Macroeconomics and the Environment

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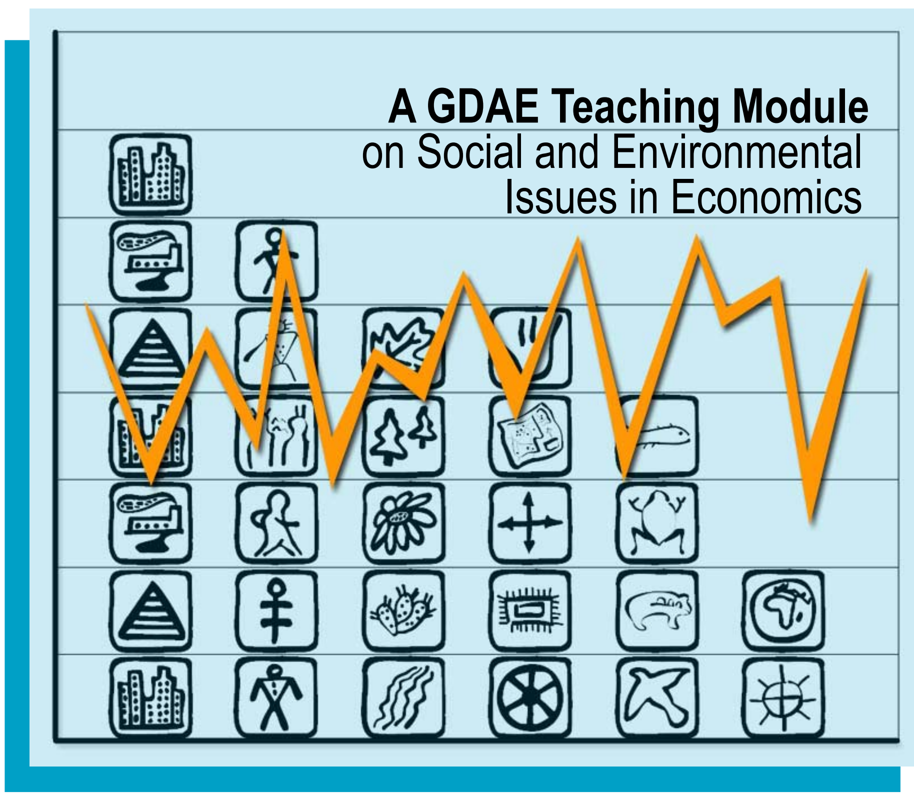

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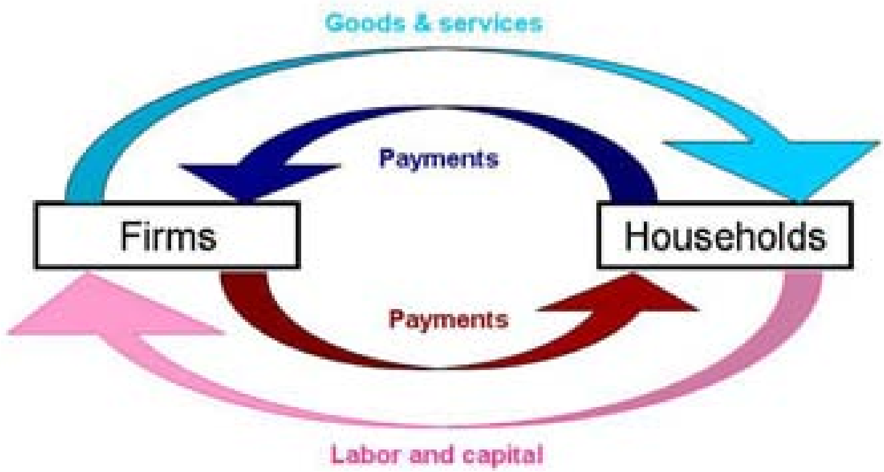
1. THE CIRCULAR FLOW MODEL AND THE BIOSPHERE

The Economic System and the Environment

A basic building block of economic theory is the standard "circular flow" model of an economic system. As illustrated in Figure 1, this model shows the exchange of goods, services, and factors of production between two types of economic actors, consumers (households) and producers (firms). However, the environment and the natural resources which make economic production possible do not appear in the usual version of this model.

Figure 1. The Standard Circular Flow Model



When a good or service is purchased, two kinds of flow occur: the good moves from the firm to the household and a corresponding payment moves from the household to the firm. Similarly, when firms purchase factors of production, a payment of money for the use of these factors accompanies the flow of factor services from households to firms. These transactions are symbolized on the graph above by the arrows going in both directions – from firms to households and vice versa. We distinguish between the two kinds of flows, real economic flows and the monetary flows which are their counterpart. The former are called "real" as they correspond to transfers of tangible things: goods and services flowing from firms to households; factors of production flowing from households to firms.

Can we locate the environment or natural resources in this picture? Certainly natural resources are essential to production: agriculture requires productive soils, industry requires fuels, water, and minerals. Consumers need drinking water, and many environmental resources, such as beaches and woodland, are in high demand. How is all this reflected in the circular flow?

Factors of production, which are also called inputs for the production process, have traditionally been divided into three categories: **land**, **labor**, and **capital**.

"Land" is the term which is used by economists to represent all natural resources used in economic production, including soils, water, forests, species, minerals, fossil fuels, and other such resources. The first thinkers who studied economic mechanisms during the eighteenth and nineteenth centuries recognized the importance of land in the production process, and emphasized the existence of natural constraints on economic growth. These theorists included the Physiocrats such as Quesnay, who developed the first circular flow approach in 1758, and the Classical Economists of the late eighteenth and nineteenth centuries, including Adam Smith and David Ricardo.

Later, in the second half of the 19th century, economists focused increasingly on the two other factors of production, capital and labor, which were essential in the growth of the industrial sector, as rapid industrialization became the major economic phenomenon of these times. The eclipse of natural resources in economic thought lasted more than a century. Only recently, with the increasing urgency of environmental and resource problems at local, national, and global levels, have economists once again focused on the issues of natural resource constraints and the issue of what has come to be called **natural capital**. Natural capital includes all natural resources as well as the environment. It is essentially an updated interpretation of the classical economic concept of "land".

Using the term "natural capital" emphasizes the importance of these natural factors to the production process. It also indicates that what we ordinarily call "capital" is really **manufactured capital**. Both types of capital are essential to the productive process, and both contribute to society's wealth.

Linking the Economic Sphere and the Biosphere

Returning to the circular flow model from Figure 1, let's consider whether the simple diagram deals adequately with natural capital. Economic models of the circular flow are usually presented as totally self-contained. But who or what ultimately provides households with the factors of production which will become inputs for the production sphere?

It is fairly clear that labor and manufactured capital are regenerated through the circular flow model in Figure 1 -- the provision of food and other necessities makes more labor possible, and investment builds up manufactured capital over time. But what about the first factor of production, natural resources?

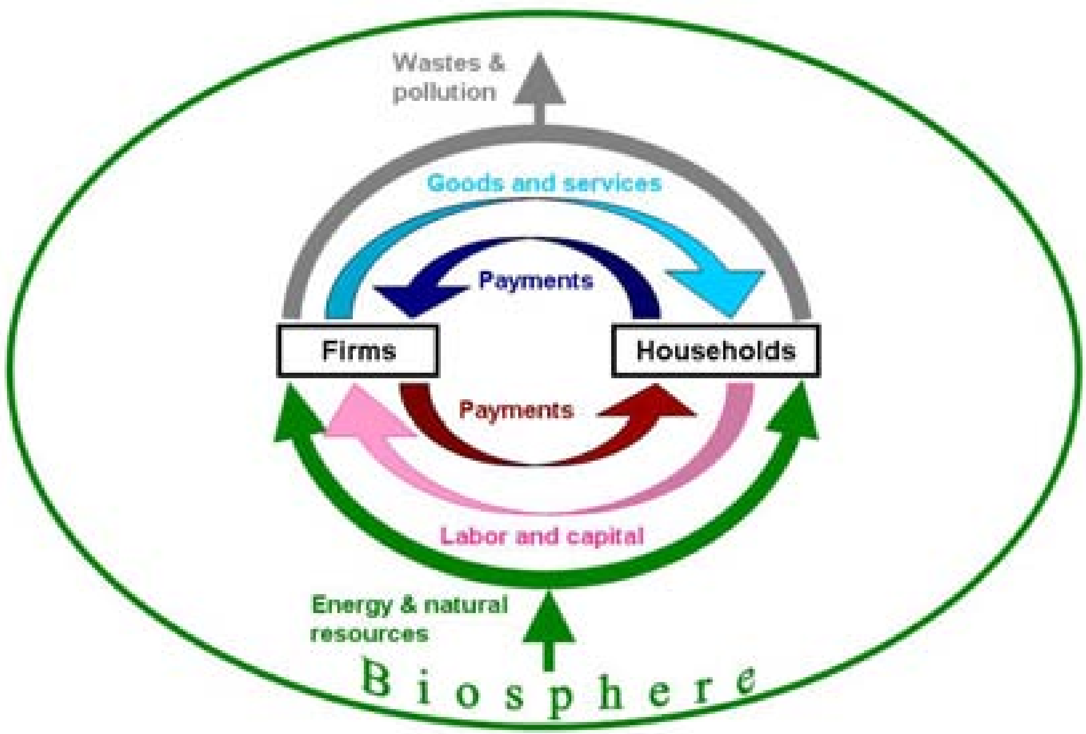
NOTE – terms denoted in **bold face** are defined in the **KEY TERMS AND CONCEPTS** section at the end of the module.

Obviously, households and firms do not "create" energy, minerals, soils, water, forests, species, and all the diverse elements which form the broad category of natural capital. They may "own" them - if the legal system adequately defines private property rights to these different resources -- but they cannot generate them, or replace them if they are used up. The "hidden" provider of these amenities, whether you call it Nature, Planet Earth or the **biosphere**, needs to be reintroduced in the picture as a major actor -- or perhaps better as the stage -- without whom the whole economic "show" could not take place.

How can we introduce the biosphere into the circular flow? We need to show the complete picture of its relationship with economic activity: as a provider of natural resources and also as the receptor of various undesirable outputs of the production/consumption processes (pollution and wastes).

Since the sphere of economic activity (we will call it the "economic sphere") is embedded in the biosphere, we can replace the previous graph by a more complete one that represents the diverse flows of inputs and outputs between the biosphere and the economic sphere as well as inside the economic sphere. This is shown in Figure 2 below.

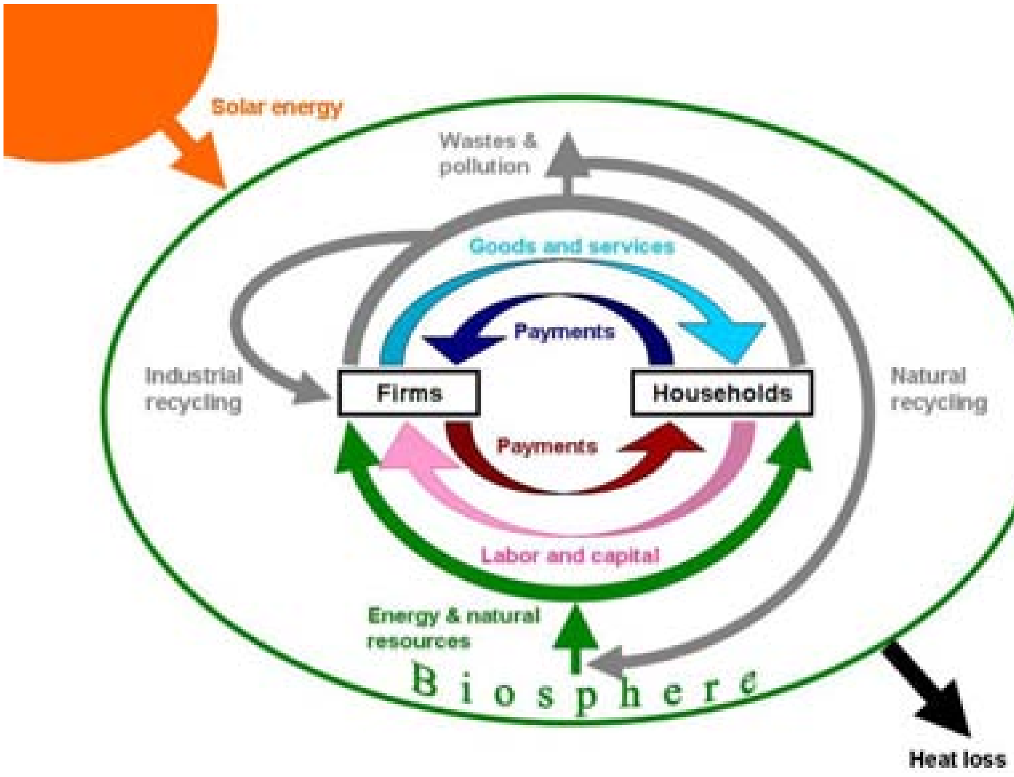
Figure 2. The Circular Flow Linked to the Biosphere



We must also take into account the fact that some of the wastes and pollution rejected in the biosphere are naturally recycled through biological processes and geophysical processes. For instance, wetlands play an essential role in purifying polluted waters. A few of the wastes of the production process are also recycled through the industrial system itself (including some paper, glass, and metals) and reinjected again into the production process as raw material.

In addition, the earth itself is not a closed system and exchanges flows of energy with outer space - the energy flows it receives from the sun and the flows it releases in space (heat loss). If we include these additional flows, we obtain a more detailed version of the circular flow – presented in Figure 3.

Figure 3. Circular Flows with Energy and Recycling



What does this new and expanded picture of the circular flow imply for economic theory? There are at least two major implications:

1. The recognition that natural processes provide an essential support to human well-being that needs to be adequately taken into account in all attempts at measuring well-being.
2. The recognition that this support is finite and that there are limitations both in terms of the inputs which can be extracted from the biosphere and the waste outputs which can be put back into it.

This means that we have to do some rethinking of standard economic concepts such as gross national product and economic growth. If we take the full circular flow into account, we will need to revise the standard ways of measuring economic wealth and income, and also to reconsider the effects of continual economic growth on human well-being.

2. REDEFINING NATIONAL INCOME AND WEALTH

Limitations of GNP/GDP

Economists measure the economic output of a society using indicators such as **gross national product (GNP)** or **gross domestic product (GDP)**[1]. While it is widely recognized that such measures do not quantify human well-being, both economists and policy makers often assume that an increase in GDP corresponds to an increase in welfare. But an understanding of what GDP includes, and excludes, suggests that the relationship between economic production and welfare is more complex. We now turn to a discussion of the limitations of GDP.

GDP is not a good measure of human well-being.

Human well-being depends on consumption of goods and services, but on many other factors as well. We can distinguish between two broad categories of human activities: those which are "rewarded" by a payment - a monetary flow- and those which aren't. Only the first type are taken into account in the computing national income. All the others -- including domestic and family tasks, taking care of children and elderly relatives, volunteer community work, and leisure time activities such as reading, cooking, playing music, going to the beach -- are not included in standard economic indicators We can revise our circular flow diagram to show that the sphere of human activities, while included within the biosphere, is broader than the purely monetary activities which are measured as GDP.

Figure 4 shows the division inside the sphere of human activities between the monetary portion of activities and the non-monetary part. The gross domestic product measures only the first area and neglects the second. However, when measuring human well-being or welfare, it is necessary to take into account the entire scope of the human sphere.

The first attempt to take into account some of these non-monetary activities in the measure of economic welfare was done by Nordhaus and Tobin in 1972. They calculated a

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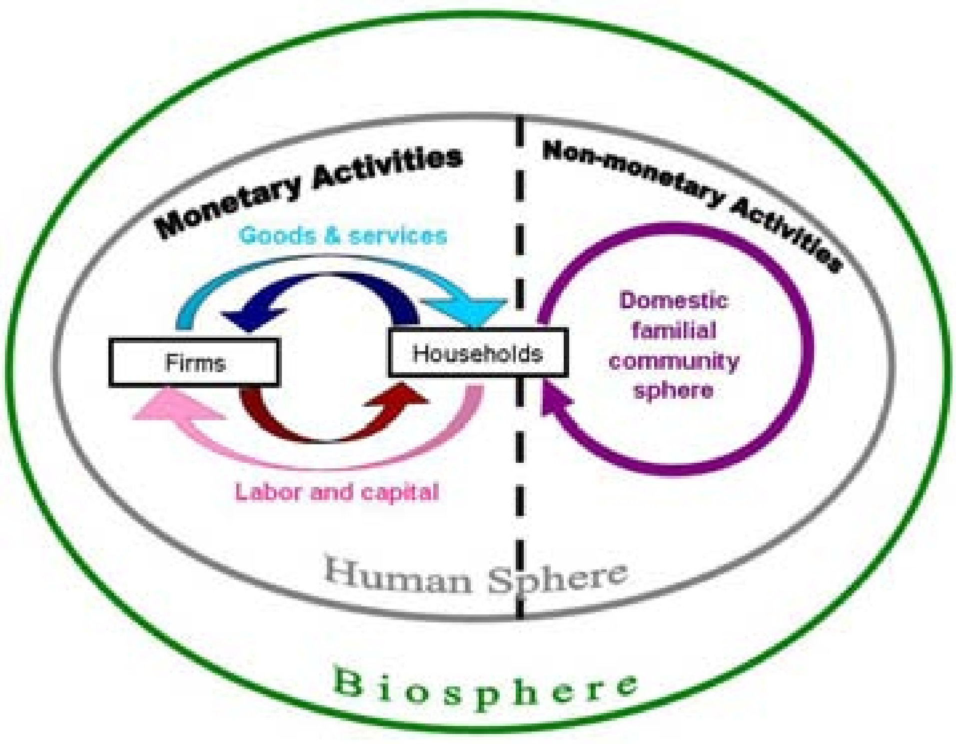
[1] The difference between GNP and GDP is whether or not the foreign earnings of individuals and corporations are included in the total. U.S. GNP, for example, includes the foreign earnings of U.S. residents and corporations, but excludes the earnings of foreign individuals and corporations from activities in the U.S. U.S. GDP includes all income earned within the U.S., regardless of the nationality of the resident, but excludes earnings of U.S. residents and corporations from foreign sources. GDP replaced GNP as the primary measure of U.S. productivity in 1991.

value for such factors as unpaid household labor and "urban disamenities" (such as congestion and pollution). Using these values to modify the standard GNP measure, they constructed a "Measure of Economic Welfare" (MEW). However, their effort has not been systematically followed up. Most economic analysis generally uses GDP as a measure of economic success, and -- by default -- as a measure of welfare.

Figure 4: Monetary and Non-Monetary Activities



GDP includes monetary flows which correspond to a decrease in well-being

When there is a car accident, all kinds of activities involving monetary flows result: mechanical services to repair the cars, medical services if passengers are injured, insurance services to assess the costs, and possibly legal services if parties to the accident hire lawyers to sue other parties. All these flows enter positively into the calculation of GDP -- so the car accident causes an overall increase in GDP. But we certainly cannot say it has contributed to human well-being!

The car accident is destructive for human beings - potentially leading to permanent damage or even death - as well as destructive of durable goods (the cars). It has obviously reduced the human well-being of the victims of the accident. The services involved to deal with the consequences of the accident may at most "repair" the cars and the people to try to get back to the state of things before the accident (healthy people and functioning car).

Overall this action of putting things back in their previous state does not create well-being but at best prevents a net loss of well-being. And these "repairing" activities all have a cost in terms of the amount of time and effort required and equipment used. In a proper measure of well-being, the costs associated with a car accident should not be considered as "pluses". Possibly they should be seen as "minuses" which reduce well-being. At the least, they should be excluded from a measure of economic activities contributing to well-being.

How can economists deal with monetary flows which not only do not increase well-being but may even decrease it? One approach is to measure **defensive expenditures** made to eliminate, mitigate or avoid damages caused by other economic activity. These defensive expenditures can then be deducted from a standard measure of GDP or GNP. A calculation of such defensive expenditures for the Federal Republic of Germany as a percent of German GNP is shown in Table 1 and represents more than 10% of total GNP.

Table 1. Defensive Expenditures in Germany, 1985

Defensive Expenditure Category	Percent of GNP
Environmental Protection Services of Industry and Government	1.33
Environmental Damages	0.80
Cost of Road Accidents	1.1
Costs of Extended Travel Routes	2.2
Higher Housing Costs Due to Urban Agglomeration	0.75
Costs of Personal Security	1.26
Defensive Health Care Costs	2.6
TOTAL	**10.24**

Source: Leipert, 1989:41.

GDP neglects the depreciation of natural capital

GDP can be measured as the sum of the domestic **value added** in all sectors of the economy. But economic production also involves some loss of value: machines, equipment and infrastructure wear out over time, requiring repair and eventual replacement. This process of wearing out, repairing, and replacing capital is taken into account by measuring the **depreciation** of manufactured capital. If we subtract an estimate of manufactured capital depreciation from gross domestic product, we obtain **net domestic product** (NDP):

NDP = GDP – depreciation of manufactured capital

NDP is generally considered to be a better measure of true income than GDP. If, for example, we had high short-term consumption but allowed all our capital stock to wear out without replacement, measured GDP would give an erroneously positive impression of how well we were doing economically. NDP would be a better measure since it would show the negative effects of the loss of productive capital.

But this method of measuring and accounting for capital depreciation applies only to what we have defined as manufactured capital. What about natural capital? The process of production uses up **nonrenewable natural resources** such as coal, oil, and minerals. Often **renewable natural resources** such as productive soils, forests, and fisheries are also depleted or damaged through over-use. And the wastes emitted from the production process also pollute air, water, and land, and damage ecosystems. All of this can be defined as depreciation of natural capital. Despite the obvious importance of this kind of depreciation, it is not accounted for at all in standard measures of NDP or net investment. Only the depreciation of human-made capital such as buildings and machinery is counted.

To give a more accurate picture of depreciation losses in an economy, we clearly need to measure and subtract the losses from resource depletion, soil erosion, air and water pollution, and other environmental impacts. Sometimes this is difficult, both because good records of the stocks and flows of natural resources are often unavailable, and also because it can be difficult to put a dollar value on something like soil erosion. But some efforts have been made to tackle the problem, and this has given rise to several efforts to revise, improve, or replace the standard GDP measure.

Alternatives to GDP

Adjusting GDP for natural resource depletion

In many developing countries, economic growth is strongly dependent on the exploitation of natural resources. When raw materials and forest, fishery, or agricultural products are sold domestically or on international markets, these natural resources are transformed into monetary flows which contribute a significant portion of the gross domestic product of these countries. However, this kind of growth depends upon the depletion of natural capital.

As mentioned above, net domestic product is obtained by subtracting the depreciation of manufactured capital from GDP. Further adjusting GDP to account for the depreciation of natural capital yields **environmentally-adjusted net domestic product** (EDP):

EDP = GDP – depreciation of manufactured capital – depreciation of natural capital

Note that calculation of EDP requires a monetary estimate for the depreciation of natural capital. While data on NDP are readily available for most nations, estimates of EDP are available for only a few countries. In studies of a number of developing countries, researchers at the World Resources Institute calculated the loss of natural capital for three types of resources such as forests, soil and petroleum. They found that in the case of Indonesia, during the period from 1971 through 1984, these three forms of resource depletion subtracted an average of 9% from the official GDP each year. A study of EDP in Korea from 1985-1992 indicated that subtracting out environmental degradation due to air and water pollution lowered GDP by an average of 3%.[2]

Another approach to broadening national accounting considers how much a nation is saving for the future. National net savings rates are widely calculated as the total domestic saving less the depreciation of produced capital. The World Bank's **genuine saving** measure (S*) adds a social and environmental element to national saving rates. A nation's genuine saving rate is calculated as:

S* = gross domestic saving – produced capital depreciation + education expenditures – depletion of natural resources – pollution damage

A higher value of S*, measured as a percentage of GDP, indicates that a nation is saving more for the future. Notice that the genuine saving rate may be negative if rates of produced capital depreciation of depletion of natural resources are high. In other words, a nation's net positive investments in produced capital can be more than offset by the depletion of its natural capital.

The World Bank has estimated genuine saving rates for many countries by quantifying, in dollars, the effects of energy, mineral, and forest depletion as well as the damage from carbon dioxide. As seen in Table 2, genuine saving rates vary across regions. Genuine saving rates are lowest in the poor nations, primarily a result of the depletion of energy resources. Several nations in Africa and the Middle East have negative genuine saving rates. For example, the depletion of energy resources in Saudi Arabia is estimated to be 44% of GDP, leading to a genuine saving rate of -14%.

[2] United Nations, 2000.

Table 2. Genuine Saving Rates as a Percentage of GDP, 1997

Region	Gross Domestic Saving	Depreciation of Produced Capital	Education Expenditure	Natural Resource Depletion & CO_2 Damage	Genuine Saving
Low-income nations	17.0	8.0	3.4	7.8	4.8
Middle-income nations	26.2	9.2	3.5	5.6	15.0
High-income nations	21.4	12.4	5.3	0.8	13.5
East Asia & Pacific	38.3	6.9	2.1	3.8	29.7
Europe & Central Asia	21.4	13.7	4.2	6.6	5.6
Sub-Saharan Africa	16.8	9.1	4.5	8.7	3.4
Middle East & North Africa	24.1	8.8	5.2	20.7	-0.3
World	22.2	11.7	5.0	1.8	13.6

Source: Hamilton, 2000.

The importance of natural capital is also quantified in the World Bank's efforts to determine the true "wealth" of nations. Typical estimates of national wealth consider only the value of productive assets. But along with produced capital, natural capital is a critical input towards achieving the goals of a society. See Box 1 for details about the World Bank's research.

Accounting for natural capital: The satellite accounts approach

During recent years both the United Nations and the U.S. Department of Commerce have launched significant revisions of their national income accounting systems to respond to some of the criticisms of standard accounts. The proposed revisions do not alter the fundamental structure of standard GNP/GDP accounting. Rather, they provide additional or "satellite" accounts dealing with the impacts of economic activity on natural resources and the environment.

These **satellite accounts** include developed natural assets like cultivated biological resources, developed land, exploited subsoil reserves, as well as nonproduced environmental assets like uncultivated biological resources, undeveloped land, air and water, unproved subsoil assets. Satellite accounts measure list these assets in quantitative terms (tons, hectares, cubic meters, etc...) although these quantities can be converted to dollar values.

Box 1 : The World Bank's Estimates of National Wealth

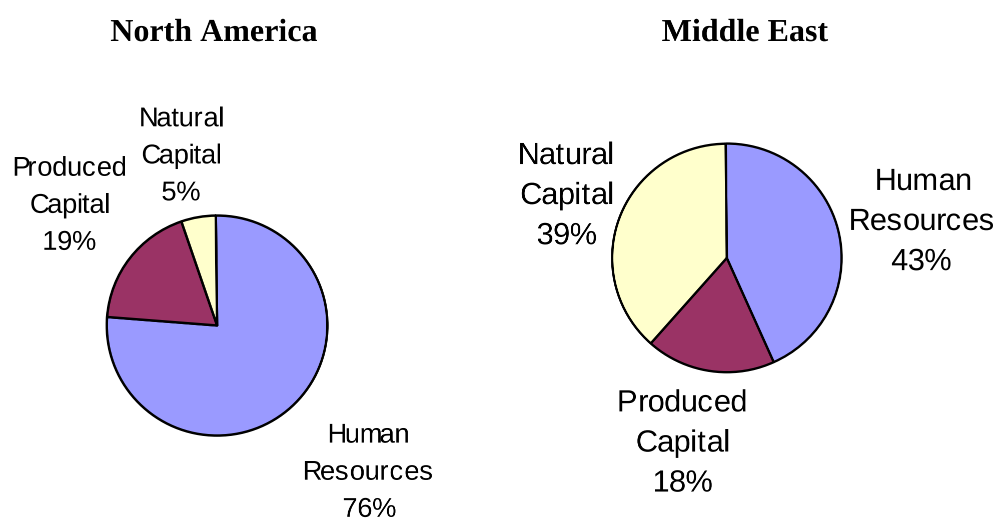
When Adam Smith wrote *The Wealth of Nations* in 1776, he was concerned about why some nations were wealthier than others in terms of physical and financial assets. Today, many economists are starting to realize that a true measure of a nation's wealth should consider other types of capital. The World Bank has expanded the measure of national wealth to include human and natural resources.

Human capital is the value of the knowledge and skills of people. Human resources are valued by the World Bank as the future potential earnings of a nation's workforce. The World Bank's research quantifies several types of natural capital: agricultural cropland, pasture land, timber, nontimber forest benefits, protected areas, and metal and mineral resources.

Expanded measures of national wealth have been estimated for about 100 nations. Across all nations, human resources are largest share of wealth – accounting for 60% or more of total wealth. For most nations, the value of produced capital exceeds the value of natural capital. As seen in the figure below, produced capital is valued about four times higher than the value of natural capital in North America.

However, in the Middle East and parts of Africa, the value of natural capital exceeds the value of produced capital. In the Middle East, as seen below, the value of natural capital is about twice the value of produced capital. The relative importance of natural capital is highest in poor nations. An important policy question is whether these nations can develop economically without depleting their stock of natural capital.

Composition of Wealth



Source: The World Bank, 1997.

Unlike attempts to quantify a "green" GDP as a single value, the satellite account approach presents a detailed picture of each of several types of natural capital. Over time, using satellite accounts one can determine whether a nation's wealth in different types of natural capital is increasing or decreasing. An advantage of satellite accounts is that the depletion of specific critical natural capital, such as safe drinking water, can be identified and tracked.

"Green National Product": The Index of Sustainable Economic Welfare and Genuine Progress Indicator

The most ambitious effort to reform the calculation of an indicator of economic welfare has resulted from the partnership between an economist, Herman Daly, and a theologian, John Cobb. Daly and Cobb named their proposed substitute for GDP the **Index of Sustainable Economic Welfare** (ISEW). They proceed in three steps:

1. They construct an indicator of aggregate welfare by taking into account the current flow of services to humanity from *all* sources (and not only the current output of marketable commodities which is relevant to economic welfare)
2. They deduct spending whose purpose is defensive or intermediate and not welfare-producing
3. They account for the creation and losses of all forms of capital by adding the creation of man-made capital and deducting the depletion of natural capital

A more recent measure, the **Genuine Progress Indicator** (GPI), is estimated similar to the ISEW but also includes factors such as the cost of underemployment, the loss of leisure time, and the loss of old-growth forests. Table 3 gives the details of the GPI for the United States in 2000. We see in Table 2 large deductions for the depletion of nonrenewable resources and long-term environmental damages, such as climate change. Note that a deduction is also made for the unequal distribution of income – the U.S. has the greatest level of income inequality of any developed nation. Unlike GDP, the GPI includes the value of some non-market activities, such as household and volunteer work.

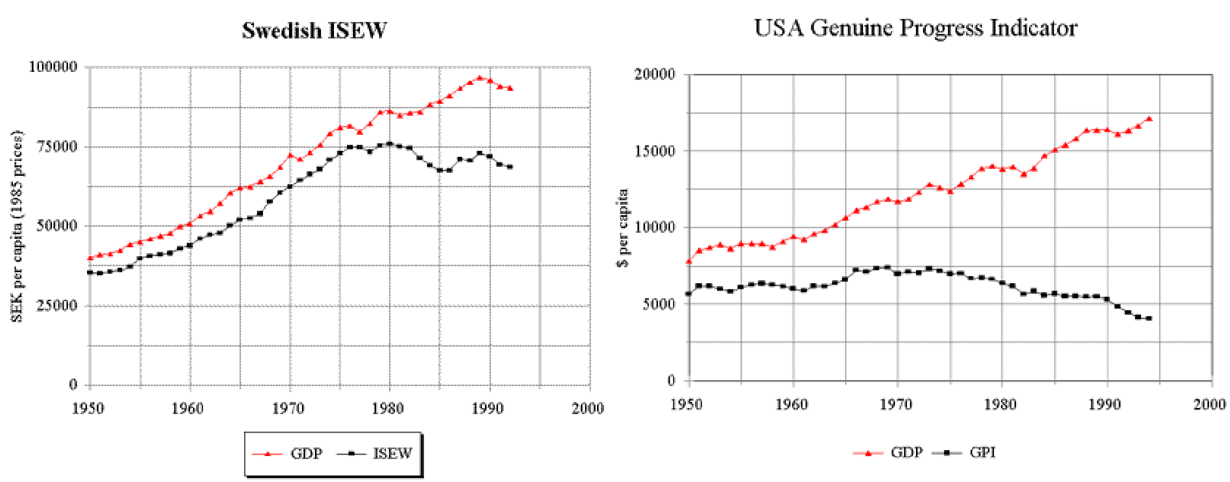
An important comparison is how the GPI relates to traditional measures of economic production over time. A divergence of the GPI and GDP would suggest that economic growth is coming at the expense of other contributors to well-being, such as environmental quality or leisure time. Nonprofit organizations have calculated ISEW or GPI for a number of countries. As seen in Figure 5 the growth in ISEW for Sweden closely parallels the growth in GDP for the period from 1950 up to about 1980. After that, GDP continued to grow while the ISEW has stagnated. The divergence between GDP and the GPI for the United States is more extreme. GDP has grown steadily in the U.S. since 1950. However, the GPI grew only slightly from 1950 to 1965, stayed relatively constant from 1965 to 1975, then fell steadily from 1975 to the early 1990s.

Table 3. The Genuine Progress Indicator for the United States in 2000

Cost/Benefit	Value (billions of 1996 dollars)
The GPI's starting point	
Personal consumption	6,258
Costs ignored by GDP that are subtracted	
Automobile accidents and commuting	-613
Crime and family breakdown	-93
Loss of leisure time and underemployment	-451
Air, water, and noise pollution	-108
Loss of wetlands and farmlands	-583
Depletion of nonrenewable resources	-1,497
Long-term environmental damage	-1,179
Other environmental costs	-417
Adjustment for unequal income distribution	-959
Net foreign lending or borrowing	-324
Cost of consumer durables	-896
Benefits ignored by GDP that are added	
Value of housework and parenting	2,079
Value of volunteer work	97
Services of consumer durables	744
Services of highways and streets	96
Net capital investment	476
Genuine Progress Indicator	2,630

Source: Cobb et al., 2001.

Figure 5. Index Measures of Welfare versus Economic Production over Time, Sweden and the United States



Source: Friends of the Earth, 2004.

If we take the GPI as a reasonable measure of human welfare, then the goal of most policy makers to increase GDP appears misplaced. An important part of economic growth may be due to an increase in defensive/preventive expenditures, as well as an increase in pressure on the environment and depletion of natural capital.

Which measures should guide policy – traditional measures of economic production or the newer measures of human welfare? Many economists feel that even if GDP does not directly measure well-being, it measures the ability of a society to obtain the materialistic inputs necessary to a high quality of life. A higher GDP per capita gives people more options to make choices that improve the quality of their lives. Others would respond that the quantity of goods and services available in an economy may be one factor in improving the quality of life, but there are many more dimensions to human well-being. Using GDP as a measure of how well we are doing reduces the quality of life to only one of its many dimensions.

Much more than measures such as GDP, measures of human welfare require subjective judgments about what to include and how to value different variables in dollar terms. Clearly, room exists for disagreement about how to construct an index measure of human welfare. Yet the information provided by these measures provides important insights that would be missed with an exclusive focus on economic production. It is widely recognized that money is only a means to an end and that, ultimately, the goal of policies should be to increase human well-being. Attempts to construct measures such as the ISEW and GPI at least provide the starting point for evaluating whether a society is headed in the right direction.

3. LONG-TERM GROWTH AND SUSTAINABLE DEVELOPMENT

Ecosystem Limits

The complete circular flow picture in Figure 3 showed us that the biosphere is a source of natural resources for the economic sphere, as well as a sink where the wastes and pollution produced by human activity are deposited[3]. All economic activities ultimately depend on the biosphere continuing to perform these functions.

As long as natural limits were not apparent, as long as nature seemed endless to humans, everything obtained from it could be taken from granted. In particular, economics, the science dealing with scarcity, was not concerned about these free gifts of nature to humankind. From the point of view of economic theory, if a good is free (i.e. has no price), there is no reason to limit consumption, whereas if it has a price consumption will be limited by income.

[3] The terms "source" and "sink" are used in theories of complex systems to indicate the places where materials and energy originate ("sources") and where they end up ("sinks"). Since 100% recyling of materials is impossible, there must always be some source and sinks in any physical system.

In the past, some civilizations have reached the limits of the ecosystems on which they relied. Ecological stresses and degradation have then appeared, preventing any further development of these societies and sometimes leading to their collapse, as discussed in Box 2.

But never before in human history have we reached the limits of the global ecosystem itself. Today, there are more and more signs that the biosphere as a whole may be affected in its regulation of biological and geophysical processes by the current scale of human activities.

The potential threat of global climate change due to accumulating atmospheric emissions of carbon dioxide and other "greenhouse" gases is one example of economic activity pressing up against global limits. Similar global problems are apparent in the degradation of ocean ecosystems, loss of species diversity, and damage to the earth's protective ozone layer. As the scope of human activity grows, its impact on the natural sphere has changed in magnitude: what used to be negligible- and was neglected as such - becomes significant and potentially threatening.

These new global ecological problems have lead to the recognition that the natural support is finite and that there are limitations both in terms of the inputs which can be extracted from it and the wastes which it can absorb.

Kenneth Boulding was the first economist to address the necessity of a shift in the way the economic system functions, from what he calls the "cowboy" economy to the "spaceship" economy. In the first case nature appears endless, and in this "frontier" environment economic growth can occur as freely, as ranching expanded across the open plains of the Western United States in the nineteenth century. However, as it becomes apparent that the natural world is not endless but limited, economic behavior must change dramatically. By the late twentieth century, Boulding suggested that the earth was best viewed as a finite spaceship – a lifeboat – in which human kind is embarked and which must be piloted in a wise and not wasteful way[4].

How close are we to the limits? One way of answering this question is based on the fact that all animal life on earth depends on green plants, which capture solar energy through photosynthesis. (Without green plants, humans and all other animals would die of starvation since animals cannot produce food directly from the physical environment).

According to one study, almost 40% of all terrestrial photosynthesis is already directly or indirectly used by human kind[5]. This means that 40% of the flow of solar energy which is received on the terrestrial part of the planet is somehow used – through the agricultural processes or the direct exploitation of natural ecosystems - for human needs.

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[4] Boulding, 1966.

[5] Vitousek et al., 1986.

Box 2: Exceeding the Limits: The Collapse of a Civilization

The first literate civilization in the world collapsed due to its failure to recognize ecological limits. Around 3000 B.C. the Sumerians of southern Mesopotamia, between the Tigris and Euphrates rivers, built a complex society based on irrigated agriculture, and invented wheeled vehicles, yokes, plows, and sailboats, as well as accounting and legal systems.

But their growing population placed too heavy a demand on the natural resources of the region. Deforestation and overgrazing led to heavy soil erosion. Irrigation caused the underground water table to rise, depositing salts which poisoned cropland. Eroded soils loaded the rivers with silt, leading to catastrophic flooding.

"The limited amount of land that could be irrigated, rising population, the need to feed more bureaucrats and soldiers, and the mounting competition between the city states all increased the pressure to intensify the agricultural system. The overwhelming requirement to grow more food meant that it was impossible to leave land fallow for long periods."

"Short-term demands outweighed any considerations of the need for long-term stability and the maintenance of a sustainable agricultural system. . . Until about 2400 B.C. crop yields remained high, in some areas as high as in medieval Europe and possibly even higher. Then, as the limit of cultivable land was reached and salinization took an increasing toll, the food surplus began to fall rapidly. . . by 1800 B.C., when yields were only about a third of the level obtained during the Early Dynastic period, the agricultural base of Sumer had effectively collapsed."[1]

The process of irrigation, salinization of soils, and agricultural collapse was repeated twice more as later societies attempted to rebuild in the same region. Finally the land was exhausted. "Once a thriving land of lush fields, it is now largely desolate, its great cities now barren mounds of clay rising out of the desert in mute testimony to the bygone glory of a spent civilization."[2]

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[1] Ponting, 1993.
[2] Hillel, 1991.

If the human population doubles over 1986 levels (which many projections show occurring within the next fifty years), could its increased needs be met without destroying many other species and ecosystems? Possibly, if we became much more efficient in our production and use of food and other necessities. But the 40% figure certainly implies that we have to be aware of ecosystem limits, since doubling our demand to 80% of the planet's capacity would drive many other species to extinction.

In traditional macroeconomics, economic growth is always considered desirable. But as we move from a relatively empty world to a relatively full world, an exclusive emphasis on economic growth could produce serious, and possibly irreversible, ecological damage. The implications of humanity now approaching natural limits is one important difference between the new field of **ecological economics** and mainstream economics, as explained further in Box 3.

Box 3: Ecological Economics

Ecological economics has emerged in the past twenty years as a new field of research and study. This new approach builds on a long tradition of thinkers who have been concerned with the issue of the ecological limits to economic activity. Ecological economics claims that the mainstream economic approach to environmental problems is inadequate to deal with the contemporary crises of environment/human interactions and to respond adequately to the complexities of issues such as global climate change, species loss, and ecosystem degradation.

Paradoxically, mainstream economics focuses on problems of allocation of scarce resources, but has proven particularly unable to take into account the growing scarcity or degradation of many natural resources and ecological systems. Ecological economics emphasizes the issue of the scale of human activities, which potentially threatens the natural capacities of ecosystems to regenerate.

The main founders of the field of ecological economics were economists who had the ability to bring a multidisciplinary perspective on social sciences, such as Kenneth Boulding who introduced in economics many concepts coming from system analysis, or Nicholas Georgescu-Roegen who applied the physical laws of thermodynamics to economic processes. Leading contemporary contributors to the field are Herman Daly and Robert Costanza, who have developed the concepts of long-term sustainability, economic and ecological valuation, and optimum economic scale.

For more information on the field of ecological economics, see Krishnan et al., 1995.

The Growth of Economic Activity

There are two important dimensions in the growth of human impacts on the environment:

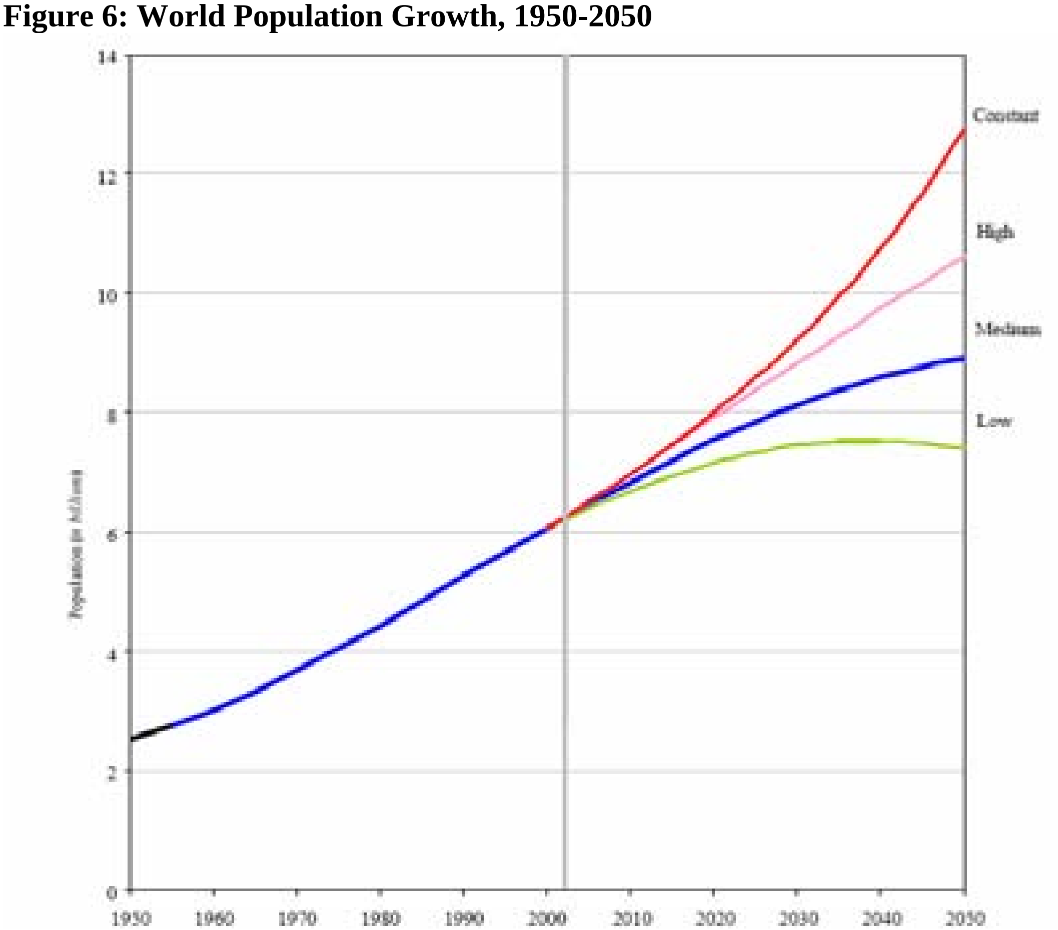
- *Population Growth:* Each individual has certain basic needs for food, water, and living space, so a large population will generally have a higher resource requirement and higher environmental impact.

- *Economic Growth:* As per capita income rises, each individual tends to consume more, increasing resource demand and waste production.

Population growth

At the beginning of the 20th century the world population was less than 2 billion people. In 2004, the global population reached 6.4 billion. The tripling of world population a century is a unique phenomenon in human history. Figure 6 illustrates the growth of the human population with projections up to 2050.

Figure 6: World Population Growth, 1950-2050



Source: United Nations Population Division, 2003.

Note that there is considerable uncertainty about the human population in 2050. The "constant" scenario in Figure 6 assumes a constant rate of growth – an unlikely possibility given that population growth rates have been slowing in recent decades. The other three projections still produce a range of about 7 to 11 billion.

The projected growth of the human population in the coming decades is expected to be highly concentrated in the less developed regions of the world. According to the United Nations medium projections, population growth in the industrial nations is expected to be only 1% from 2003 to 2050. Meanwhile, population growth during this same period in the least developed regions is expected to be over 130%.

Demographic projections for the next century take into account several factors. The **fertility rate**, which is the average number of children born per woman, is one of the major determinants of population growth. In the industrialized world, fertility rates have constantly decreased in the past century to reach current levels below 2 children per woman, which means that the population growth in developed "North" is very slow, about 0..2% per year.

However, in developing countries, it is still very common to have average fertility rates of 3 to 5 children per woman, which corresponds to a high population growth rate, in the range of 2 to 3% per year. At this rate the doubling time of the population of these countries is between 20 and 30 years (See Box 4).

Therefore the "North" and the "South" show very different patterns in terms of population growth. The North represents today around 25% of the world population. By 2050, if world population reaches 8.9 billion people as projected by the United Nations, the share of the North will have dropped to less than 15% of world population.

The reduction of fertility is a universal phenomenon, but occurs at different rates in different countries. Fertility patterns are closely linked with social and cultural norms and family structures. A change in fertility requires a dramatic shift in social structures and in mentality, notably in the status of women which plays an important role in the determination of fertility patterns.

The environmental impact of standards of living

Different patterns or styles of living imply different impacts on the environment. Take for example an African family living in a rural area and cultivating their fields with traditional agricultural techniques. This family has a limited impact on their local environment in terms of their use of local soil and water resources. Their fuelwood needs may contribute to the deforestation of local forested areas. But their production of pollution and non-degradable wastes is almost nil.

Box 4: The Exponential Nature of Growth

If a population grows at a rate of 3% per year - a rate which is seen in some developing countries such as Nigeria and Guatemala - how long does it take for the population to double?

Growth is a cumulative process: if you start with a population P_0, one year later the population will be $P_1 = P_0 + 0.03P_0 = 1.03\ P_0$. Between year 1 and year 2 the population P_1 will again be multiplied by a factor 1.03, so that the population in year 2 will be:

$$P_2 = 1.03\ P_1 = 1.03 * 1.03\ P_i = (1.03)^2 P_0.$$

After 20 years, the population will be:

$$P_{20} = (1.03) * (1.03) * \ldots\ldots * (1.03)\ P_0 = (1.03)^{20}\ P_0 = 1.806\ P_0.$$

It takes almost 24 years to double the initial population with a growth rate of 3% per year. If this rate of growth continues, the population will double every 24 years. This is called **exponential growth**.

No population can grow exponentially forever. Ultimately the population will reach the limits of its natural environment to sustain it. This limit is called the **carrying capacity** of the environment. Currently population growth rates in most areas are slowing, so that global population growth is less than exponential. But global economic output is still growing exponentially.

Mathematical note:
There is a mathematical way to find population doubling time without going through all the iterations year after year. We know that the population we are looking for will be $2\ P_0$ and this will happen after a certain number of years n when:

$$P_n = (1.03)^n\ P_0 = 2\ P_0$$

This means that we are looking for a number of years n such that: $(1.03)^n = 2$. To find n, we need to apply natural logarithms to both sides of this equation:

$$\text{Ln}\ [(1.03)^n] = \text{Ln}\ 2$$

Since $\text{Ln}\ [(1.03)^n] = n\ \text{Ln}\ (1.03)$ we can easily find the exact number of years n:

$$n = \text{Ln}\ 2 / \text{Ln}(1.03) = (0.69315)/(0.02956) = 23.45$$

Therefore, with a population rate of 3% per year, the population will double in 23.45 years.

On the other hand, consider the environmental impact of an American family. Through their daily consumption of food, clothing, housing, transportation, heating and air conditioning, the American family creates many environmental impacts, most of which they may not even be aware of. Some of these impacts involve the use of renewable resources (soils, water, etc...); some involve the use of non-renewable resources (fuel, gas,..); and others involve the release of pollutants into the environment (wastes from agricultural and industrial production, sewage and household garbage, and greenhouse gases like CO_2 which contribute to global climate change).

Would it be possible to create an indicator weighting all these different impacts in order to measure the global environmental impact of each human being according to his/her living style? Such an indicator would be difficult to construct -- for example, how would you compare the impact of water pollution to that of CO_2 emissions? It is practically impossible to get a single indicator of environmental impact. But we can look at the relative contributions of people in different countries to specific global environmental problems. In terms of carbon dioxide emissions, for example, U.S. emissions are about 20 tons per person, while Indian emissions are about 1 ton per person[6].

Another interesting comparison would be to look at various patterns of living in food consumption. Each time someone eats a steak, his/her impact in terms of consumption of the product of photosynthesis is seven times higher than the impact of a person consuming the same amount of protein in the form of grains. Thus people whose staple diet is primarily based on rice, corn, wheat, beans, other cereals, and root vegetables (including most people in Latin America, Africa, and Asia) have a lower environmental impact per person than residents of the U.S., Europe, and Australia, who typically consume much more meat.

Similarly, the transportation patterns of a society may have very different impacts in terms of energy use and pollutant emissions. The environmental impact of an automobile-centered society is much higher than that of a society where transportation is primarily by bicycle. For more on measuring environmental impacts as a function of different factors, see Box 5.

From Growth to Sustainable Development

Components of human development

Economists have always realized that there was more to the pursuit of "progress" than the mere growth of the quantities of goods and services produced. The process of economic development should improve people's standard of living not only in materialistic terms but also in terms of improving well-being in the broader sense of the quality of life. However, most

[6] World Resources Institute, 1996.

Box 5: The IPAT Equation

One way to decompose the environmental impact **I** of human economic activity is to take into account three dimensions of this impact:

P: the population involved in the activity;
A: the affluence factor, which represents the standard of living of this population – usually measured by an indicator of income or consumption per capita;
T: the technological factor, indicating the environmental impact per unit of income.

Then it must be true that:

I = P * A * T

For instance, considering CO_2 emissions in the atmosphere, the global impact **I** is the total amount of emissions which is the product of:

1. the number of people **P**
2. the affluence factor **A** which can be measured by the amount of energy use per person
3. the technological factor **T** which measures the amount of CO_2 released in the atmosphere for each unit of energy produced and consumed.

records of economic progress only take into account the quantitative dimension of well-being, as measured by standard GDP, without considering the qualitative dimensions.

If improving human well-being is the goal of any sound economic development, is it possible to measure the qualitative dimensions of development? The United Nations Development Program (UNDP) has constructed a **Human Development Index** which takes into account three dimensions of development:

1. GDP per capita
2. life expectancy
3. the literacy rate and school enrollment

These other dimensions represent two essential aspects of human capital: health and education. The three dimensions are combined to give a single Human Development Index. Rating countries using the Human Development Index (HDI) shows that societies which are at similar levels of GDP can have very different levels of human development (see Table 4). Panama, Belize, and Namibia all have relative similar levels of GDP but their HDI scores vary significantly. Panama has the highest HDI score because of high education levels and a relatively long life expectancy. Meanwhile, Namibia has a low HDI score primarily due to a very low life expectancy. Viet Nam, Zimbabwe, and Angola also have similar GDP per capita values but widely varying HDI scores. In Viet Nam, people are poor yet relatively educated and long-lived. Those in Zimbabwe are also educated but with much shorter life expectancies. But in Angola, people are mostly uneducated and have short life expectancies.

Table 4. HDI Scores for Selected Nations, 2002

Nation	GDP per capita (US $ 2002)	Life Expectancy	Adult Literacy (%)	School Enrollment (%)	HDI Score
Middle-income countries					
Panama	$6,170	74.6	92.3	73	0.791
Belize	$6,080	71.5	76.9	71	0.737
Namibia	$6,210	45.3	83.3	71	0.607
Low-income countries					
Viet Nam	$2,300	69.0	69.0	64	0.691
Zimbabwe	$2,400	33.9	90.0	58	0.491
Angola	$2,130	40.1	42.0	30	0.381

Source: United Nations Development Program, 2004.

Ends and means

Ecological economist Herman Daly makes a clear distinction between the ends of all human activities and the means used to reach these ends. At the one end of the spectrum he puts what he calls *ultimate ends* -- the life goals which philosophers deal with when they address the issue of happiness and the question of what constitutes a "good" life. Economic development, by contrast, is concerned with *intermediate ends* -- providing necessities of life, as well as other goods and services which contribute to people's well-being[7].

Health and education are important parts of well-being and therefore intermediate ends -- but as the Human Development Index shows, mere economic growth does not necessarily ensure that health and education will be provided on an equitable basis. Some economists have suggested that economics should be concerned only with **efficiency**, and not with **equity**. But the idea of ultimate ends suggests that true economic development must provide access to basic needs for all -- and thus that economics cannot avoid the responsibility for some moral judgments about what is or is not equitable.

If we are interested in true economic development, therefore, measures such as GDP per capita only tell part of the story. We need to consider both the equitable provision of basic human needs, and the impact of economic production on the environment. Certainly the preservation of the biosphere, which supports all human life and economic activity, should qualify as an ultimate end.

[7] Daly, 1980.

Defining sustainable development

True development must provide benefits to all, and must not destroy the natural life-support systems on which it rests. One definition of **sustainable development**, proposed by the World Commission on Environment and Development, is:

> "Sustainable development is development which meets the needs of the present without endangering the needs of the future." (WCED, 1987).

The concept of sustainability has now become more widespread in economics. However, there are differing interpretations of the economic meaning of sustainability.

One interpretation, sometimes called **weak sustainability**, is related to the concept of natural capital depreciation which we discussed above. According to this view, any loss of natural capital should be balanced by creation of new capital of at least equal value. Thus future generations will have access to a stock of capital which is of at least the same value as that which the present generation has available. But in this view, it is acceptable to use up or destroy natural resources, provided that manufactured capital of equal value is substituted for what is lost.

For example, a developing nation could cut down its forests, replacing them with plantations and sawmills, or destroy its natural fisheries and replace them with aquaculture facilities where fish are raised in pens for human consumption. This would meet the definition of weak sustainability, provided that the productive value of the new facilities was at least equal to that of the former natural systems.

This view is criticized by the ecological economics school of thought, on the grounds that economic valuation does not reflect the full value of ecological services, and therefore encourages us to ignore ecological limits. This could lead the process of economic development on very dangerous roads. In the past, destructive ecological feed-backs have caused civilizations to collapse (see Box 2).

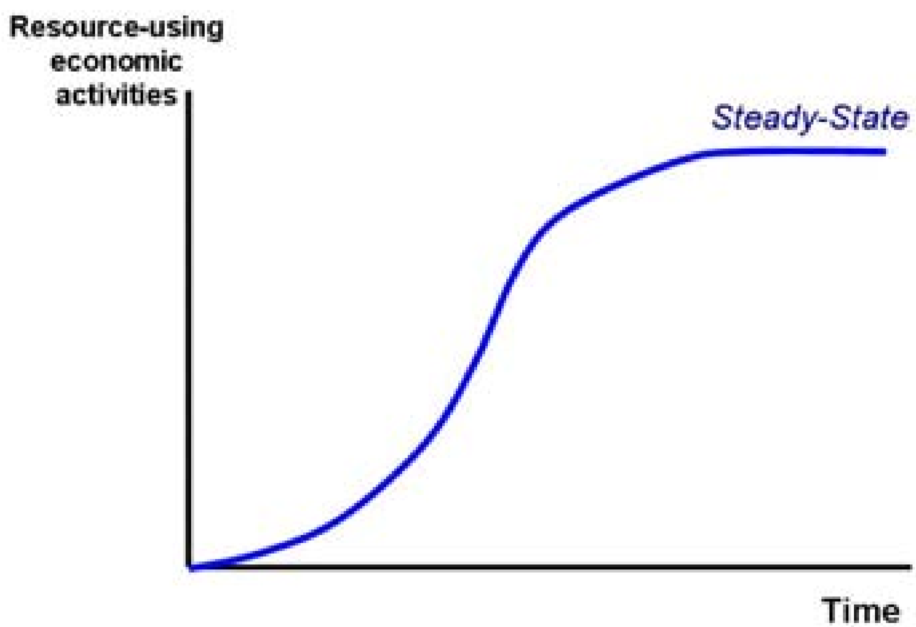
Where there is a danger of irreversibility -- damage that cannot be repaired -- ecological economists often suggest that we should observe the **precautionary principle**. This principle implies that we should not risk environmental damage which could permanently harm our own society or future generations. This argument could be applied to atmospheric emissions which result in ozone depletion or unpredictable climate change, the release of long-lived chemicals or bioengineered organisms into the environment, or the creation of long-lived nuclear wastes.

In general, advocates of **strong sustainability** argue that natural systems should be maintained intact wherever possible. They identify critical natural capital -- such as water supplies -- as resources which must be preserved under all circumstances. In this view, for example, maintaining the natural fertility of the soil is essential -- even if it is possible to compensate for degraded soils with extra fertilizer. Notice that the strong sustainability perspective is compatible with the system of satellite accounts discussed previously. Maintaining satellite accounts, policy makers can determine if critical natural capital is being depleted.

Either concept of sustainability -- but especially the "strong" version -- implies some limits to economic growth. The part of economic activity which relies heavily on natural resources, raw materials or energy, cannot keep growing indefinitely. Because the planetary ecosystem has certain limits, there must also be limits on **macroeconomic scale** -- the overall level of resource use and goods output. There is a need in the long term to reach a plateau, a **steady-state** in terms of the consumption of material and energy resources.

Rather than growing indefinitely on an exponential path -- say of 4% GDP growth per year -- national and global economic systems must follow what is called a **logistic** pattern in which growth is eventually limited, at least in terms of resource consumption (see Figure 7).

Figure 7: Growth Reaching a Steady-State



On the other hand, activities which do not involve resource consumption, which are environmentally neutral or environmentally friendly, can grow indefinitely. Such activities could include services, arts, communication, and education. Once basic needs are met and reasonable levels of consumption achieved, the concept of sustainable development implies that economic development should be increasingly oriented towards this kind of inherently "sustainable" activities.

Policies for sustainable development

Much of macroeconomic theory and policy is oriented towards promoting continuous economic growth. What kind of policies would be required to promote sustainability? Are the goals of economic growth and sustainability compatible?

Some ecological economists view "sustainable growth" as a contradiction in terms. They point out that no system can grow without limit. However, some kinds of economic growth seem essential. For the large number of people in the world who lack basic needs, an increase in consumption of food, housing, and other goods is clearly required.

For those who have achieved a high level of material consumption, there are possibilities for improved well-being through expanded educational and cultural services which, as we have noted, do not have a large negative environmental impact. But, there is nothing in standard macroeconomics which guarantees that economic growth will be either equitable or environmentally benign. Specific policies for sustainable development are therefore needed.

What might such policies involve? Some possibilities include:

- **"Green" taxes** which would shift the tax burden away from income and capital taxation, and onto the use of fossil fuels and resources. This would discourage energy- and material- intensive economic activities, while favoring the provision of services and labor-intensive industries[8].
- Elimination of agricultural and energy subsidies which encourage the over-use of energy, fertilizer, pesticides and irrigation water. Sustainable agricultural systems rely on the recycling of nutrients, crop diversification, and the use of natural pest controls, minimizing the use of artificial chemicals and fertilizer. These systems also tend to be more labor-intensive.
- Greater recycling of materials and use of renewable energy. The field of **industrial ecology** has emerged as scientists and environmental economists have explored how industrial systems can be redesigned to imitate the closed-cycle patterns of natural systems, with reuse of as many materials as possible and minimal waste output.
- Efficient transportation systems which replace energy-intensive automotive transport with high-speed trains, public transit, greater use of bicycles, and redesign of cities and suburbs to minimize transportation needs. In countries like the United States where automobile-centered systems are already extensively developed, the use of highly fuel-efficient cars would be important; in some developing countries automobile dependence might be avoided altogether.

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[8] Labor-intensive production systems are those which use large amounts of labor relative to other factors of production. Similarly, energy-intensive systems use large amounts of energy. For example, automobile transport is energy-intensive; bicycle transport is labor-intensive.

These proposals have implications for macroeconomic policy. If policies aimed at promoting sustainability also encourage labor-intensive development, this could help to achieve full employment. Public investment in rail transit and renewable energy would have budgetary implications, as would the reduction of subsidies for roads and fossil fuels. Tax changes could be **revenue-neutral**, meaning that every dollar collected in new energy and resource taxes would be matched by a dollar of income, payroll, corporate or capital gains tax reduction. But even if new tax systems were revenue-neutral, there could be macroeconomic effects due to the different incentives created for employment of labor and capital, and the implications for investment.

Thus analysis of macroeconomic issues needs to take account of long-term sustainability. Policies oriented towards economic growth alone risk damage to the broader "circular flow" of the biosphere, unless they are modified to include consideration of environmental impacts and sustainable scale. This adds a new dimension to the debate over macroeconomic policy, a dimension which will be increasingly important for both developed and developing economies in the twenty-first century.

KEY TERMS AND CONCEPTS

Biosphere: all areas on earth that contain life forms, including air, soil, land, and water.

Capital: any resource that is valued for its potential economic contributions.

Carrying capacity: the level of population and consumption sustainable by the available natural resource base.

Defensive expenditures: expenditures made to clean up pollution or repair or compensate for environmental damage.

Depreciation: the wearing out or depletion of capital over time, applicable to manufactured or natural capital.

Ecological economics: an economic perspective that views the economic system as a subset of the broader ecosystem and subject to biophysical laws.

Efficiency: the use of resources in a way that does not involve any waste.

Environmentally-adjusted net domestic product (EDP): net domestic product less adjusted for the depreciation of natural capital.

Equity: fairness in the relative distribution of goods or services across a population.

Exponential growth: a value that increases by the same percentage in each period, such as a population increasing by the same percentage every year.

Fertility rate: the average number of live births per woman in a society

Genuine saving (S*): a measure that estimates the amount of national income being saved, taking into account natural resource depletion, net foreign borrowing, and net additions to capital stocks.

Genuine Progress Indicator (GPI): an index measure of human well-being that that deducts certain costs from GDP, such as the costs of environmental damage, income inequality, vehicle accidents, and crime, and adds certain benefits, such as the value of housework, parenting, and highway services.

"Green" taxes: taxes based on the environmental impacts of a good or service.

Gross domestic product (GDP): all income earned within a given country regardless of the nationality of the resident or business.

Gross national product (GNP): all income earned by residents or businesses of a given country regardless of where that income is earned.

Human capital: people's capacity for labor and their individual knowledge and skills.

Human Development Index (HDI): an index measure of economic and social development that combines GDP with data on life expectancy, literacy, and school enrollment.

Index of Sustainable Economic Welfare (ISEW): an index measure of human well-being that subtracts defensive expenditures from economic output and accounts for natural resource depletion, pollution damages, income inequality, and the value of non-marketed services.

Industrial ecology: the application of ecological principles to the management of industrial activity.

Labor: the flow of time, effort, skill, and knowledge that humans directly provide as inputs into productive activities.

Land: the term traditionally used by economists to represent all natural resources used in economic production, including soils, water, forests, species, minerals, fossil fuels, and other such resources.

Logistic growth: an S-shaped growth curve that eventually stabilizes at some upper limit.

Macroeconomic scale: the total scale of an economy; ecological economics suggests that the ecosystem imposes scale limits on the macroeconomy.

Manufactured capital: all physical assets that have been made by humans.

Natural capital: the available endowment of land and resources including air, water, soil, forests, fisheries, minerals, and ecological life-support systems.

Net domestic product (NDP): gross domestic product adjusted for the depreciation of manufactured capital.

Nonrenewable natural resources: resources available in fixed supply, such as metal ores and oil.

Precautionary principle: the view that policies should account for uncertainty by taking steps to avoid low-probability but catastrophic events.

Renewable natural resources: resources that are supplied on a continuing basis by ecosystems; renewable resources such as forests and fisheries can be depleted through exploitation.

Revenue-neutral (tax policy): policies that are designed to balance tax increases on certain products or activities with a reduction in other taxes, such as a reduction in income taxes which offsets a carbon-based tax.

Satellite accounts: accounts that estimate the supply of natural capital in physical, rather than monetary, terms; used to supplement traditional national income accounting.

Steady-state: an economy with a constant level of consumption of material and energy resources over time.

Strong sustainability: the view that natural and human-made capital are generally not substitutable and, therefore, natural capital levels should be maintained.

Sustainable development: development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Value added: a measure of the true economic contribution of a firm; calculated as a firm's revenues minus the cost of inputs

Weak sustainability: the view that natural capital depletion is justified as long as it is compensated for with increases in manufactured capital; assumes that manufactured capital can substitute for most types of natural capital

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DISCUSSION QUESTIONS

1) What kinds of flows circulate in the traditional circular flow model? What different kinds of flows exist between the economic sphere and the natural environment?

2) How would you define natural capital? Give examples of natural capital.

3) What does the complete circular flow model including the biosphere indicate about economic systems which is different from the simple circular flow?

4) What elements of human well-being are not included in the calculation of GDP? Give examples.

5) Show how GDP includes monetary flows which correspond to a decrease in human well-being. Give examples.

6) Explain what the depreciation of capital is in traditional economics. What kind of capital is taken into account in this conventional economic perspective? What is the net domestic product in this perspective? Should a measurement of the net domestic product take into account the depreciation of natural capital?

7) Why are economists like Kenneth Boulding and Herman Daly concerned about the scale of human activities in relation to the biosphere? Explain the expressions "cowboy economy" and "spaceship economy". What are the differences between these two economic situations?

8) Explain why the growth of GDP does not represent a satisfying indicator of development.

9) How would you define sustainable development? Explain the difference between the concepts of "weak" and "strong" sustainability.

PROBLEMS

1. Here is some macroeconomic information for the simple three-sector economy of the developing nation of Equatoria (expressed in international $ values):

Agricultural sector output (domestic value added)	$1200 million
Mining sector output (domestic value added)	$ 650 million
Industrial sector output (domestic value added)	$ 900 million
Depreciation of manufactured capital	$ 220 million

Equatoria experiences several environmental problems. Here is some information about natural resources and environment in Equatoria:

Agricultural area (million ha)	12
Soil erosion (tons/ha/year)	200
Value of crop yield loss for each 100 tons per hectare eroded	$10
Industrial pollution (SO_2) per year (thousand tons)	1200
Damage estimate per ton of SO_2 emitted	$80

a. Calculate the standard measure of gross domestic product (GDP) and net domestic product (NDP) for this economy.
b. Calculate an environmentally adjusted measure of net domestic product (EDP) for Equatoria.

2. Calculate the Genuine Progress Indicator (GPI) given the following economic data:

	million $
personal consumption adjusted for income distribution	2,000
services of household labor, parenting, and volunteer work	500
services of highways and streets	10
services of consumer durable goods	200
cost of crime and family breakdown	50
spending on consumer durable goods	240
cost of commuting and auto accidents	70
cost of air, water and noise pollution	40
net capital investment	25
net foreign lending	+10
loss of wetlands and farmland	60
depletion of nonrenewable resources	400
long-term environmental damages	450
loss of leisure time and underemployment	180
other environmental costs	60

3. An African country had a population of 50 million inhabitants in 1990. Assuming that its current annual population growth rate (2.5%) will remain unchanged in the near future, what will be the population of this country in 2010? When will the population of this country reach 100 million inhabitants?

4. The total amount of CO_2 emissions can be decomposed according to an IPAT equation of this kind:

   CO_2 emissions = Population * GDP per capita * CO_2 emissions per $ of GDP

   Let's write this: CO_2 = P * A * T

   For the United States:

   Population = 263 million
   GDP/capita = $ 26,980
   Total CO_2 emissions = 4,880 million metric tons.

   In India:

   Population = 930 million
   GDP/capita = $ 340
   Total CO_2 emissions = 770 million metric tons.

   Calculate CO_2 emissions per capita in both the U.S. and India and compare them. Calculate the technological factor (T) for both countries. (Calculate T in kilograms of CO_2 per dollar of GDP. There are 1000 kilograms in a metric ton.)

   Suppose the affluence factor is multiplied by 5 in India and the population multiplied by 1.5 over the next 20 years. With the same technological factor as today, by how much would CO_2 emissions increase? If during the same time period India achieves a technological level equal to the current United States level, by how much would CO_2 emissions increase in India?