Essay

Is Current Consumption Excessive? A General Framework and Some Indications for the United States

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Abstract: *Many prior studies have explored the implications of human population growth and environmentally problematic technologies for biodiversity loss and other forms of environmental degradation. Relatively few, however, have examined the impacts of the level and composition of consumption. We offer a framework that shows how the level and composition of a society's total consumption relate to the uses of various forms of capital and to the sustainability of natural resources and human well-being. We relate the framework to two main approaches—top-down macro studies and bottom-up computer models—for measuring whether overall consumption in the United States satisfies a sustainability requirement. Existing top-down studies have shortcomings that bias their results toward optimism, and current computer simulation models, although strong on revealing biophysical outcomes, are limited in their ability to evaluate impacts on human well-being. Although some ambiguities arise in determining whether overall consumption in the United States is excessive, our conclusions regarding the composition of U.S. consumption are unambiguous. Distorted consumption patterns and associated production methods lead to excessively rapid natural resource depletion; greater conservation would yield gains to current and future generations that more than compensate for the sacrifices involved. Public policies that deal with the composition problem not only would help conserve natural resources and improve current welfare but also would reduce the costs of meeting the goal of sustainability.*

Keywords: composition of consumption, environmental protection, human welfare, natural capital, natural resource conservation, overall consumption, sustainability

¿Es Excesivo el Consumo Actual? Un Marco de Referencia General y Algunas Indicaciones para E.U.A.

Resumen: *Muchos estudios previos han explorado las implicaciones del crecimiento de la población humana y de las tecnologías ambientalmente problemáticas para la pérdida de biodiversidad y otras formas de degradación ambiental. Sin embargo, relativamente pocos han examinado los impactos del nivel y composición del consumo. Ofrecemos un marco de referencia que muestra cómo se relaciona el nivel y composición del consumo total de una sociedad con los usos de varias formas de capital y con la sustentabilidad de los recursos naturales y el bienestar humano. Relacionamos el marco con dos enfoques principales - macro estudios arriba-abajo y modelos de computadora abajo-arriba - para medir si el consumo total en los Estados Unidos satisface un requerimiento de sustentabilidad. Los estudios arriba-abajo existentes tienen defectos que sesgan sus resultados hacia el optimismo, y los modelos actuales de simulación en computadora, aunque robustos para revelar resultados biofísicos, están limitados en su habilidad para evaluar los impactos sobre el bienestar humano. Mientras surgen algunas ambigüedades para determinar sí el consumo total en los Estados Unidos es excesivo, nuestras conclusiones en relación con la composición del consumo en E.U.A. son claras. Los patrones de consumo distorsionados y los métodos de producción asociados conducen a una reducción drástica y rápida de los recursos naturales; mayor conservación produciría ganancias para las generaciones actuales y futuras que compensarían los sacrificios involucrados. Las políticas públicas relacionadas con el problema de composición no sólo ayudarían a conservar los recursos naturales y a mejorar el bienestar actual sino también reducirían los costos para alcanzar la meta de sustentabilidad.*

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Palabras Clave: bienestar humano, capital natural, composición del consumo, conservación de recursos naturales, consumo global, protección ambiental, sustentabilidad

Introduction

Conservation biologists have long been concerned that the pattern and scale of human activities are having very serious impacts on the environment and human welfare. One worry is that the continued increase in both population size and consumption per person will lead to a further dwindling of critical natural resource inputs such as potable water and agriculturally viable soils. A related concern is that greater scale will lead to pollution discharges that continually exceed the assimilation capacity of the biosphere, resulting in environmental damages, including harmful climate change, increased toxicity of air and water, and losses of population and species diversity and the associated decline in ecosystem services.

Environmental scientists have often used the well-known $I = PAT$ equation (Holdren & Ehrlich 1974; Ehrlich & Ehrlich 1990) to express the damage to natural capital and the environment as the product of three factors: population size (P), per capita consumption (termed affluence, or A), and the damage per unit of consumption (termed technology, or T). There has been a great deal of attention to population size (e.g., Abernathy 1993) and technology (e.g., Lovins & Lotspeich 1999), but much less to the key issue of consumption per capita.

This paper examines the ways that current patterns and levels of consumption can threaten the natural resource base and jeopardize human welfare. We distinguish the level and composition of consumption. The level of consumption is roughly equivalent to the total amount of overall spending on consumer goods and services. The composition of consumption is the way spending is divided across particular goods and services.

We consider the following questions: When, in general, is the level of overall consumption excessive? What is the criterion for excessiveness? When is the composition of consumption a problem? Under what circumstances would a change in the composition of consumption improve human welfare? In the United States, in particular, is the level of consumption currently excessive? And what problems arise with the composition of consumption in the United States?

Connections between Consumption and Sustainability

What Needs to Be Sustained?

When is the level of overall consumption—the total spending on goods and services—excessive? We apply a sustainability criterion: the level is excessive if it is incompatible with sustainability.

Use of the term *sustainability* calls for its definition. Pezzey (1992), Costanza (1994), Daly and Cobb (1994), and Hediger (2006) provide a range of definitions. What is sustainability? More specifically, what is it that must be sustained? Ecologists often focus on sustaining natural resources. From this perspective, consumption is excessive if it threatens natural resource stocks (animate or inanimate) or the flow of ecosystem goods and services they provide, such as pollination, water filtration, climate regulation, and the provision of habitat for biodiversity. Ever-increasing levels of consumption tend to imply ever-larger threats to critical resources and systems and thus are a cause for concern.

Economists often view sustainability differently. They tend to claim that the main objective should be to sustain human welfare, not natural resources. Current consumption patterns are seen as excessive if they jeopardize the ability of future generations to enjoy the same level of well-being as the current generation.

The two views of sustainability are closely linked. Some natural resources are essential to well-being. Some are critical to life itself. Thus, sustaining certain natural resources is crucial to sustaining well-being. Ecologists and economists tend to agree that at least some natural resources or environmental amenities deserve full protection. Where opinions may differ is on the range of natural resources that require preservation. The strictest "sustain-resources view" would call for sustaining every major class of natural resource. Along with most economists and many ecologists, we favor a somewhat less stringent approach that allows for the diminishment or depletion of at least some natural resources—particularly, those for which there are good substitutes. As long as sufficient substitutes can be cultivated or produced, well-being need not fall.

But how can we know the extent to which substitutes are available or will become so? Vast uncertainties surround the myriad connections between natural capital stocks, ecosystem services, and human welfare. The recognition of these uncertainties helps justify a conservative, precautionary approach to natural resource preservation. It widens the range of natural resources deserving preservation and thereby narrows the gap between the sustain-resources and sustain-welfare approaches.

To evaluate further the prospects for sustaining welfare, we provide a general framework that expresses the connections among natural capital stocks, other forms of capital (which may or may not substitute for natural capital), various types of consumption, and well-being. We then relate this framework to attempts to assess empirically the biophysical and human-welfare impacts of U.S. consumption.

Capital, Consumption, and Well-Being

Well-being defies easy definition or measurement. We define it as the enjoyment of various goods and services, both material and intangible. Figure 1 illustrates connections among capital stocks, goods and services, and well-being. The designation *capital* applies to the various stocks because they are durable assets that generate streams of goods and services. Natural capital (K_N) includes both renewable resources such as forests, pollinators, natural enemies of pests, and fresh water, as well as nonrenewable resources such as reserves of petroleum and other minerals. Reproducible (or built) capital (K_R) encompasses factories, roads, vehicles, machinery, and so on. Human capital (K_H) is the productive capacity of human beings and reflects the skills acquired by people.

These capital assets contribute to well-being in two ways (Fig. 1). First, they produce goods and services for consumption. For example, reproducible capital in the form of a hospital building and the medical equipment within it, plus human capital in the form of skilled medical-care personnel, plus some natural capital in the form of medicines derived from plants yield medical-care services, a contributor to well-being. Second, some capital assets contribute directly to well-being when they are enjoyed for their own sake, as natural capital does when people view wildlife. Hence the line in Fig. 1 showing a direct connection between capital assets and well-being.

The goods and services offered by various capital assets include both necessities (food) and life-enhancing luxuries (bird watching, enjoying an opera). In addition, these goods and services are not restricted to those sold in a market. They include nonmarketed goods and services such as hiking in the wilderness.

Finally, Fig. 1 indicates that capital assets can be devoted to investment as well as to production of current consumption goods and services. Positive investment can take many forms: creating reproducible capital (producing new structures), increasing human capital (expanding skills through job training), or augmenting natural capital (restoring a wetland). Investment in natural capital may also include the expansion of fish stocks through catch limitation or aquaculture or of tree stocks through replanting. *Investment* here refers to capital expansion, not to a financial flow.

Consumption, Investment, and Sustainability

Investment plays a central role in achieving sustainability. It is needed to maintain capital assets and thus a society's ability to provide goods and services. Investment helps maintain capital three ways. First, it yields new capital that replaces worn out or retired old capital. Reproducible capital physically depreciates with time and use, and investment in its repair or replacement can help maintain or augment its current effective quantity. Similarly, a society's stock of employed human capital would also decline in the absence of investments in education because workers age and retire. Educating new and younger workers offsets what otherwise would be a reduction in human capital.

Second, for renewable natural capital (e.g., fish, pollinators) the stock can be maintained by reducing the harvesting rate or by habitat restoration. This allows the recovery of stocks through natural reproduction. Even when efforts of this type involve no financial outlay, they constitute "investment" because they lead to the expansion of capital.

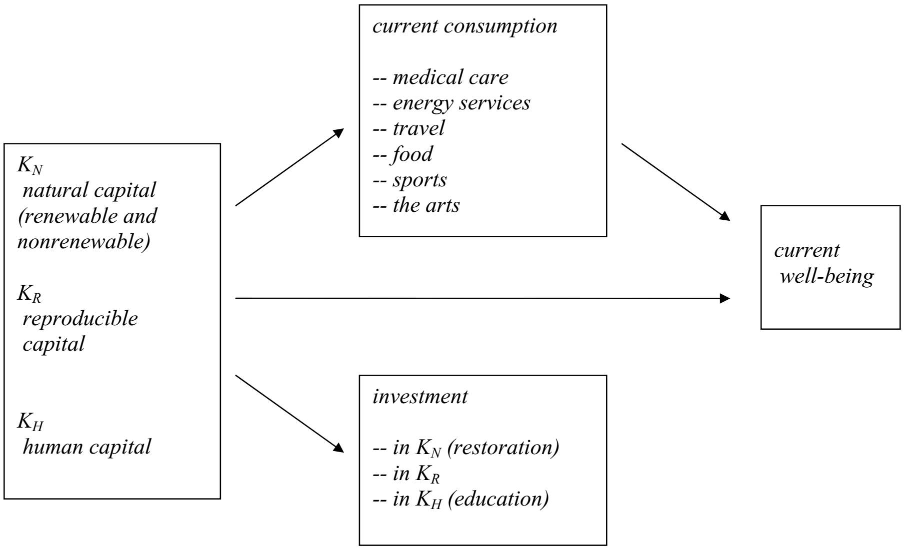

Figure 1. Connections between capital stocks, consumption, and human well-being. The symbols K_N, K_R, *and* K_H *refer to natural capital, reproducible (or built) capital, and human capital, respectively.*

For nonrenewable natural capital, investment can contribute to sustainability a third way. For these resources, there can be no "production" of new stocks within the relevant time frame—only on a geological time scale are new stocks produced. Although society cannot produce new stocks of, say, petroleum, it has the potential to maintain its overall productive capacity and offset the decline in this asset by expanding the stocks of other capital assets (e.g., solar-hydrogen energy systems, or wind farms). Thus, investment in a different type of capital can potentially offset the loss of natural capital stocks.

As indicated in Fig. 1, investment in reproducible capital—producing more machines or factories—requires natural resource inputs. Hence, this investment is accompanied by the depletion of nonrenewable resources. Despite this depletion the overall productive base—the capacity for producing goods and services now and in the future—need not fall. When natural resources, labor, and other inputs are organized to produce new capital, this change in organization makes possible (but does not guarantee) greater output of useable goods and services in the present and future. We return to this issue below in connection with the issue of the scale of the economy.

How does investment relate to consumption? Capital stocks can be devoted either to producing capital goods (i.e., to investment) or to making consumption goods (Fig. 1). Consumption competes with investment. Thus, if consumption levels are especially high, the level of investment may not be sufficient to maintain the capital stocks in some aggregate sense, and the ability of a society to maintain well-being may be compromised.

Consumption can also work against sustainability by contributing to damage to capital stocks. For example, the demand for food produced in environmentally unfriendly ways damages natural capital. Certain farmers use large amounts of nitrogen-based fertilizers in growing crops. Some of the nitrogen leaches into water supplies, which threatens fish stocks and (by contaminating well water) human health.

Hence consumption can work against sustainability two ways: by competing against investment in new capital and by taking a form that contributes to damages to existing capital stocks, including human capital. The first channel pertains to the *level* of overall consumption (as opposed to the level of investment). The second focuses on the *composition* of this consumption. The two threats to sustainability are connected. If a society's pattern or composition of consumption causes great damage to existing capital stocks, then to maintain well-being considerably more investment in restoration or in alternative forms of capital is necessary to achieve sustainability. Indeed, if the current pattern or composition leads to an irreversible loss of some particularly critical form of natural capital, then sustainability cannot be achieved no matter how much effort is put into restoration or alternative investment.

The level- and composition-of-consumption issues correspond to two ways that the public sector can help promote sustainability. The first is through policies that encourage the devotion of a greater share of the current capital stock toward investment rather than consumption. The second is through policies that cause a shift in the composition of consumption—shifting consumption away from goods whose production or use leads to significant loss of natural capital and toward other goods that involve less damage to such capital.

Applying the Framework: Is Overall Consumption Excessive?

How can the framework be applied to help assess whether a nation's overall consumption violates the sustainability criterion? We contrast two main approaches. The first is a top-down, "macro" approach with broad economic variables: aggregate consumption, aggregate investment, and general categories of capital (natural, human, and reproducible). The other is a bottom-up approach involving detail about production methods, consumption patterns, and sectors of the economy. A virtue of the macro approach is its ability to yield a simple formula (indicated later) that constitutes a condition for sustainability. The bottom-up approach yields no such formula, but through simulation modeling it can project the time path of an economy (including welfare levels) and thereby indicate whether the sustainability criterion is satisfied.

Macro Assessments

THE PRODUCTIVE BASE AND SHADOW PRICES

Central to macro assessment is the productive base, an index of the society's ability to provide goods and services, including ecosystem services and environmental amenities. It measures the overall ability of K_N, K_R, and K_H to yield goods and services. In macro assessments, a nation's consumption is excessive (violates the sustainability criterion) if it fails to maintain, on a per capita basis, its productive base.

The macro approach is presented in detail in Arrow et al. (2004), the World Bank (2006), and Dasgupta (2007). We briefly present it here. Let W_t represent the productive base at time t, where W_t stands for the potential for future well-being embodied in the capital stocks available at time t. It corresponds to the value at time t of all of the marketed and nonmarketed goods and services that the current capital stocks can produce now and in the future. The productive base at time t (W_t) can be expressed as a function of the capital stocks:

$$W_t = f(K_{Nt}, K_{Rt}, K_{Ht}). \qquad (1)$$

In the macro assessments the sustainability requirement translates into the condition that W_t must not fall from one period to the next. The variable W^t, the productive base at time *t*, is equal to the integral of the discounted value of utility (momentary or annual well-being) from time *t* into the indefinite future. In the macro approaches, the sustainability requirement involves a comparison of these integrals: W_{t+1} must be at least as large as W_t, with *t* corresponding to the present time. (An alternative sustainability requirement [Pezzey 1992] is that utility not be declining.) At time *t* there will usually be disinvestment (decreases) in some forms of *K* (e.g., depletion of natural capital) and investment in other forms (e.g., augmentation of reproducible capital). To determine whether the sustainability requirement is being met at that time, we need to know how much one form of capital might substitute for another in order to maintain *W*, if substitution is possible at all.

Under the macro approach, the rates of substitution of one form for another are expressed through shadow prices. The shadow price of a given type of capital represents the overall impact on human welfare (or the productive base) of a one-unit change in the availability of that type of capital. (Shadow prices generally differ from market prices, as discussed below.) Let λ_i denote the shadow price of capital type *i* ($i = N, R, H$). The shadow prices are defined by $\lambda_i \equiv \partial W/\partial K_i$. These definitions imply

$$W = \lambda_N K_N + \lambda_R K_R + \lambda_H K_H \tag{2}$$

and

$$\Delta W = \lambda_N \Delta K_N + \lambda_R \Delta K_R + \lambda_H \Delta K_H. \tag{3}$$

The shadow prices—the relative magnitudes of the λ_is in Eq. 3—indicate how much of one type of capital is necessary to substitute for another type. For example, if λ_N is 2 and λ_R is 1, then the reduction of one unit of K_N could be offset by two (or λ_N/λ_R) units of K_R. The higher the value of λ_N, the greater the amount of other capital needed to compensate for the loss of K_N.

A common misconception is that the use of shadow prices assumes perfect substitutability among types of capital. In fact, the shadow prices allow for different degrees of substitutability. One might expect that, as natural capital becomes increasingly scarce, it will take successively larger amounts of other types of capital to substitute for each further reduction in natural capital. This means that as K_N becomes lower, the shadow price λ_N rises. Substitution becomes increasingly difficult. This idea is expressed in Fig. 2. The curves W_1, W_2, and W_3 each represent different welfare levels associated with combinations of K_N and K_R. Each curve in the figure indicates combinations of K_N and K_R that leave *W* unchanged (assuming no change in K_H); W_3 is the highest level and W_1 the lowest. For any given value of K_R, reductions in K_N imply a reduction in *W*. The negative of the slope at a given point on any of the *W* curves is the ratio λ_N/λ_R. On each curve, this slope increases (λ_N is higher) when K_N is smaller, in keeping with the idea that an increasing amount of reproducible capital is required to compensate for a given reduction in natural capital.

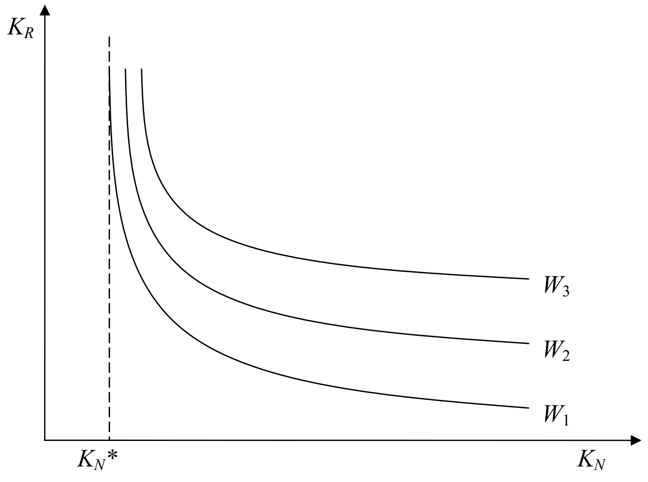

Figure 2. Levels, substitutability, and essentiality of capital (K_N*, natural capital;* K_R *, reproducible capital;* W_1*,* W_2*, and* W_3 *are different human welfare levels associated with combinations of* K_N *and* K_R*).*

SUBSTITUTABILITY VERSUS ESSENTIALITY

Researchers differ in their viewpoints as to the extent to which substitution is possible. (e.g., Costanza 1994; Daly & Cobb 1994; Pearce 1998; Hediger 2006). Regardless of the extent to which substitution is possible—and the issue is clearly controversial—it is important to recognize that substitutability and essentiality are distinct. Claiming substitutability is not the same as proposing that natural capital is nonessential. Consider a specific form of natural capital—the stock of clean (breathable) air. Air is clearly essential to human life, yet a *small* diminishment in air quality (the stock of clean air) is not necessarily life threatening. Moreover, if a small reduction in air quality were accompanied by an increase in some other form of capital (to provide more of other goods, or to offer better health care), it would be possible to claim that *W* (and the quality of life) would be maintained. Nevertheless, if the stock of natural capital were reduced substantially, we could reach the point where no amount of other capital could yield even a minimal quality of life.

These ideas are expressed in Fig. 2. Assume that W_1 is the lowest *W* consistent with life itself. Let K_N now represent a particular type of natural capital—clean air. The figure indicates that if K_N ever were to fall below K_N*, then no matter how much one "compensated" for the loss of K_N the quality of life would still be below

W_1—that is, life would not be possible. A minimal air quality is thus essential to life itself. Essentiality of a given natural resource does not rule out its substitutability. Rather, it means that substitution is not possible once the stock of that resource falls below some critical value. Analysts often overlook this crucial point.

THE SIGNIFICANCE OF SCALE

Many analysts are concerned that the ever-increasing scale of human activities—and, in particular, of natural resource use—poses a threat to sustainability. Here we indicate how the macro framework above relates to scale.

Scale can be defined in terms of inputs, outputs, or other variables. To facilitate the connection with the terminology used above, we define scale here in terms of the rate of use of natural resources. That is, the scale of the economy will be defined as the rate of depletion of natural capital, that is, as $-\Delta K_N$. Equation 3 above might seem to imply that sustainability can be achieved at any scale: no matter how great the rate of depletion, one can achieve sustainability by suitably large, offsetting increases in other forms of capital. Whatever the scale turns out to be, sustainability is achieved if $-\lambda_N \Delta K_N$ is matched by the sum of $\lambda_R \ \Delta K_R$ and $\lambda_H \ \Delta K_H$.

Nevertheless, scale remains important. Although Eq. 3 specifies the condition for sustainability, it will not always be possible for an economy to meet that condition. The reason is that scale affects shadow prices. As depletion makes natural capital more scarce, the shadow price of this capital rises. Both the higher shadow price and the reduction in natural capital contribute to an increase in the absolute value of $-\lambda_N \ \Delta \mathrm{K_N}$. As the magnitude of $-\lambda_N \ \Delta \mathrm{K_N}$ increases, ever-larger increases in other forms of capital are needed to offset natural resource depletion. But it can become increasingly difficult to achieve this offset. Here the fact that natural capital is needed to produce new capital goods is highly relevant. The needed additional capital—especially reproducible capital—puts demands on natural resources and on the other inputs needed for producing such capital. This increases the rate of depletion, which in turn means that even more reproducible capital is needed to achieve sustainability.

At a sufficiently high scale or rate of natural resource depletion, sustainability will not be possible. The cycle becomes vicious: greater investment in other forms of capital ends up widening the gap between $-\lambda_N \ \Delta K_N$ and $\lambda_R \ \Delta K_R + \lambda_H \ \Delta K_H$. This is not a problem at low rates of depletion because at low rates the productivity of other forms of capital, as well as substitution possibilities and technological progress, allow for a full offset. But at sufficiently large scales (if they persist) sustainability becomes impossible. Substitution and technological progress (and associated increases in productivity) cannot keep pace with the rising shadow price. Consider, for example, the impossibility of substitution and technological progress to offset the social cost of depleted water resources, if water resource stocks were to become exceptionally low.

At what scale will this occur? This is an empirical matter. Some argue that many, if not most, societies have already exceeded the critical level of scale beyond which sustainability becomes impossible. Analytical growth models indicate that the greater the potential for substitution and the greater the rate of technological progress, the greater will be the ability of the economy to achieve higher scale without losing the potential for sustainability.

Huge uncertainties surround values for shadow prices, changes in capital stocks, substitution possibilities, and future rates of technological progress. Society can reduce the risk of losing the potential for sustainability by promoting policies that provide increased incentives toward invention and technological progress and that slow the rate of natural resource depletion. The latter policies could include tax policies that raise natural resource prices to their full social cost or that shift the composition of consumption toward goods and services that involve fewer natural resource inputs. They could also include policies to reduce population growth rates.

Thus, achieving sustainability is more than a matter of investing in human capital and reproducible capital. It requires avoiding a scale that (if prolonged) would so seriously deplete natural resource stocks as to make sustainability impossible.

FINDINGS FOR THE UNITED STATES

A number of studies have used the macro framework in an effort to determine whether various nations are meeting the sustainability requirement. These studies consider the changes in each of the various capital stocks over a recent time period and assign shadow prices to determine the values of the changes with a formula like Eq. 3. In *Where Is the Wealth of Nations?* the World Bank (2006) applies this framework and arrives at the conclusion that the United States has been meeting the sustainability criterion defined here. Arrow et al. (2004) also tentatively reach this conclusion (while indicating the uncertainties related to the assessment). In both of these studies investments in reproducible and human capital are estimated to be more than enough to compensate for the loss of natural capital. Table 1 summarizes the World Bank's finding for the United States.

The macro studies have made important contributions to assessments of economic performance by expanding and improving our measures of wealth and income, and by revealing significant weaknesses in conventional (narrower) performance measures such as national saving

Table 1. Summary of the World Bank's estimates (World Bank 2006) of change in U.S. productive base (values are for the year 2000).*

1. Net national saving (ΔK_R)	*2. Education expenditure (proxy for ΔK_H)*	*Natural resource depletion (ΔK_N)*					*8. Genuine saving (ΔW) (row 1 + row 2 - sum of rows 3 through 7)*	*9. Genuine saving as percentage of genuine wealth*	*10. Population growth rate (%/year)*	*11. Percent change in per capita genuine wealth*
		3. Energy depletion	*4. Mineral depletion*	*5. Net forest depletion*	*6. PM_{10} damage*	*7. CO_2 damage*				
5.7	4.2	1.2	0.0	0.0	0.3	0.3	8.2	1.5	1.1	0.4

**Adapted from appendixes 2–4 of* Where Is the Wealth of Nations? *(World Bank 2006). Figures in columns numbered 1-8 are percentages of U.S. gross national income. Net national saving is the annual change in reproducible capital (K_R) net of annual depreciation of that capital. PM_{10} (column 6) refers to particulate matter ≤ 10 μ. Column 8, labeled genuine saving, is the estimated change in the productive base.*

or gross domestic product (GDP). Correspondingly, they indicate that "economic growth," as conventionally defined, is a poor indicator of improvements in well-being, a point emphasized, for example, by Czech (2006) and Frank (1985).

But current macro studies also have significant limitations. First, many important forms of natural capital—such as terrestrial and marine biodiversity, water resources, natural detoxification capacity, and agricultural soils—are not captured. Second, the studies do not account for important environmental damages: the only air pollutants considered are particulate matter (PM_{10}) and carbon dioxide, and water pollution is neglected entirely. Third, the studies do not account for welfare impacts associated with losses of biodiversity and associated ecosystem goods and services. Fourth, the studies have not closely examined the extent to which the potential ability of the United States to meet the sustainability requirement is due to favorable international trade terms. As indicated by Dasgupta (1990) and others, many of the poorest nations of the world are unable to enforce property rights on natural resources (such as forest area). As a result, they export resource-based products at bargain prices. This tends to improve the sustainability picture as measured for the United States, although it comes at the expense of the exporting nations' sustainability. This brings up a very serious equity issue in the *distribution* of consumption, which we do not have the space to discuss here.

Difficulties also surround the application of shadow prices. Because of limited information, the researchers often use actual market prices as proxies for shadow prices. Theory indicates that in an economy with perfectly competitive markets, no externalities, and perfect information, the market prices will be the same as the shadow prices. Obviously, real economies do not meet these conditions, so the two prices generally differ. The loss of natural resource stocks often generates negative externalities, implying that the true cost to society from the loss of such capital exceeds the market price of the extracted resource. For example, when an area of forest is cut down to allow for urban development, the gross cost to society (ignoring any offset from development-related investment) generally exceeds the market price of the forestland or the timber on it because the full cost includes the lost external benefits from forests (e.g., lost ecosystem services such as carbon storage, water purification, and provision of habitat). For natural capital true shadow prices generally exceed market prices. Thus, setting shadow prices equal to market prices generally leads to an understatement of the true social costs associated with the loss of natural capital.

Uncertainty also makes the use of market prices problematic. In theory the shadow prices should represent the present value of all the goods and services made possible by an increase in a given stock of capital.

Equivalently, it is the present value of the cost implied by a decrease in that capital stock. These costs are highly uncertain. Although a central estimate or "best guess" might be that a unit reduction in a given form of natural capital would not imply huge costs, it is possible that a given decline in natural capital could cause the stock to cross an important threshold, leading to sharp discontinuities in welfare outcomes. Such a threshold event would occur, for example, if depleting the capacity of the atmosphere to safely absorb greenhouse gases resulted in a sudden shift in the thermohaline circulation or rapid slippage of the West Antarctic Ice Sheet. Large downside risks of this type justify higher shadow values for natural capital than those typically used in macro studies. For all of these reasons, we conclude that the results from the macro studies should be regarded as suggestive rather than as conclusive.

Bottom-Up (Computer Simulation) Studies

MAIN ELEMENTS

The other main approach to assessing sustainability employs large computer simulation models. These models use detailed information about production possibilities in each of various sectors of an economy (e.g., transportation, energy, manufacturing, services). The "production functions" containing this information indicate the potential for substituting various types of capital for one another within each sector. The models also contain details on household demand patterns—in particular, the extent to which households are likely to substitute some consumption goods or services for other ones when prices change. In the models, economic growth depends on the time profiles of capital stocks, which depend on resource extraction rates and investments in human and reproducible capital. In most of these models, labor input is assumed to be proportional to population size; thus, the rate of population growth is an important determinant of economic output.

By linking the information on population growth, production opportunities, and consumption possibilities, the models yield time paths of resource use, income, consumption, and investment. They generate predictions of changes in overall consumption and well-being, from which one can observe whether the nation or region is on a sustainable path. A major attraction of the simulation approach is it does not require the imposition of (highly uncertain) shadow prices. Instead of being determined by exogenously imposed shadow prices, the substitution possibilities are an emergent property of the simulation models, reflecting the diverse production and consumption possibilities in the various sectors of the models and the interactions across sectors. Although the macro approach uses a formula like Eq. 2 to arrive at the indicator of sustainability (e.g., last column of Table 1), the simulation approach yields time-profiles of consumption. By observing whether the projected level of overall consumption is being maintained through time, one can assess whether the sustainability condition is satisfied.

FINDINGS

Although the computer simulation approach has great potential, to date relatively little of this potential has been realized. At present nearly all of these models have a global focus rather than a focus on a particular nation or region. Examples of global long-run growth models are the World 3 Model (Meadows 2004), the International Futures Model (Hughes 1999), and the FUGI Global Model (Onishi 2005). Each of these models incorporates assumptions about initial resource stocks, population growth, opportunities for substitution, and technological progress. Results vary. The World 3 Model is relatively pessimistic, suggesting economic growth over the next several decades followed by a decline in output and incomes (by over 40% from their peak values) as a result of limits in available land, natural resource inputs, and environmental quality. The FUGI model yields somewhat more optimistic outcomes, largely because it includes greater opportunities for substitution.

The few models that provide detail for the United States tend to concentrate on one or two important natural resources rather than embrace a wide range. For example, many computer models have been developed to consider groundwater supplies in the United States. These models have a spatial as well as intertemporal dimension, and they contain great detail on hydrogeological conditions. They have been used to predict future water levels in underground aquifers and associated impacts on the water table. In particular, a model developed by the U.S. Geological Survey (Barlow 2006) indicates that the Ogallala Aquifer under the high plains of the United States is being pumped at a rate eight times higher than its rate of recharge. This is important information—but it relates to only one of several important forms of natural capital.

Another limitation is that the models tend to emphasize only the biophysical outcomes rather than offer explicit measures of human-welfare impacts. Thus, although the existing models can help reveal how resource availability or environmental quality might change in the future (absent some major policy changes), they give no direct indication of whether human welfare might nevertheless be maintained through investments in other forms of capital or other types of substitution. Thus, although the detailed computer models offer considerable promise, we still lack models sufficiently comprehensive to suggest whether overall U.S. consumption exceeds a level consistent with sustaining well-being.

Is the Composition of Consumption a Problem?

Although considerable uncertainty surrounds the question of whether the level of overall consumption in the United States is excessive, one may draw fairly strong and unambiguous conclusions about the composition of U.S. consumption. In some sectors consumption produces significant social costs—notably, environmental damages—that are not captured in market prices. As a result, the composition of U.S. consumption is biased against natural capital and environmental quality in the following sense: current and future well-being would be enhanced if consumption were redirected away from these underpriced goods and services.

As indicated above, the full social cost of a given good includes both the private cost (the cost borne by producers) and the external cost. When the price of a consumer good falls short of social cost, at the margin (i.e., for the last unit produced or consumed) the cost to society of producing and using that last unit exceeds the benefits to people of consuming that last unit. If there were less consumption of that good, society would enjoy greater net benefits because resources would be freed up for more productive uses.

The prices of goods and services are significantly below social cost in at least three major sectors of the United States: agriculture, electricity, and transportation. In these sectors, the prices fail to account for major environmental externalities associated with production and consumption. Here we simply outline the issues. In the agriculture sector the failure to address important externalities, along with direct subsidies to various inputs and outputs, have significantly distorted the patterns of food production and consumption. The externalities include off-site damages to biota resulting from the leaching of nitrogen from fertilizers, salinization of groundwater, and land subsidence due to overuse of groundwater. Subsidies to water and other agricultural inputs cause prices to depart even further from social cost.

The electricity sector also generates distorted consumption decisions. Here external costs and inefficient pricing rules are responsible. The production of electricity leads to significant releases of pollutants of carbon monoxide, carbon dioxide, sulfur dioxide, and nitrogen oxides. Existing regulations on emissions from electric power plants have helped move electricity prices toward the full social cost, but prices still remain below social cost.

In the transportation sector gasoline prices do not fully account for the various externalities associated with gasoline use. These externalities include respiratory problems from tailpipe releases of carbon monoxide, nitrogen oxides, and various particulates and climate-change damage stemming from tailpipe emissions of carbon dioxide. Gasoline prices below social cost contribute to excessive reliance on gasoline and hamper the ability of more fuel-efficient cars (such as hybrids) to penetrate the marketplace.

In sum, below-social-cost prices of food, electricity, and gasoline generate a bias toward excessive consumption of these items and excessive environmental damage. The departures from social-cost pricing distort both production methods and consumption choices.

Public policies that move prices closer to the full social cost would reduce the amount of depletion of natural capital at no net cost to society. Indeed, social benefits would exceed the social costs. In addition, by slowing the rate of natural resource depletion, such policies would reduce the amount of investment in reproducible and human capital necessary to offset the natural resource depletion that still occurs. Thus, dealing with the composition problem reduces the cost of dealing with the level-of-consumption problem, that is, the cost of achieving sustainability.

Conclusions and Broader Perspectives

We examined when consumption is a problem, either in terms of its level or its composition. The level is deemed excessive if it violates the sustainability requirement, that is, if it is not consistent with maintaining well-being over generations. This occurs when consumption prevents society from maintaining its productive base, either by directly harming natural capital or by crowding out investments in reproducible and human capital that could offset declines in natural capital.

Two main approaches—top-down macro studies and more detailed computer simulation models—can measure whether overall consumption in the United States satisfies this requirement. These approaches have shed important light on the issue, but to date their results are far from conclusive. In the macro studies findings based on central estimates or "best-guess" values for parameters suggest that the United States might in fact be meeting the sustainability requirement. Nevertheless, these studies disregard important forms of natural capital and sources of pollution; depend critically on highly uncertain parameters (shadow prices) to determine the degree of substitutability between forms of capital; are highly aggregated and thus can ignore important bottlenecks; and fail to deal explicitly with uncertainties and related downside risks. As a result, they seem biased toward optimism.

The detailed computer simulation models offer an alternative approach to the level-of-consumption issue. Although they show much promise, the current crop of such models tends to concentrate on particular sectors or natural resources and thus cannot offer conclusions of broader scope. In addition, the models tend to focus on biophysical outcomes rather than impacts on consumption and well-being. Hence they do not yield conclusions regarding the sustainability of human welfare.

Both the macro and the computer models make assumptions about substitution possibilities: the macro models through shadow prices, the computer models at a more disaggregated level through specified production functions. The empirical basis for the specifications regarding substitution is often minimal or nonexistent. Future collaborative work involving conservation biologists and economists might help narrow the empirical gap.

Given the limitations of existing studies, one cannot draw definite conclusions regarding the level-of-consumption issue beyond articulating potential biases in current studies and, importantly, recommending precaution.

In contrast, one can reach definite conclusions regarding the composition issue—conclusions with strong implications for public policy. In several major sectors of the U.S. economy—agriculture, electricity generation, and transportation—inefficient price signals lead to distortions in production and in consumption patterns, in the sense that a redirection of consumption would improve human welfare.

Public policy has a major role to play in dealing with current biases in consumption. The removal of subsidies would deal with part of the problem. In addition, a range of policy instruments can be invoked to deal with externalities. Emissions taxes and tradable emissions allowances can help prices better approximate social cost. Alternatively, the public sector could invoke other instruments—including efficiency standards and tax credits for cleaner production—to address externalities. Of course, removing subsidies or introducing environmental regulations often imposes costs on powerful stakeholders, such as energy-supplying industries. A major challenge is to overcome the potential political opposition to such policies. Offering compensation to parties that would face unusually large costs could help overcome political constraints.

Finally, our framework involves a fairly simple treatment of well-being, implicitly regarding well-being as a monotonically increasing function of overall consumption. An expanding literature suggests a more complex relationship. In particular, work by Easterlin (2001), Czech (2006), and others suggests that reported happiness does not increase with income (or overall consumption) once income exceeds some minimal level. This finding and ethical considerations support the idea that sustainability initiatives should be focused especially on helping poorer nations achieve a higher level of income and consumption, rather than on maintaining or increasing the levels of overall consumption in rich nations. In addition, there is increasing evidence that an individual's reported well-being depends importantly on his or her consumption *relative to* others' consumption (e.g., Frank [1985]; Howarth [1996]; and Schor [1998]). A more comprehensive assessment of well-being would examine not only how average consumption changes over generations (the focus of sustainability) but also how consumption (or income) is distributed across individuals within a given generation.

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