Are We Consuming Too Much?

by

Kenneth Arrow[a], Partha Dasgupta[b], Lawrence Goulder[a], Gretchen Daily[a], Paul Ehrlich[a], Geoffrey Heal[c], Simon Levin[d], Karl-Göran Mäler[e], Stephen Schneider[a], David Starrett[a], and Brian Walker[f]

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[a]Stanford University; [b]University of Cambridge; [c]Columbia University; [d]Princeton University; [e]Beijer International Institute of Ecological Economics; [f]CSIRO Sustainable Ecosystems Division.

Please address all communications to Kenneth J. Arrow, Department of Economics, Stanford, CA 94305-6072, arrow@stanford.edu. We are grateful to Geir Asheim and the editors of this journal for very helpful suggestions, and to Oren Ahoobim and Justin Diener for excellent research assistance. We also thank the William and Flora Hewlett Foundation for financial support, and the Beijer Institute for Ecological Economics, Stockholm, for sponsoring the workshops from which this paper emerged.

1. Introduction

Is our use of Earth's resources endangering the economic possibilities open to our descendants? There is wide disagreement on the question. Many people worry about the growth in our use of natural resources over the past century. Some of this increase reflects the higher resource demands from a growing world population. But it also reflects the growth of per-capita output and consumption. During the twentieth century, world population grew by a factor of four to more than 6 billion, and industrial output increased by a factor of 40. Per-capita consumption in industrialized nations today is far higher than it was 100 years ago, and some would argue that this is irresponsible in light of its implications for resource demands. In the last 100 years, energy use has increased by a factor of 16, annual fish harvesting by a multiple of 35, and carbon and sulfur dioxide emissions by a factor of 10. The application of nitrogen to the terrestrial environment from human use of fertilizers, fossil fuels, and leguminous crops is now at least as great as that from all natural resources combined (McNeill, 2000). If we look at specific resources and services, such as fresh water, the atmosphere as a carbon sink, and a wide variety of ecosystem services, evidence suggests that continuing growth in their utilization rates is unsustainable (Vitousek et al., 1986, 1997; Postel, Daily and Ehrlich, 1996).

On the other hand, it may be claimed that, just as earlier generations invested in capital goods, research, and education to bequeath to current generations the ability to achieve high levels of consumption, current generations are making the investments that are necessary to assure higher real living standards in the future, despite stresses on the natural resource base. Indeed, historical trends in the prices of marketed natural resources and the recorded growth in conventional indices of economic progress in currently rich countries suggest resource scarcities have not bitten as yet (Barnett and Morse, 1963; Johnson, 2000). This optimistic viewpoint emphasizes the potential of capital accumulation (increases in manufactured capital, human capital, and knowledge) to compensate for the diminishment of natural resources.

This paper, the outgrowth of discussions among a group of ecologists and economists, offers an analysis that we hope will go some way toward reconciling the conflicting intuitions. The binocular vision that can be obtained from using both ecological and economic insights raises questions that might not occur in either viewpoint alone. We discuss criteria for deciding whether consumption is excessive, and identify factors in the economic and ecological domains that determine whether or not it is in fact so.

By what criterion should we judge whether consumption is or is not excessive? Economic analysis has tended to emphasize the criterion of maximizing the integral of the discounted values of current and future utility from consumption – what we will call *intertemporal social welfare*. Current consumption is deemed excessive or deficient depending on its level relative to that called for by this optimization problem. However, analysts with a different perspective have applied a criterion of "sustainability," which emphasizes the ability of the economy to maintain living standards. In this paper we will elaborate on the two criteria and consider what empirical evidence might exist on whether consumption is excessive.

2. Alternative Criteria for the Evaluation of Consumption

In the framework presented here, the underlying elements of intertemporal social welfare are consumption (broadly defined) and utility. Let s and t variously denote time (where $s \geq t$). Assume for now that population is constant. Let $C(s)$ denote a society's aggregate consumption and $U(C(s))$ the flow of utility, at time s. Marginal utility is assumed to be positive. We let V_t denote intertemporal social welfare at time t, defined as the present discounted value of the flow of $U(C(s))$ from t to infinity, discounted using the constant rate δ (>0).[1] In focusing at each moment on aggregate consumption, rather than its distribution, our framework abstracts from intratemporal equity issues. The equity issues that preoccupy us are intertemporal.

One of the determinants of V_t is the "productive base" at t, which consists of society's institutions and capital assets at t. The capital assets include manufactured capital, human capital, the knowledge base, and natural capital. Although institutions are frequently regarded to be capital assets themselves (as in the term "institutional capital"), it is useful to distinguish them

[1] Assuming continuous time, we have:

$$V(t) = \int_{s=t}^{\infty} U[C(s)]e^{-\delta(s-t)}ds$$

In calling U "utility", we are not necessarily subscribing to Classical Utilitarianism. We are assuming, more generally, that consumption has a social worth, which we call utility $(U(C))$, and that V_t is a numerical representation of an ethical ordering over infinite utility streams beginning at t. Koopmans (1972) has identified conditions on orderings that permit one to express V_t in the form we are using here.

from capital assets. We view institutions as guiding the allocation of resources – including capital assets. Institutions include the legal structure, formal and informal markets, various agencies of government, interpersonal networks, and the rules and norms that guide their behavior. (However, we will see in Section 4, where we study data on movements in total factor productivity, that it can be difficult to disentangle technological change from changes in the character of an economy's institutions.)

We now discuss the two criteria we have referred to for judging whether or not current consumption is excessive. For simplicity of exposition, we adopt a deterministic framework until Section 5.

2.1 The Max-PV Criterion

One can think of V_t as a function of initial conditions – the productive base and level of technology at time t – and the choices from time t forward as to how to allocate output between investment and consumption. Consider the time-profiles of investment and consumption that maximize V_t . According to the *max-PV criterion,* actual consumption today is regarded as excessive if it is greater than the level of current consumption prescribed by this optimal consumption path. To put it in the language of social cost-benefit analysis, current consumption is excessive if lowering it and increasing investment (or decreasing disinvestments) in selected capital assets could increase future utility that, even though discounted, more than compensates for the loss in current utility.

The optimal path depends, among other things, on the discount rate, δ. A higher value for δ, other things being equal, means that less weight is placed on future utility. The "right" value of δ has long been a matter of debate. Ramsey (1928) argued that in a deterministic world the appropriate value of δ is zero, implying that the utility of future people ought to receive the same weight as that of people today. Koopmans (1960), however, showed that applying a zero social rate of pure time preference can lead to paradoxes. Lind (1982) and Portney and Weyant (1999) contain diverse arguments concerning the appropriate choice of δ.

One of the interesting aspects of the optimal consumption path according to the max-PV criterion is that it can be linked, theoretically, to the outcome of a decentralized market economy. In a fully competitive economy with a complete set of futures markets and no externalities, and in which individuals discount their future utility at the social rate δ, the time-path of consumption will correspond to the optimal consumption path. However, in a world where markets for many future goods and many types of risk-bearing do not exist and where environmental externalities prevail, consumption would not be optimal. Nevertheless, it is possible to conduct social cost-benefit analysis in order to judge whether a policy reform at t increases inter-temporal social welfare (Dasgupta, 2001a; Arrow, Dasgupta, and Maler, 2003b). This enables one to identify public policies that would alter current consumption in the appropriate direction.

2.2 The Sustainability Criterion

An alternative yardstick for evaluating time profiles of consumption is the *sustainability criterion.* The terms "sustainability" and "sustainable development" became commonplace after the publication of a report by the World Commission on Environment and Development (1987), widely known as the Brundtland Commission (after its chairperson). Sustainable development was defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Several interpretations of sustainability are compatible with this phrase (see Pezzey, 1992; Solow, 1992; Heal, 1998; and Asheim, 2003). Here we opt for an approach consistent with the view that what is to be sustained is intertemporal social welfare, as defined above. We therefore take sustainability to mean that V_t must not decrease over time.

Several features of this criterion for sustainability deserve emphasis. First, the criterion concentrates on the change in V, not on V's level. Second, even if a consumption path were to satisfy the criterion today and at all future dates, it would not imply that utility (U) in each future moment will be as high as it is today (Asheim, 1994). Third, the criterion does not identify a unique consumption path: the criterion could in principle be met by many consumption paths. Fourth, if exhaustible resources are sufficiently important in production and consumption, then it is conceivable that no sustainable development program exists (Dasgupta and Heal, 1979: Ch. 7).

Fifth, it can be that even if a consumption path satisfies the sustainability criterion today, V will fall below its present level at some future date. Sixth, and most importantly, in defining sustainable development there is no presumption that the consumption path being followed is optimal in the sense of maximizing V.

The notion of productive base is closely connected to the issue of whether the sustainability criterion is satisfied. Let $\boldsymbol{K_t}$ denote the vector of stocks of all capital assets at t. Plainly, V is a function of $\boldsymbol{K_t}$. In the particular case where V is stationary (that is, where t itself does not directly influence V), we can write $V_t = V(\boldsymbol{K_t})$. Let K_{it} denote the stock of the ith capital good at date t. By the chain rule of differentiation,

$$dV/dt = \sum_i (\partial V/\partial K_{it})(dK_{it}/dt) = \sum_i p_{it} I_{it} \tag{1}$$

where $p_{it} \equiv \partial V/\partial K_{it}$, and I_{it} ($\equiv dK_{it}/dt$) denotes the rate of change in K_{it}. We refer to p_{it} as the accounting price of K_{it}.

The right-hand side of (1) may be called *genuine investment*. It is the accounting value of the changes in the stocks of all society's capital assets at t, inclusive of manufactured capital assets, human capital, natural capital, and the knowledge base. Expression (1) indicates that $V(t)$ is non-decreasing at t if and only if genuine investment is non-negative at t. Since genuine investment can be interpreted to be the change in *genuine wealth* at constant accounting prices, we may restate the finding to say that development is sustainable at t if genuine wealth at constant accounting prices does not decline at t.[2]

Note that in an economy with imperfections, p_{it} is typically not equal to the i^{th} capital asset's market price at t. Indeed, if the external diseconomies created by the use of a capital asset exceed the private benefit from it use, its accounting price would be negative.

It is as well to note that non-negative genuine investment – or a non-declining V – does not necessarily require maintaining any particular set of resources at any given time. Even if some resources such as stocks of minerals are drawn down along a consumption path, the sustainability criterion could nevertheless be satisfied, if other capital assets were to be accumulated sufficiently to offset the resource decline. In evaluating the social losses from

[2] This result was proved for optimally managed economies by Pearce and Atkinson (1993) and for arbitrary economies by Dasgupta and Maler (2000).

reductions in natural resources – and thus the alternative investments necessary to offset such losses – in principle one needs to consider all of the contributions of natural resources to present and future utility. Such contributions may be direct, as, say, objects of natural beauty; or they may be indirect, as in the vital contributions of numerous ecosystem services, such as water purification, flood control, climate stabilization, pollination of crops, control of agricultural pests, and the generation and maintenance of soil fertility (Daily, 1997); or they may be both (a wetland).

While the criterion for sustainable development is simple to express, implementing it poses severe empirical challenges. Measuring changes in capital stocks – especially stocks of natural resources such as minerals, fossil fuels, fish or insects – is difficult. Anticipating future increases in knowledge and their potential to augment the productive base is another great challenge. And at least as difficult is the task of determining the accounting prices p_{it} . These prices are meant to indicate how much more of one type of capital asset would be needed to compensate for the loss of one unit of another type of capital asset. Such rates of substitution are extremely difficult to assess. Ecologists express concerns that the fact that certain natural resources have only a limited set of substitutes is not sufficiently appreciated by economists. To the extent that economists are overly optimistic about opportunities to substitute other capital assets for certain natural resources, the accounting prices associated with those resources will be too low. Reductions in their stocks would then receive too little weight in estimates of genuine investment, with the result that the estimates would be biased upward. A major goal of ecological economics is to increase our understanding of the various ways in which different kinds of natural capital contribute to human well-being and the extent to which they are substitutable for one another and for other kinds of capital assets.[3]

[3] On substitutability see, for example, Dasgupta and Heal (1979, Chapter 7), Ehrlich and Ehrlich (1990), Daily (1997), Daily *et. al.* (2001), Levin (2001), Heal *et. al.* (2001), and Heal (2002). An important complication related to assessing substitution possibilities is that the potential for substitution – and thus the appropriate accounting price – can vary by location. A natural resource in one place (e.g., local woodland) is not the same economic commodity as the same natural resource in another place. Since migration can be very costly, the rural poor in the poorest countries often have no substitutes available to them when their local resource base is degraded. The accounting price of a local natural resource could well be much higher than its market price. The implications of local non-substitutability for the world's poorest people are discussed in Dasgupta (1993). For an interchange on the relative importance of substitution possibilities at aggregate and local levels, see Johnson (2001) and Dasgupta (2001b).

2.3 Extending the Sustainability Criterion to Account for Changing Population

Our initial discussion of intertemporal social welfare, V, assumed population size was constant. Beyond the empirical difficulties in forecasting the time-profile of population, dealing with a changing population poses very challenging (and unresolved) theoretical issues.[4] Is the arrival on earth of additional people enjoying positive utility invariably a good thing (even if it implies lower average utility), or should intertemporal social welfare be some form of average welfare over all people – now and in the future? How should our notion of intertemporal social welfare be revised by the fact that people devote resources to raising children and reducing mortality rates?

One way to proceed is to regard population as another asset, in addition to the forms of capital we have already considered. This implies that for any given conception of intertemporal social welfare, there is an accounting price of population (which may or may not be positive). Under this approach, genuine wealth is the accounting value of all capital assets, including population. The sustainability criterion continues to require that genuine wealth at constant accounting prices must not decline, but now invokes a broader notion of genuine wealth.

Of particular interest is the case where intertemporal social welfare function is taken to be the discounted present value of the flow of total utility divided by the discounted present value of population size over time, where the discount rate used in both the numerator and denominator is the social rate of pure time preference, δ. This is a form of "dynamic average utilitarianism."[5] Dasgupta (2001a) has shown that if dynamic average utilitarianism represents inter-temporal

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[4] One empirical challenge is to discern the connection between a current change in population and future population sizes. Would an increase in current population lead to an increase in all future population levels proportionately (as with exponential growth), or would it have a diminishing effect over time (as with population growing in accordance with a logistic equation)?

[5] The formula for V in this case is:

$$V(t) = \int_t^\infty N(s)U(c(s))e^{-\delta(s-t)}ds \Big/ \int_t^\infty N(s)e^{-\delta(s-t)}ds$$

where *c(s)* and *N(s)* represent per capita consumption and population size, respectively, at time s. Notice that, to the extent that the denominator of the above form of V_t is not affected by policy, the max-PV criterion implies the same optimum no matter whether "total" or "dynamic average" utilitarianism is adopted as the conception of intertemporal social welfare. In assessing sustainability, however, it matters hugely whether "total" or "dynamic average" utilitarianism is adopted. Thus, there is an important difference in this instance between optimality and sustainability. For further analysis of sustainability under changing population size, see Arrow, Dasgupta, and Maler (2003a).

social welfare, then, under certain conditions a non-declining V_t is equivalent to the intuitively appealing requirement that *genuine wealth* per capita at constant accounting prices must not decline. The conditions in question are that (i) population changes at a constant rate, (ii) per capita consumption is independent of population size (but presumably dependent on per capita capital assets), and (iii) all transformation possibilities among goods and services exhibit constant returns to scale. We shall make use of this finding when deriving the empirical results we report in Section 4.

2.4 Extending the Sustainability Criterion to Account for Technological Change.

In the presence of technological change (changes in knowledge), output and consumption could rise, and thus V could increase, even if aggregate investment in terms of manufactured, human, and natural capital were negative. Our initial expression for the change in V (equation (1)) did not account for changes in knowledge. Here we wish to take such changes into account in assessing changes intertemporal social welfare, V.

Here we must enter uncharted territory, since there appears to be no prior literature that makes such a connection. We explore this relationship by examining how total factor productivity alters the assessment of V.[6] In a very special model – one that makes strong simplifying assumptions – we derive a formula for incorporating total factor productivity in V. Let γ represent the percentage change in total factor productivity per unit of time. γ is often called the "residual," since it is what remains after subtracting the influence of other factors on output growth. Let η refer to the elasticity of marginal utility of consumption. Assuming that η is greater than one, we show in Appendix A that γ raises the growth rate of intertemporal social welfare (dV/dt) by the amount $\gamma(\eta/(\eta-1))$.

A further issue is that there are serious problems with published estimates of the "residual." Because national accounts do not include the economy's use of non-marketed natural

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[6] We note that movements in total factor productivity include not only technological change, but "exogenous" institutional changes too. When estimating whether or not development has been sustainable in recent decades, we will not be able to separate institutional changes from the technological changes that may have taken place simultaneously.

and environmental resources, growth in total factor productivity could be overestimated. Suppose that over a period of time, an economy at a certain stage of development extracts from its natural resource base at an increasing rate. Suppose, however, that the depletion is not recorded. Then it is clear that the residual would incorrectly include the positive contribution to measured output growth that derives from increased depletion. This additional recorded growth in total factor productivity would not be due to an improved knowledge base, but to increased resource use.

This problem seems real, since all published estimates of the residual that we are aware of are based on aggregate production functions that exclude non-marketed natural resource inputs. At the same time, it is very hard to know how much bias this neglect introduces into our interpretation of improvements in knowledge. In Section 4, when we offer our own estimates of movements in genuine wealth at constant prices in a selected number of countries and regions, we shall try to correct for this bias by incorporating information about the use of depletable resources in production.[7]

2.5 Does Satisfying One Criterion Imply That the Other Is Satisfied?

The two criteria we have offered for assessing whether consumption is too high reflect different ethical considerations. An economic program that satisfies the sustainability criterion may not be optimal in terms of the max-PV criterion. Conversely, an economic program that is optimal under the max-PV criterion might not satisfy the sustainability criterion.

To see this, suppose that aggregate output is a Cobb-Douglas function of manufactured capital and the flow of an exhaustible natural resource. (Returns to scale may be either constant or decreasing.) Solow (1974) showed that sustainable development is technically feasible if the output elasticity with respect to manufactured capital exceeds the output elasticity with respect to the flow of the natural resource in production. Dasgupta and Heal (1979) showed, however, that

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[7] A further issue might be noted. Since environmental resources are often under-priced, new technology can be rapacious in its reliance on the environment. This means that technological change could increase the profitability of using environmental resources. But this in turn means that the prospect of future technological change could increase the scarcity value of natural resources. This implies that the correct accounting prices will be higher than the prices one might calculate if this phenomenon is ignored.

so long as $\delta > 0$, optimal consumptions paths (i.e., those that maximize V) involve consumption approaching zero in the long run; and thus do not reflect sustainable development.

The differences between the two criteria have potential implications for public policy. An investment project that passes the social cost-benefit test (namely, that its acceptance would increase today's V), could result in a decrease in V at some future date. Therefore, the standard policy remedies for improving economic efficiency (establishing property rights, addressing externalities, and so forth) do not guarantee sustainability.

3. Empirical Evidence Relevant to the Max-PV Criterion

According to the max-PV criterion, today's consumption is excessive if it is higher than the level of current consumption along the consumption path that maximizes the current V. However, no one can seriously claim to be able to determine with precision the optimal level of current consumption for an actual economy. Thus, a direct test, involving a comparison of actual current consumption with the optimal level is not possible. However, theoretical considerations can be used to identify factors that would cause current consumption to be different in a predictable direction from the optimal level.

Economic theory offers clues about the links between market prices and social costs. To study those links, we first consider the relationship between market rates of return on investment and optimal social interest rates on consumption. We then consider market prices of contemporaneous goods (including those of current capital goods), and relate them to the social costs of those commodities.

3.1 *The Market Rate of Return on Investment and the Social Rate of Interest on Consumption*

For a consumption path in a market economy to be socially optimal, the market rate of return on investment, i, must be equal to the social rate of interest on *consumption.* Let r denote the latter. We may conclude that if i exceeds r, markets are biased toward insufficient saving and excessive current consumption.

It can be shown that, if intertemporal social welfare is given by the form of *V* we have postulated here, *r* is given by the relation, $r = \delta + \eta g$, where δ is the social rate of pure time preference, η is the elasticity of marginal (social) utility, and *g* is the rate of growth in aggregate consumption. (For a derivation, see for example, Arrow and Kurz (1970). For additional discussion, see Arrow *et al.* (1996).) The parameter δ reflects impatience, as is well known. The second term in the equation (η times *g*), requires explanation, however. One can view η as accounting for the fact that, to the extent that future generations have higher (lower) incomes, their consumption will be higher (lower) and the marginal utility of their consumption will be lower (higher). However, η need not simply reflect diminishing marginal utility of consumption to an individual: it can be interpreted as a *social* preference for equality of consumption among generations. Thus its function can be similar to the social rate of pure time preference, δ.

Does *i* exceed *r*? One might argue that this cannot be answered from empirical observation alone. One could claim, in particular, that the choice of δ is a value judgment, and that since people differ in these judgments, the matter cannot be resolved except arbitrarily. One could make similar claims about the choice of η.

Fortunately, one can adopt a different approach, and assume that a "typical" individual's preferences should guide our choices of δ and η. This assumption is clearly open to debate, but nevertheless we will adopt it here, since it seems worthwhile to consider what it implies for the relationship between *i* and *r* and thus for the level of consumption.

Several considerations suggest that the market will not act in such a way as to enable typical individuals' preferences regarding δ to be realized.[8] One reason why this may be so is that, because of externalities, the utility discount rate that most people would endorse as socially conscious beings differs from the rate of time-preference emanating from market transactions. The externalities in this case are the positive utility that individuals derive (outside of the

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[8] Hence the justification for a "lower" δ may remain, despite the fact that equilibrium outcomes from individuals' market behavior at first blush suggests a higher δ. On this, see Marglin (1963), Lind (1964), and Sen (1967). In discussing this issue, we have just referred to an externality related to individuals' concerns for future generations' well-being. Elsewhere in this paper we refer to externalities associated with the use of natural resources. One could interpret individuals' inefficient (excessively rapid) exploitation of natural resources as evidence that they care little about future welfare. However, a better interpretation is that such externalities make it impossible for individuals to express their concerns about the future in their individual production or consumption decisions.

marketplace) from the welfare of future generations. Many years ago, Ramsey, Pigou, and Harrod had insisted that the only ethically justifiable value for δ is zero. Solow (1974, p. 9) put the matter thus: "In solemn conclave assembled, so to speak, we ought to act as if the social rate of (pure) time preference were zero." This argument implies that δ is less than the rate of pure time preference that is expressed in the market. This in turn implies that the optimal social rate of interest on consumption is less than the market rate of return on investment, which implies that the market encourages too much current consumption. This "externality" argument above might call for "low" values of δ, in the range, say, of 0-0.5 percent per annum.

What about the other term -- ηg -- in the expression for r? If we again base our choices on a typical individual's preferences, then η should reflect an average person's elasticity of marginal utility of consumption. The value of η is linked to σ, the intertemporal elasticity of substitution in consumption: $\eta = -(\sigma-1)/\sigma$. Hall's (1988) time-series estimates of σ suggest that plausible values for η might lie in the range of 2-4. If we assume per capita growth rates in consumption (g) to have been of the order of 1.5 percent *per annum*, we arrive at 3 to 6 percent per annum for the term ηg. Together, these considerations would tentatively suggest a value for r in the range 3.0-6.5 percent per annum.

How does this value compare with i? To answer this, we need to arrive at an appropriate market interest rate with which to make the comparison. Securities are alternatives to physical capital formation, so that high interest rates discourage investment. Rates of return on different securities vary so much that the comparison becomes difficult. The real rate of return on private capital in the United States (as directed for use in government project analysis, United States Office of Management and Budget, 1992) is 7.0%, on equities (1970-2000) 7.4%, but on Treasury bills (1970-2000) 1.6%. (The last two figures are derived by computation from the Wharton-Data Resources website.) We want to compare r with a *risk-free* rate. If these different returns simply reflected differences in risk characteristics, one could aim to translate these varying rates into a common (or nearly common) risk-free rate. If one interprets Treasury bills as the risk-free asset, then the market rate seems as low or lower than the value for r we calculated above. Thus, this rough comparison provides little support for the argument that consumption is excessive. If aspects of asset markets support the idea of excessive consumption, the evidence must lie elsewhere.

Two other aspects that seem to supply evidence that market rates of return on investment exceed the social rate of interest on consumption are the incompleteness of markets and the existence of capital taxes. Turning to the former, the absence of a complete set of risk-bearing markets, for example, implies that risks cannot be pooled perfectly. Returns from investment are therefore more uncertain, and so recipients (savers) would be expected to attach a lower value to investments than they would have if risks had been pooled more effectively. Consequently the rate of saving is lower. The absence of complete pooling tends to promote excessive consumption.

Similarly, the taxation of capital income lowers the private return on capital below the social return and thus discourage saving and promote excessive consumption. However, capital income taxation should only be evaluated in the context of commodity prices and other forms of taxation. For example, the taxation of labor income can discourage labor supply so much that consumption is below the optimal level both in the present and in the future. Moreover, if such factors of production as natural resources are priced below their social costs, labor taxes could conceivably encourage greater efficiency by discouraging the use of natural resources. So we turn next to the pricing of natural resources.

3.2 Under-pricing of Natural Resources Relative to Social Cost

The level of consumption depends not only on market interest rates but also on the price of current consumption relative to its social cost or, more specifically, its price relative to other contemporaneous goods. To the extent that consumption goods are priced below their social cost, consumption will tend to be excessive.

Some natural resources are consumption goods, others are direct or indirect inputs in the production of consumption goods, and many are both. The underpricing of natural resources may contribute to the pricing of consumption goods below their social cost. Such underpricing also alters the relative prices of different consumption goods, thereby leading to inefficiencies in the *composition* (as well as overall level) of consumption: too much consumption of resource-intensive goods and services relative to consumption of other goods. Thus, when natural resource inputs are priced below social cost, both the overall level and the composition of consumption can be affected in ways that lead to excessive natural resource use.

The underpricing of natural resources can stem from at least three sources. One is insecure or poorly defined property-rights. This can lead to excessively rapid resource exploitation if the exploitation does not require much prior investment (Bohn and Deacon, 1993). A second source of natural resource underpricing is the failure of the market to incorporate the (negative) externalities associated with the use of natural resources. Examples of such externalities include the various damages stemming from the use of fossil fuels (such as acid precipitation, climate-change), and the loss of such ecosystem services as flood control, water-filtration, and habitat-provision when wetlands are drained for conversion to farms.

A third source is represented by subsidies to the use of natural resources. The World Bank's 1992 *World Development Report (Figure 3.2)* examined fossil fuel, electricity, and water prices in 32 developing countries. In all but three of those countries, subsidies caused prices to fall below cost, even before accounting for potential externalities. Similarly, the International Energy Agency (1999) has estimated that in India, China, and the Russian Federation, full-cost pricing would reduce energy consumption by 7, 9, and 16 percent, respectively. In these countries, most of the departure from social cost pricing is attributed to energy subsidies. (For estimates of aggregate global subsidies on the use of environmental and natural resources, see Myers and Kent, 2000.)

The influence of OPEC on the international market for oil could function as a counterbalance to the above arguments, potentially raising world oil prices up to or beyond social cost. However, there is as yet no clear consensus as to whether current world prices are above or below social cost. In addition, it should be noted that social cost pricing of oil might well be the exception to the general pattern of underpriced natural resources.

Note that the under-pricing of natural resource inputs can also reduce the prices of *investment* goods. If such under-pricing is especially pronounced for investment goods, it could promote a higher ratio of investment to consumption. This does not undo the problem of excessive use of natural resources, which is a more fundamental concern. If the natural resource inputs in the production of investment goods are under-priced, the rates of depletion of natural resources will be too rapid. The rate of accumulation of manufactured capital may or may not exceed the optimal rate, but *genuine* investment – that is, overall investment, inclusive of changes in stocks of natural capital – is likely to be insufficient because of the under-pricing of natural resources and the associated excessively rapid depletion of these resources.

3.3 Interdependence in Consumption

Interdependence in consumption can also lead to prices of consumption below social cost. Building on Veblen (1899) and Duesenberry (1949), a small but growing body of empirical work (for example, Frank, 1985a,b; Ng, 1987; Howarth, 1996; Schor, 1998) suggests that a person's sense of well-being is based not only on her own level (and composition) of consumption, but also on the level (and composition) of her consumption relative to the level (and composition) of her "reference group." When others' consumption rises in comparison, an individual could suffer from a loss of well-being because her relative consumption now falls. This interdependence in consumption can be viewed as an externality, which can compel individuals to work harder and consume more in order to keep up with neighbors. It is individually rational behavior, but collectively sub-optimal. Public policies to discourage consumption (including a general consumption tax) could raise individual well-being. A formal "growth model" incorporating these ideas has been developed by Cooper, Garcia-Peñalosa, and Funk (2001).

However, interdependence in consumption does not necessarily imply that people consume excessively. Suppose, that the "relative consumption effect" applies not only to current consumption, but also to future consumption (and to leisure, including sleep). Working harder and consuming more today would then improve one's relative current consumption, but worsen one's relative current leisure and one's relative future consumption! Thus, the bias from interdependence depends on the strength of the effects along various margins. If the effect on individual well-being of relative consumption is symmetric, operating equally on relative consumption and relative leisure now and in the future, it may have no impact on current behavior relative to what would occur if this effect were absent. In this case, the relative consumption effect operates like a lump-sum tax, reducing a person's sense of well-being without changing her allocation of labor resources or income.

3.4 General Findings

We have identified several factors influencing consumption and have shown how they enable us to judge whether consumption is excessive according to the max-PV criterion. Several factors – the inability to pool risks perfectly, the taxation of capital income, and the under-pricing of natural resources – seem to contribute toward excessive consumption. (Below we will observe that these same factors also work toward excessive consumption according to the sustainability criterion.) Among these imperfections, the under-pricing of natural resources strikes us as the most transparent.

4. Empirical Evidence Relevant to the Sustainability Criterion

4.1 A First Step: Measuring Genuine Investment

As mentioned, genuine investment at date *t* is the sum of the values of changes in capital stocks at *t,* evaluated at their accounting prices. It is the change in genuine wealth at constant accounting prices. Recall that the assets to be included are manufactured capital, human capital, natural capital, and the knowledge base (see Dasgupta and Maler, 2000; Arrow, Dasgupta, and Maler, 2003b).

In this subsection we begin evaluating whether various nations are meeting the sustainability requirement, by estimating genuine investment. This is only a first step because genuine investment by itself does not incorporate information on changes in population or technological change. In subsection 4.2 below we extend the analysis to account for these important elements.

Despite all the difficulties in measuring changes in capital assets and discerning their accounting prices, a growing body of research now aims to measure genuine investment in various countries. A lead has been taken by Kirk Hamilton and his collaborators at the World Bank (for example, Pearce, Hamilton, and Atkinson, 1996; Hamilton and Clemens, 1999; Hamilton, 2000; and Hamilton, 2002). Hamilton and Clemens (1999), in particular, offered estimates of genuine investment for nearly every nation for the year 1998. They estimated genuine investment by first adding net investment in human capital to existing country-level estimates of investment in manufactured capital. They then made a further adjustment to account for disinvestment in natural resources and environmental capital.[9]

To estimate the accumulation of manufactured capital, Hamilton and Clemens (1999) used figures for gross national saving. To estimate the accumulation of human capital, they used expenditure on education. To account for disinvestments in natural resources and environmental capital, they considered the net changes in the stocks of commercial forests, oil and minerals, and in the quality of the atmosphere in terms of its carbon dioxide content. Interestingly, the authors found that in 1998 genuine investment was positive in all the rich nations of the world and in many of the poorer nations as well. However, for 33 of the world's poor countries, including many of the nations of North Africa and sub-Saharan Africa, they estimated that genuine investment was negative.

Here we adopt the Hamilton-Clemens approach as a starting point for evaluating whether selected nations and regions meet the sustainability criterion. Rather than calculate (as in Hamilton-Clemens) the figures for a single year, we have calculated annual averages over the past three decades, using annual data from the World Development Indicators published in the World Bank's website (http://devdata.worldbank.org/dataonline). We present our estimates in Table 1. The table covers sub-Saharan Africa, the Indian sub-continent, and China, from among the poor world; the Middle East-North Africa among oil exporting nations; and the USA and the UK from among the industrialized countries.

The differences between genuine investment and the standard measure, net domestic investment, are particularly striking for the Middle East-North Africa and sub-Saharan Africa regions. In these regions, the loss of natural resources more than offset the accumulation of manufactured capital (as reflected in domestic net investment) and human capital (as reflected in expenditure on education). For the U.S. and U.K., estimated genuine investment exceeded domestic net investment, since the increase in human capital (education expenditure) exceeded value of natural resource depletion.

These figures give an initial glimpse of the change in V. We will shortly consider how the picture changes if technology and in population are taken into account. Before doing so, however, it is useful to consider potential biases in the estimation of genuine investment itself,

[9] Hamilton and Clemens (1999) employ the term "genuine domestic saving", which we treat as synonymous with genuine investment. The two cannot be distinguished from the data employed in their study, because the data do not include international capital flows.

which is one component of the calculation of V.[10] Some identifiable biases in the estimates most probably lead to an overstatement of genuine investment. First, as Hamilton and Clemens themselves emphasize, one serious problem is the lack of comprehensive data in national accounts. For many important (and declining) natural resource stocks, data are not available – at least not for every country. Diminishing natural resource stocks would constitute a negative entry in the genuine investment calculation. Among the natural resources that were not included in the Hamilton-Clemens study are water resources, forests as agents of carbon sequestration, fisheries, air and water pollutants, soil, and biodiversity. So there is an undercount, possibly a serious one.

Second, these estimates (as well as earlier estimates by Hamilton and Clemens) employ market prices as proxies for accounting prices in indicating potential trade-offs among different forms of capital. Because natural capital is typically under-priced, the use of market prices could bias the estimate of genuine investment in an upward direction.

Third, these estimates consider only very broad categories of capital. At a high level of aggregation, one can miss critical bottlenecks that impose limits on substitution possibilities open to people. Such bottlenecks might apply to various types of natural capital, implying that the accounting prices on such capital should be higher than would otherwise be expected. The rural poor in the world's poorest countries, for example, often cannot find substitutes when their water holes vanish and the local woodlands recede (Dasgupta, 1993). As migration can be very costly, especially for women with children, it can be that there are few alternative sources of these resources available to them. In contrast, the rich are often able to find substitutes from elsewhere. Highly aggregate models can easily miss these details and underestimate the accounting prices of local resource bases.

Fourth, in these calculations, disinvestment in environmental capital is calculated simply as the estimated damage associated with annual emissions of carbon dioxide. A ton of carbon dioxide emission is assumed to lead to a loss of 20 US dollars of environmental capital. However, to the extent that newly manufactured capital is expected to yield increased carbon dioxide emissions and thereby inflict subsequent damage, the value of investment in manufactured capital is reduced. The Hamilton-Clemens approach adopted here ignores this

[10] For a more extensive discussion of ways in which genuine investment could be better estimated, see Arrow, Dasgupta, and Maler (2003b).

effect.

Set against these considerations is another issue that is ambiguous in its effect. The proxy for increases in human capital – expenditure on education – neglects depreciation due to morbidity, mortality, and retirement from the work force. In this respect, it overstates the increase in human capital. On the other hand, this proxy ignores skills gained through channels other than formal education, as well as improvements in human productivity that are due to expenditures on health and nutrition. This implies the opposite bias.

As indicated at the beginning of this section, while the measure of genuine investment conveys useful information, it does not consider changes in population or technology. Accounting for population growth may make the sustainability picture look worse. Population has grown everywhere – in South Asia and sub-Saharan Africa especially so. As we observed earlier, if population grows fast enough, the long-run productive base per person could decline even if genuine investment were positive. On the other hand, accounting for improvements in technology (and institutions) would likely brighten the picture. Beneficial technological change effectively expands the productive base and thereby can raise intertemporal social welfare. However, as rates of technological improvement (or regress) vary by country, the impacts on intertemporal social welfare will differ as well. In what follows we extend our empirical assessment to consider the impacts of population growth and changes in total factor productivity.

4.2. *Population Growth, Technological Change, and Sustainability*

In Table 2 we have used data from various sources to obtain estimates of average annual genuine investment rates over the period 1970-2000 in the countries and regions covered in Table 1.[11] The first column reproduces the figures from the last column of Table 1, which are estimates of average genuine investment as a proportion of GDP over the interval 1970-2001. The second column is an initial, unadjusted estimate of genuine wealth. We arrive at the figures in this column by multiplying the numbers in the first column by a presumed GDP-wealth ratio for the country or region in question. This should be interpreted as the average GDP-wealth ratio over the three-decade interval. Since a wide array of capital assets (e.g., human capital and many

[11] A similar table, but restricted to poor countries over the period 1970-1993, appeared in Dasgupta (2001a). Because estimates of the residual during that period in poor countries were small and because empirical work based on macroeconomic models do not recognize natural resources, movements in total factor productivity were ignored in Dasgupta's estimates.

types of natural capital) are missing from national accounts, there is a bias in published estimates of GDP-wealth (or "output-wealth") ratios, which traditionally have been taken to be something like 0.20-0.30 per year. In Table 2 we have used the figure 0.15 per year as a check against the traditional bias for poor and oil-rich countries and regions, and 0.20 per year for industrialised countries. We then arrive at genuine wealth on a per-capita basis (column 4) by subtracting the population growth rate (column 3) from the initial genuine wealth figure. We will let W refer to per-capita genuine wealth.

Column 4's figures for changes in per-capita genuine wealth do not account for technological change. The next adjustments in the table are intended to account for such change as measured through changes in total factor productivity. Column 5 offers estimates of the growth of the total-factor-productivity residual, as reported for the period 1970-2000 in Klenow and Rodriguez-Clare (1997).[12] For the Middle East / North Africa and Sub-Saharan Africa regions, we obtain the residual by taking a weighted average of the estimates for the countries within each region, using GDP as weights. In the case of China, we report estimates from Collins and Bosworth (1996) for a comparable period, since Klenow and Rodriguez-Clare did not offer estimates for this country. It will be noticed that the residual was negative only in the Middle East-North Africa region.

An important problem with these estimates of the residual is that they are based on macroeconomic models in which environmental and natural resources do not appear. As mentioned in Section 2, if the rate at which depletable resources are used in production has increased over the period, published estimates of growth in total factor productivity should be judged to be too high. Let ν represent the share of natural resource use in GDP, and let the function *g(x)* represent the growth rate of *x*. In Appendix B we derive the following formula for correcting this bias:

$$g^{c}\left(\tilde{A}\right) = (1-\nu)\, g\left(\tilde{A}\right) - \nu\, g\left(R/Y\right) \qquad (2)$$

where $g^{c}\left(\tilde{A}\right)$ and $g\left(\tilde{A}\right)$ respectively stand for the corrected and uncorrected growth rates of total factor productivity, $\tilde{A}$ represents total factor productivity, R is the use of natural resource

[12] Klenow and Rodriguez-Clare report the growth rates of a transform of total factor productivity. From this information we calculate the associated growth rate of total productivity, as indicated in Appendix B.

inputs, and Y stands for GDP. In Table 2 we apply this formula to convert $g(\tilde{A})$ (column 5) to $g^c(\tilde{A})$ (column 9). We have assumed that ν, the share of natural resource use in GDP, is approximately 0.1, and we have used the growth rate in energy consumption over the period 1970-95 (World Resource Institute *et al.*, 1986, 1996, 1998) as a proxy for the average percentage rate of change in the use of depletable natural resources in production.

It remains to estimate the contribution of the corrected total factor productivity residual to changes in V. Toward this we use the simple approximation formula referred to in Section 2 (and derived in Appendix A) – namely, that the contribution of $g^c(\tilde{A})$ to movements in intertemporal social welfare (dV/dt) is $g^c(\tilde{A})$ times $\eta/(\eta-1)$, where η is the elasticity of marginal utility from consumption. Following Hall (1988) we take our base figure for η to be 3.[13] Thus the adjustment for total factor productivity growth (column 10) is 1.5 times the value in column 9. Finally, in column 11 we arrive at our productivity-growth-adjusted figure for growth in per-capita genuine wealth by adding the total factor productivity growth contribution to the growth rate of per-capita genuine wealth that was given in column 4. For purposes of comparison, we include as the far-right column the growth rate of per-capita GDP.

4.2.1 The Poor World

Our estimates in Table 2 suggest that parts of the poor world and some oil-exporting regions are not meeting the sustainability criterion: the growth rate of W, per-capita genuine wealth, is negative in the sub-Saharan Africa and Middle East / North Africa regions. This might not come as a surprise in the case of sub-Saharan Africa, which is widely known to have regressed in terms of most socio-economic indicators. In both of these regions, the growth of per-capita genuine wealth is already negative before adjusting for technological change (column

[13] As indicated in Section 2, Hall uses time-series data to estimate the intertemporal elasticity of substitution in consumption, σ. This is related to η according to $\eta = -(\sigma-1)/\sigma$. Hall's econometric work suggests that σ is in the range from 0 to 0.5, though his estimates leave open the possibility that σ is negative). A value of .25 for σ translates to a value of 3 for η.

4). In the Middle East / North Africa Region, the (uncorrected) estimate for the growth rate in total factor productivity is negative (-.23 percent) as well. Hence for this region, adjusting for technological change further reduces the estimated growth rate of per-capita genuine wealth. For Bangladesh and Pakistan, the estimates for the growth in *W* are also negative. For India and Nepal, the growth rates are a positive .31 and .52 percent, respectively.

The situation for the regions of sub-Saharan Africa and Middle East / North Africa is especially sad. At an annual rate of decline of 2.9 percent in genuine wealth per head, the average person in the sub-Saharan Africa region becomes poorer by a factor of two about every 25 years. The ills of sub-Saharan Africa are routine reading in today's newspapers and magazines. But they are not depicted in terms of a decline in wealth.

The results for China are strikingly different. The unadjusted growth rate of per-capita genuine wealth is significantly positive – about 2.1 percent. And the estimated growth rate of total factor productivity (3.6 percent) is high as well, helping to augment the growth rate of *W*. It may be noted that China's figure could be biased upward: the estimates of genuine investment do not include soil erosion or urban pollution, both of which are thought by experts to be especially problematic in China.[14]

How do changes in wealth per head compare with changes in conventional measures of economic progress? The far-right column of the table contains estimates of the rate of change of GDP per head over the interval 1970-2000. Per-capita GDP increased over this period in all of the listed countries or regions with the exception of the sub-Saharan Africa region, where GDP growth was slightly negative. These positive growth rates sharply contrast with the negative and weakly positive values for estimated growth rates of *W* in most of the regions and countries considered. For all of these countries except China, our assessment of long-term economic development would be significantly off the mark if were to look at growth rates in GDP per head.

Table 3 offers a sensitivity analysis for our estimates of the growth of *W* . One significant parameter is the GDP-wealth ratio, which we employ to translate genuine investment

[14] Hussain, Stern, and Stiglitz (2000) contains an analysis of why China has been the economic success it is widely judged to have been in recent years. However, there is no mention of what may have been happening to China's natural-resource base in the process of the country's economic development. Judith Shapiro's study of ill-conceived economic programs in Maoist China (Shapiro, 2001) is a convincing account of how suppression of civil and political liberties can contribute to the destruction of a country's natural-resource base.

into a growth rate of (unadjusted) genuine wealth. A lower value for this ratio implies a higher beginning-of-period level of wealth and lower growth rate, and thus leads to lower growth of adjusted per-capita genuine wealth. Results seem fairly sensitive to this parameter. When the output-wealth ratio is .1, the estimated growth of *W* is negative in all poor countries or regions except China. When this ratio is .25, only the sub-Saharan Africa and Middle East - North Africa regions exhibit negative growth of *W*.

We also assess the sensitivity of results to η, the elasticity of marginal utility of consumption. Our estimates are somewhat less sensitive to this parameter. Our high value for η is 1000. (The Rawlsian case would be infinity.) Our low value is 2. The higher is η, the lower the weight attached to total factor productivity growth in the calculation of the growth of *W*. Thus a higher value for η tends to lower the estimated growth rate of *W*. The exception is the Middle East-North Africa region, where a higher η has the opposite effect because the growth rate of total factor productivity in this region is estimated to be negative. In India, under our central value (3) for η, the growth of *W* was estimated to be .31 percent. Under our high value for η, this growth rate is very close to 0.

In light of the sensitivity of these results to parameters – as well as significant uncertainties about the underlying data as well as other parameters that enter these calculations – our conclusions must be tentative. However, despite all the uncertainties, it seems clear that measures of changes in per-capita genuine wealth yield a very different – and often much bleaker – picture of the prospects for poor nations, as compared with the message implied by changes in GDP per capita.

One might infer from the table that poor countries are "consuming too much." But such a conclusion would be off the mark. In many poor nations, the production of both capital goods and consumption goods is highly inefficient. The countries simultaneously suffer from low levels of genuine investment *and* consumption, and in the most important sense of the term, these nations do not over-consume. One cannot assure a satisfactory quality of life in these nations simply by devoting a larger share of productive factors toward the production of capital goods. Indeed, devoting a greater share of output toward investment could cause considerable misery by reducing what is already a very low level of *per capita* consumption. For these nations, the sustainability problem is part of a larger problem of inefficient production and low productivity, which accounts for both low genuine investment and low consumption. International assistance may be necessary to help overcome this larger problem, though there are no easy solutions. Meeting the Millennium Development Goals is a significant move in that direction (UNDP, 2003).

4.2.2 The Rich World

Table 2 also displayed estimated growth rates of *W* for the U.S. and U.K. Both the U.S. and the U.K. appear to have grown wealthier in per-capita terms, although the U.S. growth rate has been considerably smaller. The estimates of growth rates of per-capita GDP are also positive. Thus, for these countries, the differences across the two indices of economic development are less dramatic. Table 3's sensitivity analysis applies to the U.S. and U.K. as well as the poor nations or regions. In all cases, the growth rate of *W* remains positive for both countries. However, when a low output-capital ratio is assumed, the estimated growth rate of *W* for the U.S. becomes quite small (0.09 percent).

One might be tempted to conclude that the rich countries are avoiding consuming too much. But it is important to note that the figures for changes in per-capita wealth for different countries are not entirely independent. For example, the "success" of rich countries may in part be due to the "failure" of poorer nations. As we noted earlier, natural capital is very frequently under-priced in the market because property rights may be poorly defined or poorly enforced. In extreme cases such capital assets are free. Dasgupta (1990) and Chichilnisky (1994) have used this fact to argue that countries that are exporting resource-based products (they are often among the poorest) are to an extent subsidizing the consumption of those countries that are importing these products (they are often among the richest). Such hidden subsidies would help promote positive growth rates in per-capita wealth in rich countries, while working toward reduced growth rates in the poorer nations that export resource-based products. High levels of consumption in rich countries may promote excessive resource degradation in poor countries, which imperils well-being in the poorer countries. This negative by-product of rich nations' consumption is not captured in existing measures of changes in per-capita wealth.

5. Further Perspectives and Conclusions

We have evaluated consumption levels according to two criteria: the discounted present value of the utility stream (the max-PV criterion) and the maintenance or improvement of intertemporal social welfare (the sustainability criterion). Although the evidence is far from conclusive, we find some support for the view that consumption's share of output is likely to be higher than that which is prescribed by the max-PV criterion. We also find evidence that many nations of the globe are failing to meet a sustainability criterion: their investments in human and manufactured capital are not sufficient to offset the depletion of natural capital. This investment problem seems most acute in some of the poorest countries of the world.

Initial attempts to examine consumption in terms of a sustainability criterion have focused on the question whether nations manage to increase their overall productive base: that is, whether genuine investment is positive. These studies have tended to ignore the implications of changes in population and technology. In this paper we have offered a theoretical basis considering such changes, and have taken some tentative steps toward applying the theory. Instead of focusing on genuine investment, our analysis concentrates on changes in per-capita genuine wealth, where such wealth accounts for total factor productivity growth. Considering population growth causes the sustainability situation to appear somewhat worse: several nations with positive genuine investment have declining per-capita genuine wealth. Accounting for movements in total factor productivity tends to improve the picture, but for several poor nations, the sustainability criterion is violated even after accounting for such movements. And for nearly all of the countries we examine, the prospects for the future appear much dimmer when they are viewed from the perspective a sustainability criterion, as compared with other measures such as changes in GDP.

We would emphasize that insufficient investment by poor countries does not imply excessive consumption in the most important sense. For many of the poorest nations of the world, where productivity and real incomes are low, both consumption and investment are inadequate: current consumption does not yield a decent living standard for the present generation, and current investment does not assure a higher (or even the same) standard for future generations. We also emphasize that even though the rich nations appear to be meeting the sustainability criterion[15], this benign result should be interpreted with great caution. The statistics for the changes in genuine wealth in various countries are not independent: increases in the per-capita wealth at constant accounting prices of richer nations are due in part to the inability of poorer nations to price their resources and resource-intensive exports at social cost. In light of these interdependencies, richer nations should have less reason to feel complacent about the measured levels of genuine investment.

The uncertainty dimension deserves emphasis. This study and all previous studies of which we are aware provide only point estimates of genuine investment or of changes in genuine wealth per capita. Positive point estimates might suggest that the well-being of future generations is not at risk. However, given the vast uncertainties associated with the estimates, even when point estimates are positive there may remain a significant possibility that genuine investment is negative. The uncertainties justify added caution.

The presence of nonlinearities compounds the importance of uncertainty. The biophysical impacts associated with the loss of natural capital can be highly nonlinear: these impacts may be small over a considerable range, and then become immense once a critical threshold is reached. Crossing the threshold leads to a "bifurcation", that is, a situation where the characteristics of the natural system change fundamentally. To offer one example, shallow fresh water lakes have been known to flip from clear to turbid water as a consequence of excessive runoff of phosphorus from agriculture. Such flips can occur over as short a period as a month. Recent work by ecologists and environmental economists (Scheffer, 1998; Carpenter, Ludwig and Brock, 1999; Brock and Starrett, 2000; Scheffer *et al.* 2001) has uncovered the dynamics of water quality in such lakes that predicts the presence of bifurcation points and accounts for observed changes in the character of the lakes.[16]

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[15] In this paper we provide data for these two industrialized nations. It may be noted that the World Bank's estimates indicate that nearly all industrialized nations succeed in undertaking sufficient investment to increase per-capita genuine wealth. The exceptions are Australia and Israel. See Hamilton (2000).

[16] When the density of phosphorus is low, there will be very little algae in the water and sunlight can support green plants on the bottom. However, if more and more phosphorus is added to the lake through sewage or runoff from agricultural land, sunlight reaching the bottom will be reduced and the green plants will disappear. As a consequence, the bottom sediments (which contain phosphorus from dead algae) will be less stable and phosphorous will be released from the bottom. More discharge of phosphorus from outside will trigger even more phosphorus from the bottom. This positive feedback will eventually force the lake to flip (or "bifurcate") from a clear state to a eutrophic state.

The possible reversal of the Atlantic stream that now warms northern Europe represents another potential

Non-linearities in ecosystem dynamics imply that the distribution for genuine investment may be highly skewed – the downside risks associated with the loss of certain forms of natural capital can be substantial. Existing estimates of genuine investment or changes in genuine wealth per capita at constant accounting prices focus on most-likely scenarios and thus do not capture these downside risks. To the extent that societies are risk-averse, it is important to give extra weight to the possible negative scenarios. Doing so would imply lower estimates of genuine investment or of changes in genuine wealth per capita at constant accounting prices.

While there may be uncertainty about whether various countries are meeting the sustainability criterion, the need for vigorous public policies to support more efficient consumption and investment choices is unambiguous. Through regulation, taxes, or the establishment of clearer or more secure property rights, public policy can help prices of natural and environmental resources better approximate their social cost. This can help prevent excessive resource depletion and promote higher genuine investment. Such policies are justified on efficiency grounds whether or not genuine investment currently is positive.[17]

As indicated in Section 2, the implementation of public policies that satisfy a benefit-cost test does not in theory guarantee sustainability. At the same time, such policies do not necessarily conflict with the achievement of sustainability. Indeed, it is our sense that policies of this sort – especially those that deal with under-pricing of natural resources or environmental amenities – will improve matters along the sustainability dimension. When one views desertification in China, water contamination in Senegal, and forest depletion in Haiti, it is hard to imagine that the establishment of property rights or improved pricing of natural resources could worsen future generations' prospects.

Beyond policy action, there is a need for further research to identify the areas where current consumption poses a threat to sustainability, and quantify the potential losses. First and

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bifurcation. Climate models indicate that such a reversal can occur if greenhouse gases in the atmosphere increase sufficiently, although the threshold point at which reversal would be expected to occur is not known. It is evident from paleo-climatic history that reversals have been common. Mastrandrea and Schneider (2001) have employed a climate-economy model to investigate the possibility of reversals and to assess the implications for climate policy.

[17]The rationale for many public policies remains strong irrespective of whether genuine investment is positive or negative. From this one might conclude that quantifying genuine investment is not very useful. But measuring genuine investment still has significant value. By providing an overall "scorecard" as to whether a nation is investing enough to sustain the welfare of future generations, it can offer an important summary assessment that can help mobilize the general public and politicians.

foremost, we need to develop better data quantifying the losses of natural capital we currently are experiencing, and the potential for substitution between various forms of capital. This would facilitate the measurement of genuine investment on a more disaggregated basis. Further, to complement the rather simple analytical calculations genuine investment, we need to make more use of disaggregated numerical growth models. Such models can contain considerable detail in the interaction of various forms of capital and the services they generate. They can be used to project growth paths of economies under various conditions and can aid us in getting the crucial accounting prices right. Additional information of this kind will help reduce uncertainties about genuine investment and clarify the extent to which current consumption levels might imperil the quality of life of future generations.

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Appendix

A. Contribution of Total Factor Productivity Growth to the Growth of *V*

We develop a very simple model to explore the contribution of growth in total factor productivity to the growth of intertemporal social welfare, *V*. The model assumes that population is constant and that all forms of capital assets other than knowledge can be aggregated to form a comprehensive index of non-deteriorating capital, here represented by *K*. We also assume constant Hicks-neutral technological progress, and that output is proportional to a power of capital. Finally, we assume that the saving rate is constant. (We obtain the same final result when the savings rate is optimal, though we do not deal with that case here.) Thus we have:

$$Y = \hat{A}K^{\alpha}, \;\; dK/dt = sY, \;\; C = (1-s)Y, \;\; (d\hat{A}/dt)/\hat{A} = \gamma \qquad \text{(A-1)}$$

where Y is output, $\hat{A}$ is the level of technology, K is the capital index, s is the savings ratio, C is aggregate consumption, and α and γ are parameters. Note that γ is the rate of total factor productivity growth. It will be convenient to define $A \equiv \hat{A}^{1/(1-\alpha)}$, so that the production function can be written as $Y = A^{1-\alpha}K^{\alpha}$. Define $\hat{\gamma} \equiv dA/dt$. Note that

$$\hat{\gamma} = \gamma/(1-\alpha)\,. \qquad \text{(A-2)}$$

Let the utility function be isoelastic: $U(C) = (1-\eta)^{-1}C^{1-\eta}$. Assume next that the economy is in a steady state, by which we mean that the ratio *C(t)/A(t)* is constant. (The steady-state assumption is somewhat awkward, given the present paper's focus on possibilities for highly "unsteady" outcomes. However, it helps give some idea of the appropriate shadow prices in the presence of total factor productivity growth.) Define $k \equiv K/A$. Then

$$dk/dt = sk^{\alpha} - \hat{\gamma}k \qquad \text{(A-3)}$$

Provided that $\hat{\gamma} > 0$ (that is, that technological progress is positive), this equation has a stable equilibrium. Denote by k^* the equilibrium value for k. Then:

$$s(k^*)^{\alpha-1} = \hat{\gamma}. \qquad \text{(A-4)}$$

Intertemporal social welfare, *V*, is a function of the initial levels of capital and technology:

$$V \equiv \int_0^{\infty} e^{-\delta t}U(C(t))dt \;=\; V(K(0), A(0)) \qquad \text{(A-5)}$$

We want to calculate the responses of V to changes in $K(0)$ and $A(0)$ in order to then calculate the shadow prices. First, however, we will take $k(0)$ and $A(0)$ as state variables, since the calculations are simpler. We then convert to shadow prices in terms of $K(0)$ and $A(0)$. By definition of k,

$$V(K, A) = \tilde{V}(k, A) = \tilde{V}(K/A,\; A) \qquad \text{(A-6)}$$

Define the shadow prices $p_K \equiv \partial V / \partial K(0),\ p_A \equiv \partial V / \partial A(0),\ \tilde{p}_k \equiv \partial \tilde{V} / \partial k(0),\ \tilde{p}_A \equiv \partial \tilde{V} / \partial A(0)$
Then, from (A-6),

$$p_K = \tilde{p}_k A^{-1}, \text{ and } p_A = \tilde{p}_A - \tilde{p}_k K A^{-2}. \tag{A-7}$$

The condition for sustainability is that

$$dV / dt = p_K (dK / dt) + p_A (dA / dt) \geq 0 . \tag{A-8}$$

Dividing both sides of (A-8) by $p_K K(0)$ yields:

$$(dV / dt)/(p_K K(0)) = [(dK / dt)/ K(0)] + [(p_A A(0))/ p_K K(0))](1/ A(0))(dA/ dt) \tag{A-9}$$

Dividing by $p_K K(0)$ puts the measure of sustainability in terms of units of output rather than utility. Division by K(0), in particular, is intended to make the second term the extent to which the measure of sustainability differs from the rate of growth of reproducible capital. From (A-7),

$$(p_A A(0))/(p_K K(0)) = [(\tilde{p}_A A(0))/ \tilde{p}_k k(0))] - 1 . \tag{A-10}$$

We seek to evaluate the expression in brackets on the right-hand side of (A-10). Let $c(t) \equiv C(t)/ A(t)$. Since U is isoelastic,

$$\tilde{V}(k, A) = [A(0)]^{1-\eta} \int_0^{\infty} e^{-[\delta + (\eta - 1)\hat{\gamma}]t} U(c(t))dt . \tag{A-11}$$

Then, from (A-1) and the definition of $\tilde{p}_k$,

$$\tilde{p}_k = [A(0)]^{1-\eta} \int_0^{\infty} e^{-[\delta + (\eta - 1)\hat{\gamma}]t} [c(t)]^{-\eta} \partial c(t) / \partial k(0)]dt \tag{A-12}$$

Note that $c(t) = (1 - s)[k(t)]^{\alpha}$, so that,

$$(1/ c)(\partial c / \partial k(0)) = \alpha(1/ k)(dk(t)/ dk(0)),$$

or

$$\partial c / \partial k(0) = \alpha(c / k)(dk(t)/ dk(0))$$

We are seeking steady-state solutions; we mark such expressions with "*(SS)*." Along a steady-state path, c is constant at $c^* = (1 - s)[k^*]^{\alpha}$. Hence, from (A-12),

$$\textit{(SS)} \qquad \tilde{p}_k = \alpha[A(0)]^{1-\eta} (c^*)^{1-\eta} (k^*)^{-1} \int_0^{\infty} e^{-[\delta + (\eta - 1)\hat{\gamma}]t} (dk / dk(0))dt \tag{A-13}$$

We seek to identify the dependence of *k(t)* on k(0). Let $k'(t) \equiv dk(t)/ dk(0)$. By definition, $k'(0) = 1$. Differentiating (A-3) with respect to k(0) yields $dk'/ dt = (\alpha s k^{\alpha - 1} - \hat{\gamma})k'$. Therefore, from (A-4), (SS) $dk'/dt = -(1-\alpha)\hat{\gamma}k'$

so that,

(SS) $k'(t) = e^{-(1-\alpha)\hat{\gamma}t}$

Substitution into (A-13) yields,

(SS) $\tilde{p}_k = \alpha[A(0)]^{1-\eta}(c^*)^{1-\eta}(k^*)^{-1}[\delta + (\eta - \alpha)\hat{\gamma}]^{-1}$. (A-14)

Differentiate (A-11) with respect to $A(0)$, and evaluate along the steady state, so that $U[c(t)] = U(c^*) = (1-\eta)^{-1}(c^*)^{1-\eta}$ can be factored out of the integral:

(SS) $\tilde{p}_A = [A(0)]^{-\eta}(c^*)^{1-\eta}[\delta + (\eta - 1)\hat{\gamma}]^{-1}$. (A-15)

Finally, substitute (A-14) and (A-15) into (A-10) to obtain:

(SS) $p_A A(0)/(p_K K(0)) = [(1-\alpha)/\alpha]\{1 + [\hat{\gamma}/(\delta + (\eta - 1)\hat{\gamma})]\}$. (A-16)

Note that this expression does not depend on *s*. If we go back to the full expression for change in total wealth relative to ordinary capital (and measured in units of produced good), we see from (A-9) that,

(SS) $(dV/dt)/p_K K(0) = [(dK/dt)/K(0)] \;+\; [(1-\alpha)/\alpha]\{1 + [\hat{\gamma}/(\delta + (\eta - 1)\hat{\gamma}]\}\hat{\gamma}$

Noting from (A-2) the relationship between $\hat{\gamma}$ and total factor productivity growth (or γ), we can write:

(SS) $$(dV/dt)/p_K K(0) = (dK/dt)/K(0) + \alpha^{-1}\gamma\{1 + [\gamma/(\delta(1-\alpha) + (\eta - 1)\gamma)]\}.$$ (A-17)

The second term on the right hand side of the above equation is the contribution of total factor productivity growth to the growth rate of *V*. To simplify, suppose $\alpha = 1$. (Recall that *K* includes all inputs of production other than knowledge.) In this case, the contribution of total factor productivity growth reduces to $\gamma\eta/(\eta-1)$. We apply this relationship in tables 2 and 3.

B. Correcting Estimates of the Total Factor Productivity Residual to Account for Omission of Natural Resource Inputs

In Column 5 of Table 2 we reported estimates of the average annual value of the residual in our set of countries and regions over the period 1970-2000, made by Klenow and Rodrigues-Clare (1997). The problem for us is that in estimating the residual, Klenow and Rodrigues-Clare used a specification for the aggregate production function that did not include natural resources as inputs in production. As we noted in Section 2, such a specification can lead to biased estimates. We adopted the following procedure to correct for the bias.

Klenow and Rodrigues-Clare (1997) applied the following aggregate production function:

$$Y_t = K_t^{\alpha} H_t^{\beta} (A_t L_t)^{1-\alpha-\beta} \tag{B-1}$$

where K is the stock of manufactured capital, H is the stock of human capital, $A^{1-\alpha-\beta}$ is total factor productivity, and L is labor hours. We first derive an expression for the growth rate of total factor productivity residual that emanates fro this specification. Equation B-1 can be rewritten as:

$$Y/L = (K/L)^{\alpha} (H/L)^{\beta} A^{1-\alpha-\beta} \tag{B-2}$$

$$= (K/Y)^{\alpha} (H/Y)^{\beta} (Y/L)^{\alpha+\beta} A^{1-\alpha-\beta}$$

Then

$$(Y/L)^{1-\alpha-\beta} = (K/Y)^{\alpha} (H/Y)^{\beta} A^{1-\alpha-\beta}$$

or

$$(Y/L) = (K/Y)^{\frac{\alpha}{1-\alpha-\beta}} (H/Y)^{\frac{\beta}{1-\alpha-\beta}} A \tag{B-3}$$

Let the function $g(x)$ indicate the growth rate of x. Then

$$g(Y/L) = \frac{\alpha}{1-\alpha-\beta} g(K/Y) + \frac{\beta}{1-\alpha-\beta} g(H/Y) + g(A) \tag{B-4}$$

Define $\tilde{A} \equiv A^{1-\alpha-\beta}$. Note that $\tilde{A}$ is the total factor productivity residual. From (B-4),

$$g(\tilde{A}) = (1-\alpha-\beta)\, g(A) = (1-\alpha-\beta)\, g(Y/L) - \alpha\, g(K/Y) - \beta\, g(H/Y). \tag{B-5}$$

Suppose the true production relationship is

$$Y_t = K_t^{(1-\nu)\alpha} H_t^{(1-\nu)\beta} (A_t L_t)^{(1-\nu)(1-\alpha-\beta)} R^{\nu},$$

where R represents natural resource contributions to measured output, and ν is the share of R in production. The exponents for the other factors now include the coefficient (1-ν), so that the exponents again sum to 1. The above production function can be rewritten as

$$Y/L = (K/L)^{(1-\nu)\alpha} (H/L)^{(1-\nu)\beta} A^{(1-\nu)(1-\alpha-\beta)} (R/L)^{\nu}$$

$$= \left(K/Y\right)^{(1-\nu)\alpha} \left(H/Y\right)^{(1-\nu)\beta} \left(R/Y\right)^{\nu} \left(Y/L\right)^{(1-\nu)(\alpha+\beta)+\nu} A^{(1-\nu)(1-\alpha-\beta)}$$

Thus:

$$\left(Y/L\right)^{(1-\nu)(1-\alpha-\beta)} = \left(K/Y\right)^{(1-\nu)\alpha} \left(H/Y\right)^{(1-\nu)\beta} \left(R/Y\right)^{\nu} A^{(1-\nu)(1-\alpha-\beta)}$$

Again define $\tilde{A} \equiv A^{1-\alpha-\beta}$. Then

$$g^{c}\left(\tilde{A}\right) = (1-\nu)\left[(1-\alpha-\beta)\,g\left(Y/L\right) - \alpha\, g\left(K/Y\right) - \beta\, g\left(H/Y\right)\right] - \nu\, g\left(R/Y\right) \qquad \text{(B-6)}$$

where the superscript "*c*" is employed to distinguish the corrected growth rate $g^{c}(\tilde{A})$ from the uncorrected growth rate $g(\tilde{A})$ derived from the original model. Comparing equations B-6 and B-5 above, we observe that the corrected growth rate is related to the uncorrected rate according to:

$$g^{c}\left(\tilde{A}\right) = (1-\nu)\, g\left(\tilde{A}\right) - \nu\, g\left(R/Y\right)$$

We apply this correction in tables 2 and 3.

Table 1: Genuine Investment and Components as Percent of GDP

Country	Period	Domestic Net Investment	Education Expenditure	------------- Natural Resource Depletion -------------				Genuine Investment
				Damage from CO_2 emissions	Energy Depletion	Mineral Depletion	Net Forest Depletion	
Bangladesh	1973-2001	7.83	1.53	0.25	0.61	0.00	1.41	7.09
India	1970-2001	11.74	3.29	1.16	2.89	0.46	1.05	9.46
Nepal	1970-2001	14.82	2.65	0.20	0.00	0.30	3.67	13.31
Pakistan	1970-2001	10.92	2.02	0.75	2.60	0.00	0.84	8.75
China	1982-93; 1995-2001	30.06	1.96	2.48	6.10	0.50	0.22	22.73
Sub-Saharan Africa	1974-82; 1986-2001	3.50	4.78	0.81	7.31	1.71	0.52	-2.08
Middle East & North Africa	1975-2001	14.72	4.70	0.80	25.54	0.12	0.06	-7.09
U.K.	1971-2001	3.70	5.21	0.32	1.20	0.00	0.00	7.38
U.S.	1970-2001	5.73	5.62	0.00	1.95	0.00	0.00	8.94

Source: Authors' calculations, using data from World Bank (2003)

Table 2: Growth Rates of Per-Capita Genuine Wealth

Country	(1) Geniune Investment as Percent of GDP	(2) Growth Rate of Unadjusted Genuine Wealth	(3) Population Growth Rate	(4) Growth Rate of Per-Capita Genuine Wealth - before TFP Adjustment	(5) $g(\tilde{A})$ (uncorrected growth rate of total factor productivity)	(6) $g(R)$	(7) $g(Y)$	(8) $g(R/Y)$	(9) $g^c(\tilde{A})$ (corrected growth rate of total factor productivity)	(10) TFP Adjustment $[\eta/(\eta-1) \times g^c(\tilde{A})]$	(11) Growth Rate of Per-Capita Genuine Wealth - after TFP Adjustment	(12) Growth Rate of Per-Capita GDP
Bangladesh	7.09	1.06	2.16	-1.10	0.81	4.17	4.04	0.13	0.71	1.07	-0.03	1.88
India	9.46	1.42	1.99	-0.57	0.64	4.84	4.95	-0.11	0.59	0.88	0.31	2.96
Nepal	13.31	2.00	2.24	-0.24	0.51	3.56	4.10	-0.54	0.51	0.77	0.52	1.86
Pakistan	8.75	1.31	2.66	-1.35	1.13	10.98	4.87	6.11	0.40	0.60	-0.75	2.21
China	22.73	3.41	1.35	2.06	3.64	5.34	9.12	-3.78	3.59	5.38	7.44	7.77
Sub-Saharan Africa	-2.08	-0.31	2.74	-3.05	0.28	4.01	2.73	1.28	0.12	0.18	-2.87	-0.01
Middle East and North Africa	-7.09	-1.06	2.37	-3.43	-0.23	9.01	3.11	5.90	-0.79	-1.19	-4.62	0.74
United Kingdom	7.38	1.48	0.18	1.30	0.58	0.46	2.37	-1.91	0.71	1.06	2.36	2.19
United States	8.94	1.79	1.07	0.72	0.02	1.43	3.06	-1.63	0.18	0.27	0.99	1.99

Note -- These calculations employ the following parameters:

output-capital ratio - poor countries/regions	0.15
output-capital ratio - rich countries	0.20
ν (exponent for extracted resources in production functior	0.10
η (elasticity of marginal utility of consumption)	3.00

Sources:

Genuine Investment, Population Growth Rate, and GDP Growth Rate: World Bank (2003)

Growth Rate of Total Factor Productivity ($g(\tilde{A})$): for China, Collins-Bosworth (1996); for all others, Klenow and Rodriguez-Clare (1997)

Growth Rate of Energy Consumption ($g(R)$): World Resources Insitute *et al.* (1986, 1996, 1998)

Table 3: Sensitivity Analysis

Country	central case	GDP-wealth ratio = .1	GDP-wealth ratio = .25	η = 1000	η = 2
Bangladesh	-0.03	-0.38	0.68	-0.38	0.33
India	0.31	-0.16	1.26	0.02	0.61
Nepal	0.52	-0.14	1.85	0.27	0.78
Pakistan	-0.75	-1.18	0.13	-0.95	-0.54
China	7.44	6.30	9.71	5.65	9.23
Sub-Saharan Africa	-2.87	-2.77	-3.08	-2.93	-2.81
Middle East and North Africa	-4.62	-4.27	-5.33	-4.23	-5.02
United Kingdom	2.36	1.62	2.73	2.01	2.71
United States	0.99	0.09	1.43	0.90	1.07