Are We Consuming Too Much?

by

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1. Introduction

Is humanity's 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 the 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 in the form of increased manufactured capital and human capital, as well as technological change, 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.

By what criterion should we judge whether consumption is or is not excessive? Economic analysis has tended to emphasize the criterion of maximizing the present discounted value 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 examine these criteria for evaluating whether consumption is excessive, and identify factors in the economic and ecological domains that determine whether or not it is in fact so.

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. Then the intertemporal social welfare V_t at time t, can be defined as the present discounted value of the flow of utility from consumption from the present to infinity, discounted using the constant rate δ (>0).[1] In focusing at each moment on aggregate consumption, our framework abstracts from *intra*temporal equity issues. The equity issues that preoccupy us are intertemporal.

One of the determinants of V_t is the "productive base," which consists of society's institutions and capital assets at t. The capital assets include manufactured capital, human capital, the knowledge base (level of technology), and natural capital. Although institutions are

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[1] Let s and t variously denote time (where $s \geq t$). 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. 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). 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.

frequently regarded to be capital assets themselves, we will instead 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.

We now discuss two criteria for judging whether or not current consumption is excessive.

2.1 The Maximize-Present-Value Criterion

One can think of intertemporal social welfare V_t as a function of initial conditions – the productive base and level of technology (knowledge) at time t – and the choices from time t forward as to how to allocate output between investment and consumption. According to the *maximize-present-value criterion,* actual consumption today is excessive if it is greater than the level of current consumption prescribed by this optimal consumption path. To put it another way, current consumption is excessive if lowering it and increasing investment (or reducing disinvestment) in capital assets could raise future utility enough to more than compensate (even after discounting) 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 appropiate choice of δ.

One interesting aspect of the optimal consumption path according to the maximize-present-value 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. Conversely, in a world where markets for many future goods and many types of risk-bearing do not exist and where environmental externalities prevail, consumption generally will not be optimal. Nevertheless, it is possible to conduct social cost-benefit analysis to judge whether a policy reform at t increases intertemporal social welfare (Dasgupta, 2001a; Arrow, Dasgupta, and Mäler, 2003b).

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 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 (Pezzey, 1992; Solow, 1992; Heal, 1998; Asheim, 2003). Here, we take sustainability to mean that intertemporal social welfare V must not decrease over time. We will say that the sustainability criterion is satisfied at time t if $dV_t / dt \geq 0$.

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 guarantee 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, satisfying the sustainability criterion today does not guarantee that the criterion will be satisfied at all future times: a given consumption path may imply a rising V over the interval from now to the next period, but a falling V when it is evaluated over some future interval of time. Sixth, in defining sustainable development there is no presumption that the consumption path being followed is optimal in the sense of maximizing V. And seventh, a consumption path that satisfies the sustainability criterion need not be intertemporally efficient; an alternative, Pareto-superior path may well exist.

The notion of society's "productive base" is closely connected to the issue of whether the sustainability criterion is satisfied. As defined earlier, the productive base is the stock of all society's capital assets at t, inclusive of manufactured capital assets, human capital, natural capital, and the knowledge base. Let *genuine investment* refer to the change in the productive base. Genuine investment can be expressed as the sum of the values of investments or disinvestments in each of society's capital assets, where the value of each investment is the product of the change in the quantity of the asset times the shadow value or accounting price of that asset.[2] Clearly intertemporal welfare $V(t)$ is non-decreasing at t if and only if genuine investment is non-negative at t.[3] We can refer to genuine investment as the change in society's *genuine wealth*.

This requirement that the productive base be maintained 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 accumulated sufficiently to offset the resource decline.

While the criterion for sustainable development is straightforward to express, implementing it poses severe empirical challenges. Anticipating future increases in knowledge

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[2] 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 i^{th} capital good at date t. By the chain rule of differentiation,

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

where p_{it} $(\equiv \partial V/\partial K_{it})$ is the shadow price or accounting price of K_{it}, and I_{it} $(\equiv dK_{it}/dt)$ denotes the rate of change in K_{it}. The right-hand side of the expression above is genuine investment.

It is frequently convenient to divide the expression for dV/dt by the value of some one kind of capital (valued at its shadow price). Thus, if there are just two kinds of capital, denoted, say, by K_1 and K_2, respectively, genuine investment measured relative to the first kind of capital is

$$(dV/dt)/(p_{K_1}K_1) = (1/K_1)dK_1/dt + [p_{K_2}K_2/(p_{K_1}K_1)](1/K_2)(dK_2/dt)$$

This indicates that our sustainability criterion can be expressed as the growth rate of one kind of capital plus the product of the growth rate of the other kind of capital and an adjustment factor. Note that, from the definition of shadow prices above, the adjustment factor is the elasticity of K_1 with respect to K_2 along an isoquant of $V(K_1, K_2)$. We apply this expression in Section 2.4, where we extend the expression for dV/dt to account for technological change.

[3] This result was proved for optimally managed economies by Pearce and Atkinson (1995) and for arbitrary economies by Dasgupta and Maler (2000).

and their potential to augment the productive base is one huge challenge. Apart from assessing the impact of knowledge-improvements, measuring changes in quantities of capital stocks is very difficult. This is especially hard in the case of stocks of natural resources such as minerals, fossil fuels, fish or insects. In evaluating the social losses from 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 contributions of 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). Measuring these services is no easy task.

Another great challenge is the task of determining 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. Ecologists express concerns that natural resources have only a limited set of substitutes. They fear that to the extent that economists are overly optimistic about opportunities to substitute other capital assets for certain natural resources, reductions in their stocks would then receive too little weight. A major goal of ecological economics is to increase our understanding of the 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.[4]

2.3 Extending the Sustainability Criterion to Account for Changing Population

In initial discussion of intertemporal social welfare, V, we have abstracted from the impact of changes in population size. Dealing with a changing population presents empirical challenges: forecasting the time-profile of population is quite difficult. But the theoretical issues

[4] 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 (2003). An important complication related to assessing substitution possibilities is that the potential for substitution can vary by location. A natural resource in one place, like a local woodland, is not the same economic commodity as the same natural resource in another place. Dasgupta (1993) discusses the implications of local non-substitutability for the world's poorest people, who often have no substitutes available to them when their local resource base is degraded. For an interchange on the relative importance of substitution possibilities at aggregate and local levels, see Johnson (2001) and Dasgupta (2001b).

associated with a changing population may be even more challenging. Many of the theoretical problems remain unresolved. Should social welfare seek to maximize the sum of the utilities of all individuals, or should it seek to maximize some form of average welfare over all people – now and in the future? How can one compare the social value of a large population with higher total utility, versus a smaller population with higher average utility?

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. 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 intertemporal social welfare, then, under certain conditions a non-declining V_t is equivalent to the intuitively appealing requirement that *genuine wealth* per capita must not decline. The conditions in question are: (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 certain empirical results later in this paper.

[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. However, it matters hugely whether "total" or "dynamic average" utilitarianism is adopted when one is applying the sustainability criterion. For further analysis of sustainability under changing population size, see Arrow, Dasgupta, and Mäler (2003a).

2.4 Extending the Sustainability Criterion to Account for Technological Change

In the presence of technological change, output and consumption could rise, and thus intertemporal social welfare V could increase, even if aggregate investment in terms of manufactured, human, and natural capital were negative. How can we take 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. In a rather special model – one with 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 K (without subscript) represent the productive base, a composite of natural, physical, and human capital.[6] Let α be the elasticity of output with respect to K. In Section 4 we will observe that genuine savings rates are close to 0. A simple argument shows that, with zero rates of savings, total factor productivity growth at rate γ raises the growth rate of intertemporal social welfare (measured in units of capital) by γ/α.[7]

There are serious problems with published estimates of the "residual," because national accounts do not include the economy's use of non-marketed natural and environmental resources. Suppose that over a period of time, an economy extracts from its natural resource base at an increasing rate. Then additional recorded growth in total factor productivity would not be due to an improved knowledge base, but to increased resource use. On the other hand, if the rate of natural resource extraction were falling, recorded growth of total factor productivity

[6] K can also be regarded as a measure of genuine wealth prior to the adjustment in such wealth to account for technological change.

[7] Assume that $K(t)$, the productive base, is a constant (= K_0), and that consumption = output = $A_0 K_0^{\alpha} e^{rt}$, for all t. From the definition of V in footnote 2, V is constant when $A_0 K_0^{\alpha}$ is constant. Thus, the elasticity of A_0 (total factor productivity) with respect to K_0 along an isoquant of V is α^{-1}. In the second equation in footnote 2, substitute the productive base K for what was termed K_1 and total factor productivity A_0 for what was termed K_2. Since $(1/A)(dA/dt) = \gamma$, it follows from this equation that the sustainability criterion (expressed in terms of K) is the rate of growth of K plus γ/α.

would understand the true contribution of changes in the knowledge base.[8] Later in this paper, when we offer our own estimates of movements in genuine wealth in a selected number of countries and regions, we examine the growth rate in the use of depletable resources and use this information to correct for the associated mismeasurement of total factor productivity growth.

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 need not satisfy the maximize-present-value criterion. Conversely, an economic program that is optimal under the maximizing present value 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 so long as $\delta > 0$, consumptions paths that are optimal in the sense of maximizing intertemporal welfare V involve consumption approaching zero in the long run; thus they do not yield development that is sustainable over the long term.

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 – like establishing property rights, addressing externalities, and so forth – do not guarantee sustainability.

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[8] Our empirical investigation in Section 4 suggests that the more common situation is one in which the rate of natural resource extraction is increasing. A further issue might be noted. Since environmental resources are often under-priced, new technology can be rapacious in its reliance on the environment. In this case, technological change might increase the overuse of natural resources.

3. Empirical Evidence Relevant to the Maximize Present Value Criterion

According to the maximize-present-value criterion, today's consumption is excessive if it is higher than the level of current consumption along the consumption path that maximizes the current intertemporal welfare *V*. No one can seriously claim to determine the optimal level of current consumption for an actual economy. However, theoretical considerations can identify factors that would cause current consumption to be different in a predictable direction from the optimal level. Relevant theoretical issues include the relationship between market rates of return on investment and optimal social interest rates on consumption, and the relationship between market prices of contemporaneous goods (including those of current capital goods) and 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,* denoted by *r* denote the latter. 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, the social rate of interest on consumption *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.[9] The parameter δ reflects impatience, as is well known. The second term in the equation (η times *g*), may require explanation. One can view η as accounting for the fact that, to the extent that future generations have higher incomes, their consumption will be higher and the marginal utility of their consumption will be lower. 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.

[9] For one example of derivation, see Arrow and Kurz (1970). For additional discussion, see Arrow *et al*. (1996).

Does i exceed r? One might argue that this cannot be answered from empirical observation alone: one could claim that the choices of δ and η are inherently value judgments – subjective matters. However, there exists a different approach that offers a link to empirical behavior. This approach asserts that a "typical" individual's preferences should guide our choices of δ and η. In particular, it identifies the social rate of pure time preference, δ, with the utility discount rate that a typical individual would endorse. The assumptions of this approach are clearly subject to debate, but it seems worthwhile to consider what they imply for the relationship between i and r and thus for the level of consumption.

Several considerations suggest that the typical individual's preferences regarding the utility discount rate will not be reflected in the market.[10] One reason is that, because of externalities, the utility discount rate that most people would endorse as socially conscious beings is lower than the rate of time-preference emanating from market transactions. Many years ago, Ramsey, Pigou, and Harrod 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." A less extreme view would be to say that even if we don't treat δ as zero, individuals do derive a positive externality (outside of the marketplace) from the welfare of future generations. An argument combining the market rate of return on investment with the externality of caring about future generations 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

[10] 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, we prefer the interpretation that such externalities make it impossible for

value for *r* in the range 3.0-6.5 percent per annum.

How does this value compare with the market rate of return on investment *i*? We need to choose an appropriate market interest rate with which to make the comparison, but rates of return on different securities vary considerably. 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 percent; on equities from 1970-2000, 7.4 percent; but on Treasury bills from 1970-2000, just 1.6 percent. (The last two figures are derived by computation from the Wharton-Data Resources website.) We want to compare the social rate of interest on consumption *r* with a *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.

Two other pieces of evidence that market rates of return on investment may exceed the social rate of interest on consumption come from the incompleteness of markets and the existence of capital taxes. 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 Underpricing of Natural Resources Relative to Social Cost

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individuals to express their concerns about the future in their individual production or consumption decisions.

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. First, insecure or poorly defined property-rights can lead to excessively rapid resource exploitation if the exploitation does not require much prior investment (Bohn and Deacon, 1993). Second, natural resource underpricing can arise from 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.

Third, use of natural resources may be underpriced because of government subsidies. 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, the pricing of oil might well be the exception to a more general pattern of underpriced natural resources.

The underpricing 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 a person's own consumption, but also on the person's consumption relative to a "reference group." When others' consumption rises in comparison, an individual could suffer from a loss of well-being because that person's 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. 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 "consumption" of leisure and also 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 that person's 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 maximize present value 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. The assets to be included are manufactured capital, human capital, natural capital, and the knowledge base (Dasgupta and Mäler, 2000; Arrow, Dasgupta, and Mäler, 2003b). In this subsection we begin evaluating whether various nations are meeting the sustainability requirement by estimating and observing the sign of genuine investment. In the next subsection, we will extend the analysis to account for changes in population and technological change.

A growing body of research now aims to measure genuine investment in various countries. The 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.[11]

To estimate the accumulation of manufactured capital, Hamilton and Clemens (1999) used figures for net 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.[12]

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 the figures for a single year (as in Hamilton-Clemens), 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 includes poor nations (China, nations in the Indian subcontinent, and nations in the sub-Saharan Africa region), oil-exporting countries (in the Middle East-North Africa region), and industrialized nations (the United States and the United Kingdom).

The differences between genuine investment and the standard measure, net domestic

[11] 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.

[12] In calculating the reduction in natural resource stocks, Hamilton and Clemens do not include discoveries of new reserves as an offsetting element. As an accounting matter this seems correct. It is consistent with the notion that the overall global stock of mineral or fuel resources is given – that devoting resources toward exploration, and the subsequent discovery of previously unknown reserves, does not constitute an enlargement of the stock. At the same time, expenditure on exploration equipment or structures should constitute a positive investment in physical capital.

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 United States and United Kingdom, estimated genuine investment exceeded domestic net investment, since the increase in human capital exceeded the value of natural resource depletion.

These figures give an initial glimpse of the change in V. We will shortly consider how the picture changes when 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.[13] First, as Hamilton and Clemens 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. Among the natural resources 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 in indicating potential trade-offs among different forms of capital. To the extent that natural capital is typically underpriced, 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. 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). Aggregated calculations 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

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

manufactured capital is reduced.[14] The Hamilton-Clemens approach adopted here ignores this effect. A further problem is that this approach implicitly links all of the damage from carbon dioxide emissions to the country responsible for the emissions, whereas in fact a given country's emissions of carbon dioxide produce climate-impacts worldwide.

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 of human capital 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.

While the measure of genuine investment in Table 1 conveys useful information, it does not consider changes in population or technology. 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 productivity would likely brighten the picture. 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

The first column in Table 2 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 the growth rate 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 (the assumed average GDP/wealth ratio over the three-decade interval). Published estimates of GDP-wealth (or "output/wealth") ratios traditionally have been taken to be something like 0.20-0.30 per year. However, a wide array of capital assets like human capital and many types of natural capital are missing from national

[14] This does not double count. In today's genuine investment calculation, today's emissions of CO_2 constitute a reduction in "climate-system capital." This negative investment is the present value of the damages associated with these *current* emissions. At the same time, the value of today's investments in manufactured capital should be the present value of the net services associated with these manufactured assets. Future emissions and climate damages associated with these assets reduce these net service streams and imply a reduction in the value of current investment in these assets.

accounts. To offset this bias, Table 2 use the figure 0.15 per year for poor and oil-rich countries and regions, and 0.20 per year for industrialized countries. Let W refer to *per-capita* genuine wealth. We arrive at the growth rate of W (column 4) by subtracting the population growth rate (column 3) from the growth rate of 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 Rodríguez-Clare (1997).[15] 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 Rodríguez-Clare did not offer estimates for this country. 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. The production function most often used in growth analysis has output as a Cobb-Douglas function employing physical capital, human capital, and labor according to constant returns to scale, with total factor productivity increasing exponentially. Let α and β be the elasticities (production function exponents) of output with respect to physical and human capital. To deal with the misspecification of the production function – the neglect of extracted natural resources as a productive input – we introduce extracted natural resources in the production function, with v as its output elasticity, and we multiply the original physical capital and human capital exponents α and β by $1\text{-}v$ to preserve constant returns to scale. For any variable x, let $g(x)$ represent the growth rate of x. One can compare measured total factor productivity growth from the original specification and the corrected one. In the appendix to this paper (available at www.stanford.edu/~goulder), we derive the following formula for correcting

[15] Klenow and Rodríguez-Clare report the growth rates of a transform of total factor productivity. From this information we calculate the associated growth rate of total productivity.

the bias in estimating the rate of growth of total productivity induced by the omission of resources:

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

where A represents total factor productivity, $g^c(A)$ and $g(A)$ respectively stand for the corrected and uncorrected growth rates of A, R is the use of natural resource inputs, and Y stands for GDP.

In Table 2, we apply this formula to convert $g(A)$ (column 5) to $g^c(A)$ (column 7). In calculating $g\left(R/Y\right)$ (column (6), 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.

As a final step, we account for the contribution of (the corrected) total factor productivity residual to changes in intertemporal social welfare V. We use the simple approximation formula referred to in Section 2.4 fn. 7, which asserts that the contribution of $g^c(A)$ to movements in intertemporal social welfare expressed in units of capital (i.e., to movements in $V/(p_K K)$) is $(\alpha^*)^{-1} g^c(A)$, where α^* is the elasticity of output with respect to the productive base K (the aggregation of physical, human, and natural capital). In particular, $\alpha^* = (1-\nu)(\alpha+\beta)+\nu$, the sum of the exponents on the various types of capital. From Klenow and Rodríguez-Clare (1997), we take α = .30 and β = .28; and we employ a value of .10 for ν. These values imply α^* =.62. Thus the adjustment for total factor productivity growth is 1.61 times the value in column 7 of Table 2. This is added to column 4 to yield column 8, our adjusted estimate of the growth rate of W (per-capita genuine wealth), which takes account of total factor productivity growth. It should be emphasized that the assumptions invoked here are strong, and that the measurement of increased productive ability due to technical change is explored here in a very tentative way.

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. Population growth implies significant differences between the initially estimated growth rate of genuine wealth (column 2) and the growth rate on a per-capita basis (column 4). And the results in column 8, which account for both population growth and technological change, differ significantly from the original genuine investment calculations.

Despite projected technological progress, Pakistan shows a distinct decline in per-capita genuine wealth, and the rate for Bangladesh is very close to zero. India and Nepal show positive values for the growth rate of W (0.38% and 0.58% per annum).

Estimated growth rates for per-capita genuine wealth are projected to be negative in the Sub-Saharan Africa and Middle East / North Africa regions. At an annual rate of decline of 2.9% in genuine wealth per annum, the average person in the Sub-Saharan Africa region becomes poorer by a factor of two about every twenty-five 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.

In the Middle East/North Africa region, the (uncorrected) estimate for the growth rate in total factor productivity is negative (- .23 percent). Hence adjusting for technological change for this region further increases the estimated decline of per-capita genuine wealth. It is worth noting that the negative estimate for total factor productivity growth depends closely on the value one attaches to extracted energy resources. Alternative assumptions about future energy prices can significantly influence this valuation and the estimate of total factor productivity. Thus, the uncertainties in the estimates are especially great in the case of the Middle East / North Africa region.

The results for China are strikingly different from those just discussed. 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 (3.59 percent) is high as well, helping to augment the growth rate of W. However, 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.

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 mainly 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, an assessment of long-term economic development would be significantly off the mark if were to look at growth rates in GDP per head.

One significant parameter used in our estimates of the growth of W is the GDP-wealth ratio. This parameter is employed to translate genuine investment into a growth rate of (unadjusted) genuine wealth. Table 3 indicates the sensitivity of our estimates to this ratio. The first column repeats the calculations from Table 2 on the growth rate of per capita annual wealth. The second and third columns consider a lower and higher value for the GDP-wealth ratio. 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.

In the light of the sensitivity of these results to this parameter – as well as significant uncertainties about the underlying data as well as other parameters that enter these calculations – our conclusions must be tentative. But despite 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." 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.

4.2.2 The Rich World

Table 2 also displayed estimated growth rates of W for the United States and United Kingdom. Both countries 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. Under Table 3's sensitivity analysis, the growth rate of W remains positive for both countries in all cases, although when a low output-capital ratio is assumed, the estimated growth rate of W for the United States becomes quite small.

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. 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 underpriced 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 maximize-present-value 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 maximize-present-value 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.

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.

This study and all previous studies of which we are aware provide only point estimates of genuine investment or of changes in genuine wealth. 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," a situation where the characteristics of the natural system change fundamentally. For example, shallow clear fresh water lakes can absorb a low level of phosphorus with little ill effect. However, if more phosphorus is added to the lake through sewage or runoff from agricultural land, more algae grows in the water, less sunlight will reach the bottom, and the green plants on the bottom 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 clear to turbid water. Recent work by ecologists and environmental economists has investigated these dynamics and shown that such flips can occur over as short a period as a month (Scheffer, 1998; Carpenter, Ludwig and Brock, 1999; and Brock and Starrett, 2000). Another possible bifurcation arises in certain climate models which indicate that a rise in greenhouse gases might reverse the direction of the Atlantic stream that now warms northern Europe. Paleo-climatic history shows that such that reversals have been common.[16]

Non-linearities in ecosystem dynamics imply the presence of serious downside risks related to the losses of natural capital. Central estimates of the shadow prices for natural capital are likely to be too low if one only considers central cases rather than the entire distribution of potential outcomes from losses of natural capital. Thus, an uncertainty framework might well imply lower estimates for the genuine investment or changes in per-capita genuine wealth of various countries. Accounting for risk-aversion could lower these estimates even further.

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. These policies 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]

Although the implementation of public policies that satisfy a benefit-cost test does not in theory guarantee sustainability, such policies do not necessarily conflict with sustainability, either. Indeed, our sense is 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.

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[16] 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

Beyond policy action, further research is needed to identify the areas where current consumption poses a threat to sustainability, and quantify the potential losses. We need to develop better data quantifying the losses of natural capital and the potential for substitution between various forms of capital. Further, to complement the rather simple analytical calculations of 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.

help mobilize the general public and politicians.

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Table 1: Genuine Investment and Components as Percent of GDP

Country	Domestic Net Investment	Education Expenditure	---------- Natural Resource Depletion ----------				Genuine Investment
			Damage from CO2 emissions	Energy Depletion	Mineral Depletion	Net Forest Depletion	
Bangladesh 1973-2001	7.89	1.53	0.25	0.61	0.00	1.41	7.14
India 1970-2001	11.74	3.29	1.17	2.89	0.46	1.05	9.47
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 1982-2001 (without 1994)	30.06	1.96	2.48	6.11	0.50	0.22	22.72
Sub-Saharan Africa 1974-82; 1986-2001	3.49	4.78	0.81	7.31	1.71	0.52	-2.09
Middle East & North Africa 1976-89; 1991-2001	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	0.42	1.95	0.05	0.00	8.94

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

Table 2: Growth Rates of Per-Capita Genuine Wealth

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Country	**Geniune Investment as Percent of GDP**	**Growth Rate of Unadjusted Genuine Wealth**	**Population Growth Rate**	**Growth Rate of Per-Capita Genuine Wealth - before TFP Adjustment**	***g(A)*** (uncorrected growth rate of total factor productivity)	***g(R/Y)***	***$g^c(A)$*** (corrected growth rate of total factor productivity)	**Growth Rate of Per-Capita Genuine Wealth - after TFP Adjustment**	**Growth Rate of Per-Capita GDP**
Bangladesh	7.14	1.07	2.16	-1.09	0.81	0.13	0.71	0.06	1.88
India	9.47	1.42	1.99	-0.57	0.64	-0.11	0.59	0.38	2.96
Nepal	13.31	2.00	2.24	-0.24	0.51	-0.54	0.51	0.58	1.86
Pakistan	8.75	1.31	2.66	-1.35	1.13	6.11	0.40	-0.70	2.21
China	22.72	3.41	1.35	2.06	3.64	-3.78	3.59	7.84	7.77
Sub-Saharan Africa	-2.09	-0.31	2.74	-3.05	0.28	1.28	0.12	-2.86	-0.01
Middle East and N. Africa	-7.09	-1.06	2.37	-3.43	-0.23	5.90	-0.79	-4.71	0.74
United Kingdom	7.38	1.48	0.18	1.30	0.58	-1.91	0.71	2.44	2.19
United States	8.94	1.79	1.07	0.72	0.02	-1.63	0.18	1.01	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 function)	0.10
α (share of human and reproducible capital in output)	0.62

Sources:

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

Growth Rate of Total Factor Productivity (*g(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
Bangladesh	0.06	-0.30	0.77
India	0.38	-0.09	1.33
Nepal	0.58	-0.08	1.91
Pakistan	-0.70	-1.14	0.17
China	7.84	6.71	10.12
Sub-Saharan Africa	-2.86	-2.75	-3.07
Middle East and N. Africa	-4.71	-4.36	-5.42
United Kingdom	2.44	1.70	2.81
United States	1.01	0.11	1.45