty}$ except that, for $t = s', s''$, $x_t = \frac{1}{2}(x'_{s'} + x'_{s''})$. Furthermore, $(x_t)_{t=0}^{\infty}$ is as just as $(x'_t)_{t=0}^{\infty}$ but the converse does not hold. Hence, given the weak conditions imposed by the requirement that the technology be productive, one reaches the following conclusion: *To prevent injustice, development must be sustainable.*

3. Does Efficiency Ensure Sustainability?

Economic theories of natural- and environmental resources usually seek to answer the following question: How can an efficient management of natural- and environmental resources be achieved? The objective is to get the real economy to imitate a perfect market economy through internalizing external effects and to promote economic efficiency through regulating the use of natural and environmental resources when such internalization is not feasible. Traditionally, many economists have held the view that, in a perfect market economy, posterity will be made better off due to accumulation of manmade capital (including accumulation of knowledge). To the extent that the depletion of natural resources and the degradation of environmental resources have been explicitly taken into account, these economists have claimed that, due to rising resource prices and technological progress, new reserves will be added to existing resources and substitutes to these resources will be made available. A classic reference for this point of view is Barnett and Morse (1963) (see also Nordhaus, 1974).

Such a view is tenable if the world economy can be described by a model which assumes that — in addition to constant population and a stationary technology —

there exists one aggregate capital good and that each generation has sufficient altruism for the next generation. For example, let each generation t's *subjective preferences* be given by $v_t = u(x_t) + \beta \cdot v_{t+1}$, entailing that the welfare of generation t (v_t) depends on its own quality of life (x_t) though the utility function u and on the welfare of the next generation $t+1$. The term 'subjective preferences' is meant to capture 'selfish' altruism, which motivates a generation to contribute to the welfare of its children because it leads to increased welfare for the contributor. Note that the subjective preferences are non-paternalistic (in the terminology of Ray, 1987) since each generation respects the subjective preferences of its children, and thereby, takes into account the utilities of all future generations. Such recursion means that $v_t = \Sigma_{s=t}^{\infty} \beta^{s-t} u(x_s)$, where β $(0 < \beta < 1)$ is the utility discount factor. In continuous time, these subjective preferences can be represented by $v_t = \int_t^{\infty} u(x_s) e^{-\varrho s} ds$, where ϱ (> 0) is the utility discount rate. Let the production possibilities of the technology considered – referred to as technology (1) – be given by $x_t + dk_t/dt \leq f(k_t)$: The stock of the aggregate capital good (k_t) leads to a production $f(k_t)$ that can either contribute to the quality of life of generation t or be used to accumulate capital. If the economy at the outset is not much developed, so that $f'(k_0) > \varrho$, then it is a well-known result that, in such a one-sector growth model, the capital stock will be accumulated leading to the conclusion that posterity will be made better off. Hence, capital productivity combined with altruism produces a just intergenerational development. Moreover, even though our generation discounts the utilities of future generations, the quality of life of these generations will be higher than ours.

However, in general, this view can*not* be defended. At any time the present generation still determines how the resource base is being managed. Given our technological capacities, it is possible to exploit the resource base to our own advantage

at the expense of the quality of life of future generations. That economic efficiency does not necessarily lead to intergenerational fairness was forcefully argued by Talbot Page (1977) in his book *Conservation and Economic Efficiency.* He illustrated the issue by the following analogy: If someone suggested that the ocean fisheries in the Pacific should be regulated by giving full rights to the entire resource stock to Japan for one year, to the United States for the next, to Russia for the third year, and so forth, it would be natural to claim that the country that came first would exploit the resources to too large an extent. This skepticism would be especially great if the harvest methods were technologically advanced. Still, if we abstract from the fact that generations overlap, this is the way a perfect market economy (without market failure of any kind) allocates natural and environmental resources between the generations: Future generations' well being depends on the altruism that we extend to them as well as our limited capacity to exploit stocks of natural and environmental resources to our own advantage.

The following model with heterogeneous capital illustrates this. As before, let the subjective preferences of each generation t be represented by $v_t = \int_t^\infty u(x_s)e^{-\varrho s}ds$. However, assume that there are two capital goods: manmade capital (k_{mt}) and natural capital (k_{nt}). The production $F(k_{mt}, y_t)$ that can either contribute to the quality of life of generation t or be used to accumulate manmade capital depends now both on the stock of manmade capital and the extraction (y_t) of natural capital: $x_t + dk_{mt}/dt \leq F(k_{mt}, y_t)$. The extraction of natural capital is counteracted by natural renewal $g(k_{nt})$ that depends on the stock of natural capital: $y_t + dk_{nt}/dt \leq g(k_{nt})$.

If there is no natural renewal (i.e., k_{nt} is a non-renewable exhaustible resource) and the production function is assumed to be given by $F(k_{mt}, y_t) = k_{mt}^{a}y_t^{b}$, where $0 < b < a < a + b < 1$, the model investigated by Dasgupta and Heal (1974, 1979) and

Solow (1974) is obtained. In this model – which will be referred to as technology (2) – a positive and non-decreasing development for x_t is feasible by letting the increasing stock of manmade capital substitute for the dwindling extraction of natural capital. However, the marginal productivity of manmade capital will approach zero along such a path. This means that sustainability will be achieved only with an increasing altruism for future generations. In particular, with a positive and constant utility discount rate ϱ, x_t will asymptotically approach zero. This variant of the model thereby shows that even if we put almost as much weight on the utility of future generations as on our own, a perfect market economy will not necessarily ensure sustainability.

Another variant of the model is obtained by assuming a regenerative capacity for natural capital, e.g. $g(k_{nt}) = k_{nt}(1 - k_{nt})$, and by assuming that the extraction of natural capital is limited by the extractive capacity ($cf(k_{mt})$) that is established: $F(k_{mt}, y_t) = min\{cf(k_{mt}), y_t\}$. This model will be referred to as technology (3). In such a model it can be shown (see Asheim, 1978, and Hannesson, 1986) that, with small altruism for posterity (large ϱ) and a low level technology (low c), development will be sustainable if the economy at the outset is not yet highly developed (k_{m0} is small such that $cf'(k_{m0}) > \varrho$). This is because the extraction of natural capital even in the long run (as $cf'(k_{mt}) \to \varrho$) does not exceed the maximal level of natural renewal. The stock of natural capital is not reduced to a level that is smaller than the one corresponding to the maximal level of natural renewal. This implies that the natural capital does not attain a positive (shadow) price in the intertemporal equilibrium. The model therefore shares the properties of technology (1), the one-sector model that was described above. On the other hand, if the altruism for posterity is great (small ϱ) and the technological level is high (high c), development will not be sustainable if the

economy at the outset is not yet highly developed. The extraction of natural capital and the quality of life will exceed the maximum sustainable level. In the intertemporal equilibrium the natural capital will attain a positive (shadow) price, and the natural renewal rate will in the long run approach the utility discount rate $(g'(k_{mt}) \rightarrow \varrho)$, implying that the stock of natural capital is reduced to a level that is smaller that the one corresponding to the maximal level of natural renewal. It is a paradoxical result that in this version of the model, a greater concern for posterity and a higher technological level may lead production for some time to exceed the maximum level of natural renewal and thus, eventually, result in posterity being made worse off. These results are, of course, dependent on the shape of the natural renewal function.

These two versions of the model with heterogeneous capital — technologies (2) and (3) — have the following property in common: The stock of manmade capital is to a certain degree complementary to the extraction of natural capital. In the first version (technology (2)), the marginal productivity of manmade capital is positively related to the extraction of natural capital. In the other version (technology (3)), complementarity is more extreme: Manmade capital can only be used for extracting natural capital. With such extreme complementarity, the accumulation of manmade capital is a mixed blessing. In Richard Norgaard's (1991) analogy; if the livelihood of a society depends on the harvesting of a forest, future generations can gain more if the current generation invests by planting trees rather than accumulating saws.

On this basis the following conclusions can be drawn:

(1) Generational conflicts will not necessarily be solved in a perfect market economy. Distributional problems arise because the present generation through its capital and resource management policy determines the wealth of future generations.

(2) A requirement for sustainability is a requirement for a more fair inter-generational *distribution*. It is not a requirement for an efficient management of natural and environmental resources. Page's (1977) analogy of a sailing ship – where sustainability corresponds to setting the rudder according to the destination and efficiency corresponds to balancing the sails according to the wind – provides, however, the following observation: How the rudder is set influences how the sails will have to be balanced.

(3) Our bequests to future generations cannot be looked at as a stock of an aggregated capital good. The present generation may not act in the interest of future generations by leaving behind a large stock of capital that can only be used to extract natural resources or that leads to the degradation of environmental resources through its use.

4. Ethical Preferences: Criteria for Sustainable Development

Our altruism may not ensure sustainability even in a perfect market economy. However, our descendants will depend on our altruism in any case as the altruism of the present generation actually determines whether natural and environmental resources are managed today in a manner compatible with sustainable development. As a thought experiment it can still be interesting to ask the following question: How *should* we express our concern for the well being of future generations beyond the subjective concern for our own children? In the words of Harsanyi (1955), what *ethical* preferences should we have? What kind of criterion for intergenerational justice would we recommend if we did not know to what generation we belonged and considered

intergenerational distribution from an anonymous perspective? By *ethical* preferences we here mean preferences which are "costly" for the generations to abide by, and which as a consequence will not be accepted unless they are imposed as a moral obligation, distinguishing ethical preferences from the 'selfish' altruism captured by subjective preferences.

In the model of Dasgupta and Heal (1974) and Solow (1974) — technology (2) above, with heterogeneous capital, but without natural renewal — the altruism of the subjective preferences is not sufficient to ensure an ethically acceptable management of the productive resources of the economy. As long as generations discount the welfare of their children with a positive rate (*no matter how small this is*), the quality of life of distant generations will be forced to approach zero. The economy may grow within a short and intermediate time frame, but sustainable development will not be ensured in spite of the explicit assumption that such development is feasible. The reason is that the capital productivity of the economy approaches zero as an increasing stock of reproducible capital substitutes for a dwindling resource extraction. The altruism of the subjective preferences is, hence, not sufficient to ensure a just intergenerational distribution (not even a zero discount rate will help as argued in the next paragraph). Thus, if intergenerational justice is to be imposed, we need to act in compliance with ethical preferences.

What ethical preferences should be used in this specific technology? One possibility is to require that generations do not discount the welfare of their children, so that the present generation 0 is required to choose the path of quality of life which makes $\int_0^s u(x_t)dt$ "as large as possible" when $s \to \infty$. This corresponds to the Ramsey-criterion (Ramsey, 1928). In the resource model above this leads to a path where the quality of life increases above all finite bounds, as shown by Dasgupta and

Heal (1979, pp. 303-308). Instead of having their existence threatened, future generations become incredibly well off. Apart from stretching the technological assumptions of the model, this appears to go too far in favor of future generations: Why should we save for the benefit of descendants infinitely better off than ourselves?

A very different alternative is to maximize the quality of life of the generation with the lowest quality of life, i,e., $max\ inf_{t\geq 0} x_t$. As shown by Solow (1974), such a maximin-criterion leads to a constant level of quality of life, thereby producing a development that is both sustainable and egalitarian. The quality of life corresponding to such an egalitarian path can be viewed as the maximal level that is compatible with the notion of having our quality of life being potentially shared by all future generations; i.e., the maximal level that is compatible with sustainable development. Still counter arguments can be raised: (a) If the economy is poor at the outset (i.e. has a small stock of manmade capital), it becomes locked into poverty. The productive resources of the economy are managed in a sustainable way, but development is not created. (b) If generations actually care about their children, why should they not be allowed to save on their behalf?

A third alternative, which includes the two alternatives mentioned above as special cases, is the following ethical preferences: Respect that the welfare of each generation is given by its subjective preferences and hence, in its discrete-time representation, depends on its own quality of life and the welfare of its children. Then maximize the welfare of the generation that according to its subjective preferences is worst off: $max\ inf_{t\geq 0} v_t$. As I show in Asheim (1988), this leads to a growing quality of life initially when the economy is highly productive. The initial phase is eventually followed by a phase with constant quality of life, thereby ensuring the welfare of distant generations. The possibilities for development are not wasted, while at the

same time the productive resources of the economy are being managed in a sustainable manner. This alternative includes the Ramsey-criterion and the maximin-criterion as special cases since (i) if each generation on the basis of its subjective preferences does not discount the welfare of its children, then the ethical preferences are of no importance and we return to the Ramsey-criterion, while on the other hand (ii) if every generation discounts the welfare of its children heavily, then the ethical criterion forces a completely egalitarian path and no development occurs.

A fourth alternative is based on the normative foundation provided in Section 2, and is the one that I explore in Asheim (1991): Maximize the welfare of the present generation 0 in accordance with its subjective preferences subject to the constraint that the resulting intergenerational development not be unjust. Since the technology considered (technology (2), with heterogeneous capital and without natural renewal) is productive in the sense of Section 2, it follows that these ethical preferences are equivalent to the present generation 0 maximizing its welfare subject to the constraint that the quality of life be non-decreasing. This, in turn, implies that the development is exactly the same as the one obtained in alternative 3 above. Hence, in Asheim (1988, 1991) I present two alternative ethical preferences which in a discrete-time version of the model of Dasgupta and Heal (1974, 1979) and Solow (1974) give rise to the same outcome.

In both the third and the fourth alternatives, welfare is maximized subject to the constraint that the quality of life be non-decreasing. In Asheim (1988, proof of Lemma 4), the properties of such a path are spelled out. The interest rate turns out to be positive, decreasing, and asymptotically approaching zero. The implicit discount rate is equal to the discount rate of the subjective preferences as long as the quality of life is increasing. It jumps *up* just as the constraint that the path be non-decreasing

starts to bind. From then on, the implicit discount rate is equal to the interest rate and follows its decrease towards zero. If the discount rates employed by the generations when maximizing the discounted sum of future utilities were to follow this path, the development path of the third and the fourth alternatives could have been realized as an intertemporal competitive equilibrium.

5. Characterization, Rules and Policies

Can economic theory help to understand and analyze the concept 'sustainable development'? I concentrate on three questions:

1. Characterization of sustainable development. (How to describe the situation if we are heading for the right destination?)
2. Prescriptive rules for sustainable development. (How to detect if we are off course?)
3. Policies for sustainable development. (If necessary, what should and can be done to change the course?)

I will answer these questions in turn.

5.1 *Characterization of sustainable development.* Human economic activity leads to the depletion of natural resources and the degradation of environmental resources. Sustainable development requires that manmade capital (both real and human) be accumulated in order to make up for the decreased availability of natural capital. This leads to the following observations: (a) The present generation must leave behind a bequest of manmade and natural capital that will benefit all later generations. Such a transfer is facilitated if there is a technology available that allows

for accumulation of manmade capital without leading to future depletion and degradation of natural capital. I will refer to such a technology as a 'sustainable' technology. (b) An economy that develops in a sustainable way is in continuous change. In particular, the economy will not follow a stationary path even in the case with constant population and a stationary technology. These observations can be used to characterize the market interest rate along developments that are sustainable.

It may seem reasonable to claim that sustainable development cannot be realized if the market interest rate is positive. I argue the contrary. Sustainable development cannot be characterized by the market interest rate equal to zero for all t. If the interest rate is equal to zero for all t, then the present value of an annuity – a bequest that pays one unit in each period – is infinite. This implies that there are no non-accepted investment projects yielding an annuity of benefits. If *optimistic*, one would claim that such projects exist. That the present value of an annuity is infinite then means that all such projects are accepted along the sustainable development. This in turn is likely to imply that the present generation due to high investment costs, is left with a low quality of life. If *pessimistic*, one would claim that such projects do not exist. This means that the present generation cannot provide future generations with a bequest that pays one unit in each period. Thus, it becomes impossible to compensate – through accumulation of manmade capital – for the harm caused by our depletion of natural resources and our degradation of environmental resources. This undermines the possibilities for achieving sustainability. Therefore, if the economy follows a sustainable development that is reasonably egalitarian, then there exist non-accepted investment projects that produce an annuity of benefits. This in turn implies that the market interest rate is positive and does not decrease too fast. These arguments are supported by formal growth-theoretic models, such as technology (2) of

Section 3 with heterogeneous capital and without natural renewal (analyzed by Solow, 1974, and Dasgupta and Heal, 1974, 1979).

On the other hand, this result does not say anything about the level of the interest rate. It also says little about the development of the interest rate except that the market value of a benefit or a cost of indefinite duration must be finite. Since a sustainable economy is in continuous change, there is no basis for assuming that the market interest rate is constant. On the contrary, it may be reasonable to assume that the interest rate is decreasing over time since the marginal productivity of manmade capital decreases as the stocks of such capital are accumulated and stocks and the extraction of natural capital gradually vanish. This property can also be illustrated by technology (2) of Section 3. Note that a decreasing interest rate increases the profitability of investments based on a 'sustainable technology'.

Hartwick's (1977) rule (see also Dixit, Hammond, and Hoel, 1980) is a well known characterization result for a sustainable development of a certain kind, namely a development where the quality of life is held constant. The rule assumes constant population and a stationary technology and gives the following characterization: If, in a perfect market economy, the quality of life is held constant indefinitely, then the depletion of natural capital at any time corresponds in market value to the accumulation of manmade capital; i.e., the market value of net investments is equal to zero. Note that Hartwick's rule does not imply that the total value of the capital stocks is constant along a path where the quality of life is held constant. This would be the case under the assumption of a constant interest rate. However, a constant quality of life and a constant interest rate may be inconsistent in the sense that they cannot both be realized. If the interest rate is decreasing, the capital gains will be positive. In this case, a constant quality of life corresponds to an increasing total value of the

capital stocks. In Asheim (1993b) I have explored the relation between capital gains and the interest rate along an egalitarian path.

5.2 *Rules for sustainable development.* In order to derive rules for sustainable development, it is necessary to operationalize the notion of income presented by Hicks (1946) in his book *Value and Capital*: What is the maximum that a population of an economy can consume in a given period and still be as well off at the end of the period as it was in the beginning? In an economy with constant population and a stationary technology, this question can easily be answered if there is only one aggregate capital good: The quality of life does not exceed the sustainable level if and only if the stock of the aggregate capital good is not reduced. It is, however, a complicated task to answer this question in an economy with heterogeneous capital. The reason is that, if human economic activity depletes the stocks of natural capital, it is necessary to determine how much accumulation of manmade capital is required to make up for the depletion. How can relative prices be found that 'correctly' value the different kinds of capital? It is a natural point of departure to investigate whether market prices — under the assumption of a perfect market economy with constant population and a stationary technology — can be used to determine the 'correct' relative price between natural and manmade capital: Does it hold — as claimed by e.g. Mäler (1991, p. 11) and Hulten (1992, p. 17) (see also Solow, 1993) — that the quality of life does not exceed the maximum sustainable level if and only if the market value of net investments is non-negative, i.e., if the accumulation of manmade capital at least compensates in market value for the depletion of natural capital? The analyses of Hartwick (1977) and Weitzman (1976) appear to lay two alternative foundations for this view.

Foundation A. Hartwick's (1977) rule states that 'the market value of net investments being equal to zero for all t' is equivalent to '$(x_t)_{t=0}^{\infty}$ being constant'. In the

context of a competitive economy, Hartwick's rule states that an intertemporal competitive equilibrium leads to a completely egalitarian path if and only if, *at all times*, the value of depleted natural capital measured at competitive prices equals the reinvestment in manmade capital. However Hartwick's rule does *not* claim that a competitive economy that *for the moment* measured at competitive prices reinvests depleted natural capital in manmade capital manages its stocks for natural and manmade capital in a sustainable manner. For it is conceivable that such reinvestment is achieved *because* the competitive prices of natural capital are low. This in turn can be caused by the economy not being managed in a sustainable manner: If future generations are poorer than we are, they will be unable to "bid" highly through the intertemporal competitive equilibrium for the depletable natural capital we manage, leading to low prices of such capital today. Although Hartwick's rule implies that the market value of net investments is equal to zero *at any time* t if the economy follows an efficient and egalitarian path, one cannot conclude that if the market value of net investments *at some time* t is equal to zero, then the quality of life at time t is sustainable. The reason why this does not hold is the relative price of manmade capital in terms of natural capital in an intertemporal competitive equilibrium depends on the entire future equilibrium path.

Foundation B. Weitzman (1976) shows that if the development $(x_t)_{t=0}^{\infty}$ is realized as an equilibrium in a perfect market economy with a constant market interest rate r, then it holds – under the assumption that quality of life could be 'moved' along the time axis with a rate of return equal to r – that x_t plus the market value of net investments at time t would have been sustainable. In particular, if the market value of net investments at time t is non-negative, then x_t would have been sustainable under the above assumption. The problem with this line of reasoning is that the

interest cannot be taken to be constant (which the Weitzman analysis requires) and will not remain unchanged when quality of life is moved along the time axis.

In Asheim (1993a) I have shown – within the context of technology (2) of Section 3 – that the market value of net investments can be positive while at the same time x_t exceeds the maximum sustainable level. This proves formally that neither A nor B can be used as a foundation for the view that x_t is sustainable if the market value of net investments *at a given time t* is non-negative. In particular, it means that *Hartwick's (1977) rule is a characterization result, not a prescriptive rule for sustainable development.*

In practical applications, a host of different problems complicates the task of determining whether the quality of life of the present generation is sustainable. (a) If the population is growing, it is correct to require that the per capita capital stock be non-decreasing only if the relative population growth is constant – even under the assumption that an aggregate capital good exists. If e.g. the present generation is half as large as all future generations (i.e. constant population beginning with the next generation), then it is unreasonable to require that the present generation accumulate the stock of the aggregate capital stock to a size twice as large as the one it inherited, when such a requirement is not extended to the later generations. (b) The assumption that the technology is stationary means that technological progress is endogenous: Capital components measuring accumulated knowledge may be included in the production function. Exogenous technological progress – meaning that the production function changes over time – is not allowed. How restrictive this assumption is, relates closely to the next point, namely that (c) not all capital stocks can be valued given the available price information. This applies not only to accumulated knowledge, but also to stocks of natural and environmental capital. A final problem is related to the fact

that (d) our capital and resource management does not have deterministic consequences. All these problems are related to the discussion on how to measure a green national product.

The analysis above holds both for an open (national) and a closed (global) economy. However, particular problems arise when trying to prescribe rules for sustainability in an open economy: The technology must then include the gains from trade (see Svensson, 1986). This means that the assumption of a stationary technology would necessitate that the relative international prices are constant. However, from Hotelling's (1931) rule, it follows that from a resource-rich country's point of view, the terms-of-trade facing future generations will be more favorable than the one facing the present generation. This implies that a part of the capital gains on the unexploited stocks of natural resources can be considered as income in the sense of Hicks (1946), thus lowering the required compensating investments (see Asheim, 1986, 1993b).

5.3 *Policies for sustainable development.* If a perfect market economy does not give rise to sustainable development, should one then recommend that the government reduce the rate of discount used when evaluating public investment projects and intervening in the management of natural and environmental resources? In principle, economists claim that distributional policies should not be executed through administrative price manipulation by the government. In this case, this corresponds to: Do not let the discount rate of the public sector be an instrument in the transfer of wealth to future generations, since this leads to lower rates of return on public investment projects and inefficiencies (since different types of capital investments are being evaluated in different ways). The discount rate of the public sector (which in a perfect market economy equals the market interest rate) reflects, but is not an instrument for, the policies aimed at a redistribution between generations.

Even if it were possible for the public sector to contribute to a lower market interest rate in general – such that the profitability of investments were calculated on the basis of this lower market interest rate (and we abstract from the disequilibrium that would arise if voluntary savings would not be sufficient to finance investments) – this lower market interest rate would not necessarily be a good instrument for the attainment of sustainable development. It would remove the inefficiency that arises when different types of capital are evaluated in different ways. The problem is that a lower market interest rate may encourage investments in manmade capital with long-run negative natural and environmental effects. This point, illustrated in technology (3) of Section 3 – the model with heterogeneous capital, positive natural renewal, and an extreme complementarity between the stock of manmade capital and extraction of natural capital, is related to the argument made in the 1960's, namely that the interest rate ought to be "high" for natural resource protection.

If the distributional goals of a society are not reached in a perfect market economy, one should seek directly to redistribute wealth in favor of future generations, e.g. through conservation of renewable resources in a productive state and increased investment in manmade capital based on a 'sustainable technology'. Following such a redistribution, the resulting development may be characterized by a lower and decreasing market interest rate. If this lower and decreasing market interest rate is being used as discount rate, then renewable resources will to a greater extent be conserved in a productive state, investment projects leading to long-run negative natural and environmental effects will become less profitable, and investment projects based on a 'sustainable technology' will become more profitable.

If manipulation of discount or interest rates is not a good public instrument, we are faced with the following problem: What instruments are available for

distributional policies between generations? (1) It will of course contribute to sustainable development to reduce through internalization the over-use of natural and environmental resources that is the result of negative external effects. This also entails including negative environmental effects in benefit/cost analyses. However, as I have emphasized above, such internalization is not sufficient to ensure sustainable development. (2) Information regarding the long-term consequences of the present development can also contribute to sustainability: Perhaps the future will not be better off; on the contrary, their quality of life may be lower than ours if the depletion of natural resources and degradation of environmental resources are taken into account. Such information may reduce complacency. (3) Since altruism for future generations is a major force in order to implement sustainability, it is important to reinforce the bequest motive. To strengthen the degree to which nature's intrinsic value is captured by preferences of humans, may also be helpful. It is, however, unclear how public policy can contribute to this. (4) The public sector can contribute to increased public saving. Such a policy may, however, be fully or partially neutralized through a corresponding decreased private saving (see Barro, 1974). (5) The public sector can, possibly through international cooperation, contribute to the conservation of renewable resources in a productive state. An international agreement seeking to reduce emissions of greenhouse gases is an example of this. Encouraging development of 'sustainable technology' may also potentially be of great importance.

6. CONCLUSIONS

Sustainable development is concerned with distributional issues. The question of intergenerational distribution is not necessarily solved through the attainment of economic efficiency. Internalization of external effects is therefore not sufficient to ensure sustainability.

A positive market interest rate is not inconsistent with sustainable development. On the contrary, it can be argued that if the economy follows a development that is reasonably egalitarian, then the market interest rate will be positive. For some types of economies, there are reasons to assume that the interest rate is decreasing over time.

Present prices may not convey the information necessary to determine whether development is sustainable. Development need not be sustainable even if market prices for all kinds of capital are available and the accumulation of manmade capital in market prices more than compensates for the depletion of natural capital.

Finally, public policy aimed at sustainable development should seek to strengthen the mechanisms that can be used for redistribution from the present to the future. If development is not sustainable, this is a question of faulty distribution, not faulty prices.

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