3. Prepare for the likelihood that social, economic, and technological change will be more rapid and have greater direct impacts on human populations than climate change.
4. Recognize the limits of rational planning.
5. Employ the full range of analytic perspectives and decision aids from the natural and social sciences and the humanities in climate change policymaking.
6. Design policy instruments for real world conditions rather than try to make the world conform to a particular policy model.
7. Integrate climate change concerns with other, more immediate policies such as employment, defense, economic development, and public health.
8. Take a regional and local approach to climate policymaking and implementation.
9. Direct resources into identifying vulnerability and promoting resilience, especially where the impacts will be largest.
10. Use a pluralistic approach to decisionmaking.

Human choice and climate change thus begins with describing the human landscape of the Earth and centers on the role of human choice in the development of climate change as an issue, the definition of causes and likely effects, and the analysis of possible responses. Along with natural science assessments and other related assessments, this social science assessment brings together a wealth of information—but *Human choice and climate change* is not just a report on the state of the social sciences as they have been applied to climate change. Performing an assessment broadens the research focus and generates new insights by the multifaceted analyses and approaches presented here. Theoretical and practical insights that have grown out of the process of producing this assessment can also enlarge the potential application of social science insights and methods to global change—for social scientists, policymakers, and natural scientists.

References

Arrow, K. 1951. *Social choice and individual values*. New York: John Wiley.

Bruce, J. P., H. Lee, E. F. Haites (eds) 1996. *Economic and social issues of climate change*. Cambridge: Cambridge University Press.

Gore, A. 1992. *Earth in the balance: ecology and the human spirit*. New York: Houghton Mifflin.

Jacobsen, H. & M. Price 1991. *A framework for research on the human dimensions of global environmental change*. Paris: International Social Science Council.

Stern, P. O. Young, D. Druckman 1992. *Global environmental change: understanding the human dimensions*. Washington DC: National Academy Press.

Tolba, M. K. 1991. Opening address. In *Climate change: science, impacts and policy*, J. Jaeger & H. L. Ferguson (eds). Cambridge: Cambridge University Press.

CHAPTER 1

Economic analysis

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The problem of climate change exists because the scale of human activity has expanded to the point where the unintended byproducts of those human activities, namely the emissions of greenhouse-related gases, have reached a magnitude at which they are significant compared with global-scale natural processes. The scale and composition of human activities will also frame the conditions under which an altered climate will be experienced. For example, the nature, extent, and distribution of resources risk, as well as those available to societies for coping with climate change, will be largely shaped by human choices.

The field of economics has made substantial contributions to the current understanding of climate change. Indeed, the policy community has relatively uncritically adopted the tools of economics to analyze prospects for greenhouse gas emissions and the consequences of potential emissions mitigation. In this chapter, we will review the state of the art with regard to the social science understanding of the foundations of economic activity and the associated tools of analysis. Although this understanding and the analytic tool kit come largely from the discipline of economics, the chapter will examine contributions from other social sciences and consider opportunities to deepen and extend our knowledge and tools.

We begin with the insight from economic history that human economic and social institutions coevolve in response to challenges posed by both the natural environment and human wants, by generating both technological and social innovations to satisfy these needs (these topic areas are the focus of Vol. 1, Ch. 3 and Vol. 2, Ch. 6.). Of particular interest is the historical relationship between climate, economy, and society. In modern economic thinking, innovation is usually linked with the idea of growth. However, throughout much of human history, economic growth has not been seen as inevitable. Both economic growth and the study of the causes of economic growth are relatively recent, and the models are still relatively simple.

In the second section, we deal with changes in the way economics has modeled the growth process, beginning with Malthus's observations on the growth of human population, with its demands on the natural environment and the constraints on growth imposed by the environment. From the point of view of economics, climate change and the overall environmental carrying capacity of the planet are really the latest in a long series of concerns about the constraints on human activity imposed by nature. The simple Malthusian view has undergone considerable revision, as appreciation of the roles of produced capital and human learning has advanced. But concern remains about the constraints imposed by nature and (perhaps less obvious) by social organization.

The third section of the chapter documents the tools and insights that are provided by standard economic analytic principles as they have been applied

to the climate change problem, showing what has been learned about the issue itself and what could be the consequences of intervention.

The next section takes up the conceptual and measurement shortcomings of the standard economic paradigm as it has been applied to climate change, and discusses how resolving some of these shortcomings might affect the analysis.

The final section focuses the broad discussion in these previous sections on the current international process of studying climate change, which is tied to the Framework Convention on Climate Change (FCCC). In this context, the standard view of the economics paradigm, a view that regards climate as a constraint on economic development, may not be the best approach to achieving international agreement. However, expanding the standard view is likely to prove difficult, given the current situation in the international science and policy communities.

Historical perspective—climate, economy, and society

Humans have interacted with their environments and their climates for millennia, over which time the climate has been constantly subject to changes, although none so dramatic or rapid as that potentially to be encountered in the next centuries. What can humans learn from past experiences? What do they offer researchers and decisionmakers concerned with climate policy? Economic history records that human institutions have both prospered and declined as a result of climate. However, technological, social, and economic adaptations are extremely important intervening factors. A glimpse at the historical record demonstrates just how difficult it is even to correctly frame the issues involved in climate change. A little historical context can help researchers determine if they are even confronting the right set of questions. A few episodes are sufficient to show that most of the human economic activity has involved adapting to change, notably adaptations in agriculture:

- The systematic planting of crops first took place in the Near East around 8000 BC. Several authors, notably Byrne (1987), Blumler & Byrne (1991), and McCorriston & Hole (1991), have argued that this strongly seasonal Mediterranean climate, complete with mild and wet winters followed by rainless summers, was the key to the expansion of cereal agriculture in the Near East. Agricultural economies, in fact, expanded throughout the Near East and into regions of North Africa that today are too dry to support agriculture.
- Hole (1997) recorded that the sea rose rapidly from around 9000 BC until about 4000 BC, when it stabilized at approximately today's levels. A

simultaneous shift in climate patterns left the region essentially rainless, watered only by its rivers. Each response stimulated the growth of local and regional economies through new demand for, and access to, foreign commodities that could be acquired by overland and riverine routes as well as by sea. Indeed, Algaze (1989) remarked that this first internationalism saw the establishment of distant settlements along trade routes.

- As recounted in Holmes (1993) and Stanley & Warne (1993), farmers in both Egypt and Mesopotamia learned to irrigate and produced the world's first important food surpluses. Large cities grew, with specialist producers of different foods and manufactured goods coordinated not through markets but through patronage by temples, owners of diversified estates, and political leaders. The world's first system of bookkeeping to account for these goods and services was being written on clay tables by 3000 BC.
- An unusually sharp and prolonged period of drought apparently occurred about 2200 BC. The Nile floods failed in Egypt, and rainfed agriculture failed in the Near East. In fact, Bell (1975, 1979), Kemp (1983), Weiss et al. (1993), and Hole (1997) combine to describe a drought that extended at least from Greece to the Indus Valley and thereby contributed to the collapse of civilizations across a wide geographic span.
- The Roman Climatic Optimum dates from 300 BC to AD 300, when the mild Mediterranean climatic zone shifted north and then returned to its present position at the southern edge of Europe, allowing vineyards to thrive in England. Indeed, the cycle may have had a role in both the spread and fall of the agrarian-based Roman Empire.
- A subsequent climatic optimum affected the initially successful Norse settlement of Greenland. This was the Medieval Climatic Optimum, AD 900–1200, when Nordic warriors, traders, and settlers spread westward across the North Atlantic. McGovern (1994) reviewed the next several hundred years and portrayed thriving European communities in Arctic Greenland and sub-Arctic Iceland. Despite centuries of adaptation to this environment, however, the Greenland colonies died out by AD 1500.
- In the midst of potential starvation, one might have expected the Norse to engage in trade with Europe for needed foodstuffs. They embarked, instead, on a frenzy of church building, paying for imported liturgical accouterments with their only currency and praying for divine intervention. Norse Greenland did not decline exclusively because of changes in climate; their demise was a cultural phenomenon.

What is the value of such histories? One important guide to what is going to happen is to learn what actually has happened in the past—the climatic events,

their frequencies, their duration, and their amplitudes or intensities; this is the focus explored in Chapter 4. For our current discussion, such historical vignettes illustrate a strong link between economic activity (based on agriculture) and climate. They demonstrate that favorable climate acts to spur economic activity, but unfavorable climatic change requires human management and productive response to avoid economic collapse. Finally, historical studies can offer a basis for prediction of economic effects. They tell what has happened, with what frequency, and what is possible. Furthermore, they can be used to identify productive and unproductive patterns of human response (Glantz 1988).

What can we say about the responses of systems? Some of the case studies noted above imply that excessive central direction puts a system at great risk. Managers may not respond quickly enough or appropriately to changes. They might depend upon the "this is how we have always done it" school of traditional decisionmaking. Moreover, they may tend to look first to their personal welfare and not that of the state. As a result, they may inhibit others from adopting alternative strategies.

Central direction can also distort agricultural production (or any type of production, for that matter) when foreign exchange is an issue. Excessive specialization at the expense of local subsistence can easily place a population at the mercy of international trade (Crumley 1994). Consequently, a strong diverse subsistence base, managed locally, is the most resilient.

Climate variability was a normal condition in premodern times; it was expected that agriculture would fail occasionally and that some proportion of a population would die of starvation, just as diseases also took their toll. Until this century, it was normal for family members to die and for people to attribute premature death to supernatural fate. Given such facts and attitudes, and the general lack of accurate weather records, people had difficulty even in determining whether there were weather trends or just normal fluctuations. Modern communication has made it possible to monitor productivity in real time, but in earlier societies, line of sight and word of mouth were the chief means. Even with modern communications and monitoring, the implication is clear: if a problem (meaning a situation out of the ordinary) is not perceived, no corrective measures will be taken. Or, if the problems are perceived to be not of human origin, people may resort to prayer rather than, say, to irrigation.

History does not suggest that there has generally been a pattern of sustained human development consistent with the modern growth paradigm. Rather, preindustrial populations grew, declined, and regrew to approximately the same levels repeatedly. When necessary economic conditions could not be sustained, the larger entities fragmented again into smaller units which were no longer under a protective umbrella and were free to shift for themselves. An age-old tactic was to disenfranchise peripheral segments of polities in an effort to sustain the life of the core. This is the political equivalent to the socially sanctioned infanticide and gerontocide sometimes practiced by populations living in marginal environments.

No doubt advantages and disadvantages of policies like these have always been considered, but the weights attached to their component parts must have varied greatly. It is therefore perhaps difficult to draw specific lessons from the experiences of the distant past that can inform the design of policy for modern economies facing the threat of anthropogenic global change. Analysts also do not fully understand the complex interactions between humans and the environment.

Global change policies are proposed, debated, analyzed, and sometimes adopted in the face of this complexity, enormous uncertainty, and century-long time horizons. For example, the Montreal Protocol limits the production and consumption of chloroflourocarbons worldwide. The Berlin Mandate calls for strengthening industrialized country commitment to limiting emissions of other greenhouse emissions; and further commitments are to be negotiated and prepared. It is, therefore, not possible simply to declare that the problem is too hard. Analysis must and will be undertaken to support negotiating positions and perhaps even policy development; and the question is how best to proceed in support of these initiatives.

Economic growth, population, and environmental constraints

Economic growth is a relatively recent phenomenon; there have been long periods in which the concept of sustained expansion in the level of economic output would never have occurred to anyone. Even after the beginning of the industrial age, the question of whether or not economic growth was sustainable had no clear answer. Malthus, for example, was profoundly pessimistic about the prospects for sustained economic growth.

We concentrate on the neoclassical economic growth model because, if we loosen its assumptions, a range of possible linkages can be considered. This section can, at best, aim to summarize only a few basic themes, and we have chosen to concentrate on links between population and the formation of physical and human capital.

The neoclassical economic model of population and the environment is essentially microeconomic in its foundations, but macroeconomics matters as well, with prices, tastes, and economic structures (and demands on the environment) evolving as living standards rise. Arguments have gone in two opposite directions concerning growth: more people at a higher living standard

adversely affect the environment, including climate; or more people at a lower living standard have lower demands for environmental protection and will do more harm. The question thus in part involves whether population growth retards economic growth, enhances it, or is neutral. An additional question is whether population would continue to grow rapidly or fall toward replacement as economic growth proceeds. A vicious-circle view (see Vol. 1, Ch. 2) would be that, by stunting growth of demand for environmental quality and by perpetuating environmentally harsh economic structures, population growth places the global environment at greater risk.

The effects of population on physical capital formation, and thus on economic growth as it was traditionally understood, are ambiguous. In contrast, there is fairly strong evidence that, at the household level, high fertility stands in the way of human capital formation, which is now considered one of the keys to economic growth. However, reliable empirical studies (few as they are) suggest that, although significant, the causal role of high fertility in this vicious circle may be modest. In this section, we look at whether rapid population growth chokes off economic development. Population and economic development affect each other as well as climate change issues such as greenhouse-related emissions and capacity to mitigate impacts.

Pre-Malthusian views

The interpretation of population in economic rather than purely political or military terms is a surprisingly recent development in social thought. Both Plato (*The laws*) and Aristotle (*The politics*) argued that the population of the city state should be limited, but this was to avoid problems of governance arising from large populations. Roman authors regarded population in terms of the availability of soldiers and the maintenance of the elite class. As early as the reign of Augustus, low rates of marriage and fertility among the Roman aristocracy were a source of concern, leading to the propagation of laws to encourage unions among the nobility.

With the depopulation of Europe during the Dark Ages and the fourteenth-century Black Death as background, medieval writings not surprisingly stress the positive side of population growth. This strand of thought persisted through the Renaissance and found outlet in the mercantilist school, which emphasized the positive role of population growth in stimulating commercial demand.

Adam Smith (1776) was concerned with population in the context of the labor market. He observed that, when labor was scarce, the increase in wages would stimulate marriage and the survival of children, and vice versa when there was a glut of labor. The mechanisms through which population increase was regulated were two: age at marriage (and proportion never married) and infant and child mortality.

Malthus, environmental constraint, and climate

Malthus's *Essay on the principle of population*, to be distinguished from his more optimistic later writings, was published in 1798 and continues to exercise an enormous influence today. Malthus's principal interest was whether provision of relief to the poor would alleviate poverty or merely allow them to breed themselves back into destitution via earlier marriage and increased child survival as described by Smith. Economic activity (especially agriculture) and environmental limits (on food production) played crucial roles in Malthus's thinking, just as they play crucial roles in the climate change debate.

The Malthusian model is a macro-level economic–demographic vicious circle model. At its heart are the twin assumptions that, whereas increase in population *requirements* (Malthus thought in terms of food) are *linear* in population, *production* is characterized by diminishing marginal returns because the land base is fixed and, as more and more labor is applied to the same amount of land, the marginal product of labor will decline.

Europe escaped the Malthusian nightmare in three ways. First, the land base proved not to be fixed—Malthus never foresaw the opening up of the vast agricultural plains of North America, Russia, Australia, and Argentina. Second, despite the pervasive changes in agricultural technology that were going on around him, Malthus underestimated the possibilities for substituting capital and knowledge for land and labor. Similarly, he failed to anticipate improvements in storage facilities and transport networks. Finally, Malthus had no way of predicting that, during the nineteenth and early twentieth centuries, three factors—a shift in parents' attitudes toward children, followed and reinforced by changing assessment of the associated costs and benefits, and a mass acceptance of the legitimacy of fertility control—would combine to result in the Western fertility decline.

Nevertheless, the Malthusian view persists in updated form, couched in annual percentage change terms and generalized to incorporate capital formation and the demographic transition. In Figure 1.1 (from Todaro 1985), the vertical axis measures percentage change in population and income as a function of income per capita. At point A, population growth is slightly positive; it rises as death rates decline in the initial phase of the demographic transition and then falls as fertility rates eventually decline as well. The growth rate of income traces a similar path. It initially rises with output per capita because rising per capita income is, in its initial stages, associated with higher rates of saving and capital

formation. Eventually, however, diminishing marginal returns to capital and fixed factors (such as land) lead to a deceleration in the rate of output growth. Note that environmental consequences, such as the impacts of climate change on productivity, could be included as a reason for decreasing marginal returns.

As drawn in Figure 1.1, point A represents the Malthusian poverty trap. To the left of A, output growth exceeds population growth and therefore the system will move to the right. To the right of A, population growth exceeds output growth and therefore per capita income will decrease. Point A is thus an equilibrium. What Figure 1.1 does allow, however, is a possibility of escaping the Malthusian trap. If output per capita is slightly displaced to the right of point A, it will return to its original position. However, a major shock—perhaps the discovery of a new technology or a public investment program—might cause a very large displacement, so that output per capita is displaced all the way to the right of point B. Since output growth exceeds population growth, output per capita will continue to grow until a new equilibrium is reached at point C. Thus, in this model two equilibria exist: a low-level trap and a high-level steady state.

One of the predictions of the model is that real wages should vary inversely with the labor:land ratio, and, thus, the rate of change in real wages should vary inversely with the rate of population growth, a proposition for which Lee (1980) and Weir (1991) found emphatic evidence in preindustrial Europe. However, evidence from contemporary less industrialized countries is sometimes contradictory (Evenson 1988, Boyce 1991).

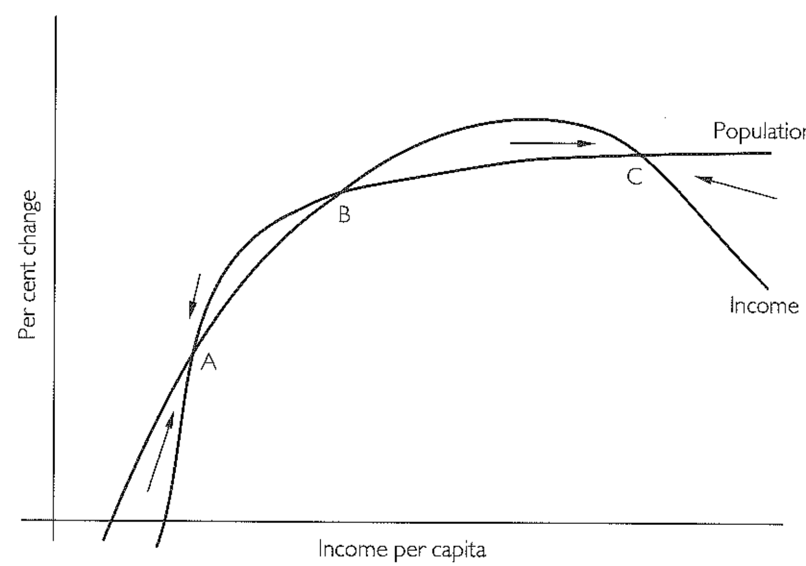

Figure 1.1 An updated Malthusian model and a way to avoid the Malthusian trap (*source:* Todaro 1985).

Various sources of economic growth have, of course, been the subject of intense study by economists for more than two centuries. Their interest has spawned a tradition that views economic growth as a process driven by a combination of basic elements, and the effects of policy on growth can therefore be traced through its effects on those drivers. Solow (1956, 1958) and Lucas (1988) contributed notably to this structure by highlighting specific drivers that explained much of the variation in aggregate economic performance observed across the industrialized and emerging economies. They both identified underlying technical change and innovation as sources of growth; and technological change and innovation are widely thought to have sustained 1.5 to 2.0 percentage points of growth per year across the countries of the Organisation for Economic Cooperation and Development (OECD) throughout the twentieth century.

Neoclassical growth models

Solow (1956) explained the OECD performance by constructing what has since been termed a neoclassical growth model. In his and other like models, labor was assumed to grow at a constant rate, and the models were asked to unveil and to analyze the properties of alternative growth paths for the economy. In some more recent models, though, the growth rate of labor was defined in quality terms to reflect the state of human capital improvement, so that attention could be paid to savings and asset accumulation. Optimal policies within these derivative neoclassical growth models subsequently explained large portions of the more recent and rapid growth across much of the Pacific Rim.

The neoclassical growth model has played an important role in climate change debates. First, the baseline projections (business-as-usual scenarios) assume a level of economic growth at the global level. Second, as climate change mitigation is expected to be a net cost, that cost is often expressed as forgone income or GDP. Third, the economic effects of climate change policies are modeled within a growth paradigm. Therefore, it is worthwhile to understand the economic model that underlies some central arguments in the debate.

The key to the neoclassical economic growth model is that capital is not in fixed supply as assumed by Malthus; rather, the stock of capital can be expanded by saving and investment. But if the rate of saving is not high enough to prevent a decline in the ratio of capital to labor, the productivity of labor, and hence per capita output, will fall. A key consideration with respect to the environment (including climate) is that investment in the environment in the simple neoclassical model does not increase the stock of capital or per capita income. In fact, it should decrease per capita capital stock since it represents a diversion of savings.

The key result of the neoclassical model may be stated thus: without productivity gains attributable to technical progress—that is, an exogenous increase in output independent of increase in inputs—output per capita eventually reaches an equilibrium level; output and population grow at the same rate in the long run. The more rapid the assumed rate of population growth, the lower the equilibrium level of per capita output. If technical progress grows at rate r, then, in the long run, output per capita will grow at rate r. In other words, barring a relationship between the rate of population and the rate of technical progress, the long-term equilibrium growth rate of output per capita is independent of the rate of demographic increase (but see Box 1.1 for further consideration of this issue).

Box 1.1 Is there an inverse correlation between population growth and economic growth?

If the neoclassical model is correct, then observations drawn from a population of economies on their equilibrium growth paths should reveal no correlation between the rate of population growth and the rate of per capita income growth. Theoreticians were thus long able to take comfort from the fact that the correlation between the rate of population growth and the rate of growth of per capita income was one of the most notorious nonrelationships in the social sciences. That is to say, when any number of researchers compared the per capita economic growth rates of countries with their population growth rates, there was no discernible relationship (see Blanchet 1991 for a summary of results and citations).

On the other hand, more recent correlation studies *have* found a significant inverse relationship for the 1970s and early 1980s, although not for earlier years and not always for the postwar decades considered as a whole. An econometric argument (Blanchet 1988) has it that the observations are being generated by an underlying Malthusian model which correlation analysis is only now starting to reveal. Another explanation is that poor countries were displaced from their steady-state growth paths during the troubled decades of the 1970s and 1980s and, failing to adjust to external shocks, remained displaced. This would be sufficient to lead to the emergence of a negative correlation; furthermore, it might be argued that countries with rapidly expanding populations found it more difficult to regain their steady-state paths than did countries with moderate rates of demographic increase. Complicating matters is the consideration that the current and lagged impacts of demographic increase may differ. Some statistical analyses (Ahlburg 1987, Bloom & Freeman 1988) have concluded that the rate of per capita economic growth is inversely correlated with the contemporaneous rate of population growth, but is positively correlated with the past—that is, lagged—rate of population growth, mostly via labor supply effects.

Implicit in this result is the key to the agnosticism that neoclassical economists have long expressed regarding rapid population growth and economic growth. Microeconomic theory posits a tradeoff between fertility and material standard of living, since both children and goods are sources of utility. If, therefore, rapid population growth is associated with lower per capita income at the macroeconomic level, this is merely the aggregation of utility-maximizing fertility decisions taken at the household level. Just as the unadorned microeconomic model gives no foundation for advising couples that they would be happier if they had fewer children, the macroeconomic growth model gives no foundation for advising national policymakers that they would be better off taking steps to encourage fertility decline. When such advice is extended, as it often is, the rationale must be found elsewhere than in the basic neoclassical economic model (Box 1.1).

Capital formation

Solow, Lucas, and others also saw the accumulation of factors of production, in both physical and human terms, playing a critical role in driving economic growth. In the rapidly growing Asian economies, for example, the accumulation of resources through high savings rates (30 percent or more) has long been thought to be one of the major determinants of the high growth of economies such as Korea, Taiwan, Hong Kong, Singapore, Thailand, China and, until ten years ago, Japan (see Balassa & Nolund 1988).

It is easy to imagine scenarios in which demographic increase would serve as an incentive for capital formation. By making labor more plentiful, population growth raises the return to capital relative to the real wage rate (Lee 1980, Weir 1991), thus favoring savings and investment. By temporarily threatening to reduce living standards, rapid population growth might even induce investment at both the national and household levels. Mortality decline should have an important accounting effect on investment decisions: by raising survival probabilities, reductions in mortality lengthen the horizon over which investment projects pay off. More important than accounting considerations may be a change in values accompanying mortality decline: less fatalistic persons are more likely to perceive and exploit profitable investment opportunities.

Human capital formation

Behrman (1990) coined the phrase "human-resource based development" to describe the contribution to economic growth of raising labor force quality via training, education, and indigenous research and development. However, the idea can usefully be broadened to include a wider range of human resource concerns: levels of health, literacy, adequacy of nutrition and housing, and so on. Moderate optimism concerning such effects can lead to strong and continuous growth in less industrialized countries (Box 1.2). In contrast to the ambiguity of the evidence regarding the effect of demographic parameters on savings and physical capital formation at the household level, rather strong evidence exists at the micro level that high fertility and large family size tend to depress children's living conditions and education and, as a result, give rise (with a lag) to low levels of human resource quality (MacKellar 1994 for citations). Recent

Box 1.2 Human resource quality and economic growth

Wheeler (1984) combined a human-resource quality approach with the neoclassical growth model of population and development. At the core of the model was a Cobb–Douglas production function in which the contribution of labor was a function of its quality as measured by the literacy rate and nutritional status. The investment rate depended on, among other things, life expectancy and literacy. Labor force participation rates were not included in the model, and the labor force was taken simply as the population over 15 years old. Calorie consumption depended largely on income growth and literacy on exogenous school enrolment rates.

Fertility was a function of income (positive), the crude death rate (positive; this embodies the quality/quantity tradeoff and its close relative, the child-replacement hypothesis), the availability of family planning services (itself a function of income) and an age-structure variable (women 25–34 as a proportion of women aged 15–49). Life expectancy was a function of income, calorie consumption and literacy. Mortality was a function of the number of doctors per capita and two age-structure variables, population younger than 15 and older than 50 as a proportion of the total population.

Wheeler did simulation runs to see if the model validated the existence of a Malthusian low-level trap. The answer, in brief, was no. If school enrolment rates were frozen at low initial-year levels and the family planning variable was set at a level consistent with no government promotion of family planning, the model traced a pessimistic scenario. However, when enrolment rates were assumed to rise in accordance with observed historical trends, and family planning was endogenized, the simulated growth path was satisfactory. For example, Africa was estimated to experience per capita growth of close to 3 percent per year over the very long term. Administering an extra upward boost to schooling improved results even more. In commenting on these results, Wheeler wrote (1984: 80):

> Is this all simple cockeyed optimism? Obviously, I cannot answer this question, but I take comfort in the fact that no one else can either. Pessimism has become so fashionable during the past decade that an attractive future for [less developed countries] under reasonable assumptions seems automatically suspect.

Wheeler hypothesized three investment scenarios with roughly equivalent costs—the first hypothesizing an increase of one percentage point in the baseline investment rate, the second hypothesizing the same amount of money invested in education, and the third hypothesizing equivalent resources invested in family planning. The alternative strategies were then ranked as to their effects on four quality-of-life indicators: income, literacy, life expectancy and nutrition. One striking conclusion emerged: for *no* indicator, including income, was the physical investment strategy dominant after roughly 15 years of age. In other words, in the medium term, investment in either schooling or family planning led to higher payoffs in income, literacy, life expectancy and nutrition, than did the traditional strategy of investment in physical capital.

advances in economic growth theory have emphasized the importance of precisely such effects. For example, Becker et al. (1990) elaborated a household-level growth model in which fertility and endowment of children with human capital are both endogenous variables and in which possibilities for intergenerational transfers exist. The model's solution is characterized by two stable equilibria: one with large family size and low endowment of human capital per child, the other with small family size and high endowment of human capital per child. The implication (practically, not formally, speaking) is that some exogenous push may be required to direct less industrialized countries away from the low-level steady state.

Technological change

A growing population might be expected to generate increasing demands for food and energy, with corresponding effects on greenhouse-related emissions. However, the population–emissions relationship is mediated by technology. Recent literature, exemplified by Romer (1986), has turned the focus to what has been termed *endogenous growth*. Modeling here focuses on the contribution of knowledge to growth through externality effects. The growth rate is thus determined endogenously in part by policies designed to harness economies of scale and other effects. Modern models therefore stress knowledge-based technologies, but they still focus attention on policies that might improve growth performance.

Role of climate change in growth models

In light of these complications, what can be said about the relationship between climate change and growth? One scenario suggests that climate change will probably induce policy attempts to slow or diminish climate change and that their effects will be largely once and for all. These scenarios see real income and production falling in the near term, but they also suggest that economies will eventually rebound, so that their potential will continue to expand.

A second view holds that mitigating policies will work to change the sequencing component of growth and thus the ability of economies to change the composition of their primary activities. Under such scenarios, climate change can retard growth over the short term and reduce its potential even over the long term, especially in less industrialized countries. Azimi (1994) noted, for instance, that China is already growing rapidly and is fast becoming a major user of carbon-based products in large measure because, in its national energy policies, it has a relatively low price policy toward carbon-based products. In fact, China currently accounts for perhaps 20–25 percent of global carbon emissions—a fraction that could grow to 40–50 percent of carbon emissions by the year 2010. Policies designed to slow carbon emissions certainly clash with this projected future for China.

Similar stories emerge from other Asian economies such as Indonesia, Malaysia, and Thailand. All of these countries have significant forest cover and

export tropical lumber and associated products. To the extent that this component of their trade pattern and outwardly oriented development strategy is crucial to their growth, policies designed to limit this trade with the aim of affecting deforestation will have significant impacts on their abilities to grow.

Focusing attention on specific sectors should remind even the most rigid growth practitioner that resource reallocation issues have been central in most model-based analyses of the impacts of climate change. Reallocation issues arise, in part, because many analyses of climate change based on macro models do not focus on climate change as such, but rather on the impact of policies designed to lessen future climate change. Proposals to introduce large taxes on fossil fuels would be designed specifically to produce large resource re-allocations; and the very distortions that such policies would exploit to achieve their desired effects would dislodge the status quo in markets that span the globe and affect the ability of all countries to meet their performance objectives. Therein lies the problematic issue in designing policy; and policy debate hinges on weighing the economic costs, measured in terms of reduced economic performance in the near term, against a frequently diffuse and uncertain array of benefits sometimes distributed well into the future.

Insights from the standard economic paradigm

The standard economic paradigm provides key insights into the global change problem. Despite their shortcomings, simple economic models have yielded insights into how and where changes in economic activity are causing greenhouse gas emissions, how such crucial factors as international trade interact with growth and emissions, the potential costs and benefits of greenhouse gas emissions and their control (at least at an aggregate level), the effect of incentives for location decisions on emissions, and the effects of institutional structure and market adjustments on emissions and climate impacts.

Measurement of income, economic activity, and trade

If the costs and benefits of climate change policies are important, then a critical question in national and international environmental–economic policymaking is how to rate performance. Economics has done this historically by counting goods and services that are transacted through markets. In dealing with such issues as climate change, this way of approaching the world has limitations. Yet the standard paradigm has produced insights into the problem.

Measuring income

Each modern measure of aggregate economic performance has been devised to accommodate a specific economic complexity, but each can nonetheless be derived from the standard notion of gross national product (GNP). GNP is, quite simply, the current value of all of the final goods and services produced by a nation during some specified period of time (usually a year). It measures a flow of real economic value through an economy over a period of time, and it can be computed in one of three ways. The first sums personal consumption, domestic investment, government purchases and net exports; the second sums wages and other employee supplements, net interest, rental income paid to people, indirect business taxes, depreciation income to unincorporated enterprises, and corporate income before taxes. Most countries use a third approach: summing the net values of final output of the various sectors of the economy (output values from which the value of inputs have been subtracted). Understanding the nuances of all of the components of the three approaches is not necessary to see that their theoretically based equivalence can be employed not only to check and to validate GNP measures, when data are available to support more than one calculation, but also to provide at least one source of aggregate measurement when data are unavailable to complete one or the other of the requisite sums. Many of the categories in each sum might not be applicable to all countries. This can cause statistical problems in collecting data and comparing results across national boundaries, of course, but it does little violence to the conceptual notion of what is being measured.

Alternative measures of the flow of aggregate economic activity abound. One of the most popular, gross domestic product (GDP), represents the total value of output produced within a nation over a given time period. Importantly, in a world of increasing economic interdependence and multinational corporate activity, GDP is not the same as GNP. GNP captures only output produced from factors of production that are owned by the citizens of a nation in question; GDP includes output produced from any resources physically located within that nation, regardless of the nationality of their owners. GNP is conceptually the sum of GDP and net factor income from abroad, less income from worker compensation from abroad, interest payments on loans held domestically, and other factor payments made to residents from abroad (less corresponding payments to residents of other countries).

Historical trends in economic activity

Table 1.1 records several World Bank estimates of the per capita GNP achieved across a relatively complete listing of the nations of the world in four specific years: 1975, 1980, 1985, and 1990. Table 1.2 also draws from World Resources Institute (1995) to provide a more detailed portrait of the year 1991.

Table 1.1 Per capita GNP—selected years ($ US).

Country	1975	1980	1985	1990
Algeria	860	1950	2610	2350
Antigua and Barbuda			2570	4270
Argentina	1810	1970	2140	2380
Australia	7110	10500	11760	16670
Austria	4730	10000	9100	19050
Bahamas	2720	5840	9010	11550
Bahrain			8260	6830
Bangladesh	130	150	150	210
Barbados	1520	3140	4670	6450
Belgium	5930	12160	8290	17580
Belize	790	1170	1120	1960
Benin	200	390	290	360
Bermuda	6790	12040	18500	
Bhutan			130	190
Bolivia	360	490	430	630
Botswana	360	870	1040	2190
Brazil	1070	2070	1640	2710
Brunei		17220	17410	
Bulgaria			2060	2280
Burkino Faso	110	210	170	270
Burundi	100	200	250	210
Cambodia				170
Cameroon	310	760	830	950
Canada	7250	10610	14230	20210
Cape Verde	220	410	340	680
Central African Republic	170	320	270	400
Chad	150	160	130	180
Chile	850	2090	1410	1940
China	170	300	330	370
Columbia	550	1200	1280	1260
Comoros	170	340	300	480
Congo	530	850	1050	1000
Costa Rica	950	1900	1330	1780
Cote d'Ivoire	490	1160	660	760
Cyprus				8230
Czechoslovakia			2760	3190

Table 1.1 (cont'd) Per capita GNP—selected years ($ US).

Country	1975	1980	1985	1990
Denmark	6900	13150	11380	22440
Dominica	380	700	1230	2220
Dominican Republic	660	1090	800	820
Ecuador	540	1260	1180	940
Egypt, Arab Republic of	320	500	670	610
El Salvador	430	740	830	1010
Equatorial Guinea				340
Ethiopia	90	120	110	120
Faeroe Islands	4780	9850	10010	
Fiji	1030	1750	1650	1860
Finland	5390	10130	11040	24580
France	5980	11860	9810	19420
Gabon	2620	3840	3430	3550
The Gambia	210	350	250	340
Germany	6670	13270	10920	22360
Ghana	280	410	370	390
Greece	2370	4380	3700	5980
Grenada				2130
Guatemala	570	1130	1210	910
Guinea				440
Guinea-Bissau	190	130	180	180
Guyana	640	710	510	390
Haiti	150	260	320	370
Honduras	360	640	790	660
Hong Kong	2210	5220	6120	11890
Hungary		1930	1940	2780
Iceland	6350	13680	11810	22540
India	160	240	290	360
Indonesia	210	470	550	560
Iran	1310	1950	4030	2500
Iraq	1140	3030	2520	2140
Ireland	2640	5060	4940	10390
Israel	3880	5390	6610	11160
Italy	3690	7500	7750	16940
Jamaica	1250	1130	920	1580
Japan	4520	9840	11430	25840

Table 1.1 (cont'd) Per capita GNP—selected years ($ US).

Country	1975	1980	1985	1990
Jordan			1940	1290
Kenya	230	420	310	370
Kiribati			560	690
Korea, Republic of	580	1620	2340	5440
Kuwait	9040	17830	15110	
Lao, PDR				200
Lesotho	230	420	390	550
Liberia	410	580	480	
Libya	4630	9760	6810	
Lithuania				3110
Luxembourg	7460	14940	14080	29460
Madagascar	280	430	310	230
Malawi	120	180	170	230
Malaysia	820	1690	1980	2340
Mali	120	240	160	280
Malta	1540	3160	3410	6690
Mauritania	300	440	410	500
Mauritius	710	1190	1110	2310
Mexico	1430	2440	2300	2610
Morocco	500	930	620	970
Mozambique			180	80
Namibia			1090	1400
Nepal	110	130	170	180
Netherlands	6410	12310	9660	17850
New Zealand	4620	6960	6940	12770
Nicaragua	630	650	880	410
Niger	230	440	230	310
Nigeria	520	1100	1020	340
Norway	6600	12900	14560	22830
Oman	1280	3650	7410	5680
Pakistan	130	290	370	390
Panama	1090	1720	2090	1900
Papua New Guinea	530	770	750	860
Paraguay	550	1350	1180	1140
Peru	1000	990	940	1040
Philippines	340	650	540	730

Table 1.1 (cont'd) Per capita GNP—selected years ($ US).

Country	1975	1980	1985	1990
Poland			2100	1680
Portugal	1540	2380	1980	5190
Puerto Rico	2480	3460	4460	6050
Qatar	7550	31160	19190	14210
Romania				1670
Rwanda	90	240	280	320
São Tomé and Principe	440	480	340	410
St Kitts and Nevis			1720	3540
St Lucia				2350
St Vincent	350	580	1080	1710
Saudi Arabia	3280	10420	8700	7070
Senegal	350	510	380	720
Seychelles	800	2020	2580	5100
Sierra Leone	220	320	340	250
Singapore	2820	4820	7880	12430
Solomon Islands	290	400	530	730
Somalia	140	110	120	120
South Africa	1460	1710	2010	2450
Spain	2770	5370	4350	11010
Sri Lanka	290	260	390	470
Sudan	250	400	370	
Suriname	1340	2420	2420	3350
Swaziland	590	830	810	1030
Sweden	8300	14350	12020	23780
Switzerland	7940	17490	16340	32310
Syrian Arab Republic	860	1450	1750	1000
Tanzania	170	280	280	100
Thailand	360	670	810	1410
Togo	250	410	260	410
Tonga			750	1100
Trinidad and Tobago	1720	4620	6180	3460
Tunisia	710	1280	1180	1440
Turkey	830	1400	1080	1640
Uganda			170	180
United Arab Emirates	13240	30190	22360	19910
United Kingdom	3900	7980	8530	16020

Table 1.1 (cont'd) Per capita GNP—selected years ($ US).

Country	1975	1980	1985	1990
United States	7400	12040	16860	21910
Uruguay	1330	2720	1550	2600
Vanuatu			970	1160
Venezuela	2370	4120	3910	2670
Virgin Islands	4570	7510	9320	
Western Samoa			630	940
Yugoslavia	1380	3250	2060	2940
Zaire	400	590	260	220
Zambia	550	600	370	460
Zimbabwe	550	710	640	680

Source: World Bank (1993a).

Of course, enormous statistical difficulties present themselves in expressing international data in a common currency, so that they can be compared across national boundaries:

- problems in defining comparable and widely applicable reporting categories and procedures
- index number problems in deciding how to weight various activities and what prices to use
- exchange rate issues to be resolved so that local currencies can be converted to an international currency such as the US dollar.

To compensate, the World Bank reviews the national accounts of all countries to evaluate their collection and reporting and to make adjustments as necessary in the data. Wide differences between official and effective exchange rates are handled by creating conversion factors.

Indices based upon purchasing power parities (PPP—see Box 1.3) provide more reliable comparisons, although they are not used by the World Bank. PPP weights are designed to be more stable when exchange rates are volatile; using them can make a large difference to international comparisons (see the technical notes attached to table 15.1 in World Resources 1995). Notwithstanding the difficulties involved in using indices, or the conceptual problems with using per capita GNP or GDP as proximate measures of welfare, these and other data can provide some insight into how economic development and growth has been generated and distributed over the recent past. Large differences among economies can be identified and considered using GNP or GDP figures; but the researcher who tries to use them to support precise and quantitative measures of small differences is on very shaky ground.

Measured in either current exchange rates or PPP terms, governments use GNP or GDP figures to monitor their own economic performance both over time

Table 1.2 Gross national product and gross domestic product, 1991.

Continent and country	Gross national product GNP 1991[a]		Gross domestic product GDP: Exchange rate based GDP 1991[b]		Purchasing power parity PPP 1991[c]		Average annual growth rate (%)		Distribution of GDP, 1991 (%)		
	Total $US million	Per capita $US	Total $US million	Per capita $US	Total million $I	Per capita $I	GNP[d] 1980–91	GDP[e] 1980–91	Agriculture	Industry	Services
AFRICA											
Algeria	51060	1991	42993	1674	144627	5640	2.1	3.0	14.0[f]	50.0[f]	36.0[f]
Angola	×	×	8375	879	×	×	×	×	×	×	×
Benin	1854	389	1898	398	7151	1500[g]	2.1	2.4.	36.1	13.2	50.7
Botswana	3399	2666	3688	2893	5980	4690	9.3	9.8	5.5	58.5	36.0
Burkino Faso	2683	290	2753	298	6936	750	4.0	4.0	44.0[f]	20.0[f]	37.0[f]
Burundi	1230	218	1170	207	4072	720	4.3	4.0	55.0[f]	16.0[f]	29.0[f]
Cameroon	10174	858	11674	985	28457	2400[g]	2.1	1.4	23.0	29.4	47.6
Central African Republic	1258	407	1278	413	3368	1090	1.2	1.4	41.0[f]	16.0[f]	42.0[f]
Chad	1206	212	1297	228	4155	730	6.3	5.5	43.0[f]	18.0[f]	39.0[f]
Congo	2436	1060	2722	1185	6434	2800[g]	3.1	3.3	13.2	38.2	48.7
Cote d'Ivoire	8416	677	9503	764	18778	1510[g]	0.3	0.5	38.0[f]	22.0[f]	40.0[f]
Djibouti	×	×	445	982	×	×	×	×	×	×	×
Egypt	32783	611	32790	611	193072	3600[g]	4.5	4.8	18.0[f]	30.0[f]	52.0[f]
Equatorial Guinea	1124	345	131	363	×	×	5.8	×	×	×	×
Ethiopia	6313	123	6602	129	19010	370[g]	1.5	1.6	47.0[f]	13.0[f]	40.0[f]
Gabon	4643	3879	5435	4540	×	×	0.9	0.2	9.0	49.1	41.9
Gambia	324	367	341	386	×	×	3.2	×	28.5[h]	13.8[h]	57.6[h]
Ghana	6496	420	7000	452	30968	2000	3.1	3.2	51.1	16.9	32.0
Guinea	2952	498	3180	536	×	×	×	×	32.0	32.6	35.4
Guinea-Bissau	184	187	211	214	679	690	3.3	3.7	46.3	15.8	37.9
Kenya	8529	350	8261	339	32933	350[g]	4.1	4.2	27.0[f]	22.0[f]	51.0[f]
Lesotho	1042	582	601	336	3385	1890	2.7	5.5	14.0[f]	38.0[f]	48.0[f]
Liberia	×	×	×	×	×	×	×	×	×	×	×
Libya	×	×	×	×	×	×	×	×	×	×	×
Madagascar	2574	207	2673	215	8812	710[g]	0.5	1.1	33.0[f]	14.0[f]	53.0[f]
Malawi	1997	200	2192	220	7989	800[g]	3.5	3.1	35.0[f]	20.0[f]	45.0[f]
Mali	2387	251	2451	258	4565	480[g]	2.5	2.5	42.1	14.2	43.7
Mauritania	1042	500	1130	543	2895	1390	0.6	1.4	22.0[f]	31.0[f]	47.0[f]
Mauritius	2585	2380	2730	2514	12141	11180[g]	7.2	6.7	11.0[f]	33.0[f]	56.0[f]
Morocco	26530	1033	27653	1077	85795	3340[g]	4.3	4.2	16.8	32.8	50.4
Mozambique	1221	84	1328	92	8697	600	(1.1)	(0.1)	64.0[f]	15.0[f]	21.0[f]
Namibia	2354	1584	2278	1533	×	×	1.6	1.0	10.0[f]	28.0[f]	62.0[f]
Niger	2419	303	2328	291	6309	790	(0.9)	(1.0)	34.8	15.9	49.3
Nigeria	34226	305	34124	304	152418	1360[g]	1.4	1.9	37.0[f]	38.0[f]	26.0[f]
Rwanda	2052	282	1630	224	4944	680[g]	0.5	0.6	40.2	18.7	41.2
Senegal	5544	736	5639	749	12649	1680[g]	2.9	3.1	20.3	18.6	61.1
Sierra Leone	860	202	755	177	3409	800[g]	1.1	1.1	×	×	×
Somalia	×	×	×	×	×	×	×	×	×	×	×
South Africa	98854	2543	107437	2763	×	×	3.3	1.3	5.0[f]	44.0[f]	51.0[f]

Table 1.2 (cont'd) Gross national product and gross domestic product—1991.

Continent and country	Gross national product GNP 1991[a] Total $US million	Per capita $US	Gross domestic product GDP: Exchange rate based GDP 1991[b] Total $US million	Per capita $US	Purchasing power parity PPP 1991[c] Total million $I	Per capita $I	Average annual growth rate (%) GNP[d] 1980–91	GDP[e] 1980–91	Distribution of GDP, 1991 (%) Agriculture	Industry	Services
Sudan	×	×	7310	282	×	×	0.3	×	×	×	×
Swaziland	933	1210	942	1222	×	×	6.8	×	×	×	×
Tanzania	2561	95	3183	118	15332	570[g]	2.0	2.9	61.0[f]	5.0[f]	34.0[f]
Togo	1558	427	1637	449	4775	1310	1.8	1.8	33.0	22.2	44.8
Tunisia	12377	1504	13183	1602	38585	4690[g]	3.5	3.7	18.0	32.0	50.0
Uganda	2949	163	2566	142	20285	1120	5.9	×	51.0[f]	12.0[f]	37.0[f]
Zaire	×	×	×	×	×	×	×	×	×	×	×
Zambia	3508	418	3628	432	8473	1010[g]	0.7	0.8	18.2	45.3	36.5
Zimbabwe	6586	641	6324	616	22175	2160[g]	3.6	3.1	20.0[f]	32.0[f]	49.0[f]
ASIA											
Afghanistan	×	×	×	×	×	×	×	×	×	×	×
Bangladesh	23883	205	23394	201	135075	1160[g]	4.2	4.3	36.8	15.8	47.4
Bhutan	275	174	253	160	977	620	9.0	7.6	43.0[f]	27.0[f]	29.0[f]
Cambodia	1730	202	1965	230	×	×	×	×	48.9	12.4	38.6
China	425623	364	371455	317	1966771	1680[i]	9.4	9.4	28.4	38.8	32.8
India	284658	330	248583	288	992157	1150[g]	5.5	5.4	31.0[f]	27.0[f]	41.0[f]
Indonesia	111165	592	115878	617	512487	2730[j]	5.8	5.6	21.4	39.3	39.2
Iran	136348	2274	117190	1955	279957	4670[g]	2.5	2.2	21.0[f]	21.0[f]	58.0[f]
Iraq	×	×	×	×	×	×	×	×	×	×	×
Israel	59879	12293	63032	12940	65564	13460[j]	3.7	3.7	×	×	×
Japan	3326646	26824	3346486	26984	2404709	19390[k]	4.3	4.2	2.5	42.0	55.5
Jordan	3880	935	4082	984	20196	4870	0.6	(1.5)	7.0[f]	26.0[f]	67.0[f]
Korea, DPR	×	×	×	×	×	×	×	×	×	×	×
Korea, Rep.	274875	6277	282970	6462	364341	8320[g]	10.0	9.6	9.0	44.7	46.3
Kuwait	×	×	11199	5369	×	×	×	×	0.6	51.0	48.4
Lao People's Dem. Rep.	943	218	1033	238	8367	1930	4.2	×	×	×	×
Lebanon	×	×	4304	1546	×	×	×	×	×	×	×
Malaysia	45798	2479	47104	2568	135731	7400[l]	5.6	5.7	×	×	×
Mongolia	×	×	756	336	×	×	×	×	16.6	33.5	49.9
Myanmar	×	×	28278	662	×	×	×	×	×	×	×
Nepal	3420	170	3333	166	22681	1130	4.7	×	59.0[f]	14.0[f]	27.0[f]
Oman	9714	6148	10236	6479	14204	8990	9.3	7.9	3.3	57.7	39.0
Pakistan	46566	383	45294	373	239325	1970[g]	6.5	6.1	26.0[f]	26.0[f]	49.0[f]
Philippines	46466	728	45162	708	155718	2440[g]	1.2	1.1	22.1	34.9	43.0
Saudi Arabia	121452	7893	108640	7060	166949	10850	0.4	(0.2)	6.7	52.4	40.9
Singapore	39967	14263	40201	14677	43167	15760	7.1	6.6	0.3	37.4	62.3
Sri Lanka	8638	495	9054	519	46216	2650[g]	4.0	4.0	27.0[f]	25.0[f]	48.0[f]
Syria Arab Republic	14607	1141	17236	1346	×	×	1.4	2.6	29.8	23.4	46.8
Thailand	94022	1697	98261	1774	291921	5270[g]	7.8	7.9	12.7	39.7	47.6
Turkey	102495	1793	107842	1886	276683	4840[k]	5.4	5.0	18.0[f]	34.0[f]	49.0[f]

Table 1.2 (cont'd) Gross national product and gross domestic product—1991.

Continent and country	Gross national product GNP 1991[a] Total $US million	Per capita $US	Gross domestic product GDP: Exchange rate based GDP 1991[b] Total $US million	Per capita $US	Purchasing power parity PPP 1991[c] Total million $1	Per capita $1	Average annual growth rate (%) GNP[d] 1980–91	GDP[e] 1980–91	Distribution of GDP, 1991 (%) Agriculture	Industry	Services
United Arab Emirates	36137	22170	34323	21057	×	×	(1.8)	×	×	×	×
Vietnam	×	×	6970	102	×	×	×	×	38.6	23.7	37.7
Yemen	6746	557	8341	689	×	×	×	×	×	×	×
NORTH AND CENTRAL AMERICA											
Belize	422	2176	420	2165	×	×	5.3	×	21.9[h]	24.8[h]	53.3[h]
Canada	559825	20740	582000	21561	521505	19320[k]	3.1	3.1	3.0[m]	33.8[m]	63.2[m]
Costa Rica	5733	1841	5635	1810	15876	5100[j]	3.4	3.1	15.8	25.7	58.5
Cuba	×	×	×	×	×	×	×	×	×	×	×
Dominican Republic	6751	922	7148	976	22549	3080[j]	1.9	1.7	17.5	26.2	56.3
El Salvador	5740	1087	5915	1120	11143	2110[j]	1.1	1.0	11.2	23.3	65.5
Guatemala	8939	944	9353	988	30105	3180[j]	1.0	1.1	25.7	19.7	54.6
Haiti	2479	375	2641	399	8075	1220	(0.6)	(0.7)	×	×	×
Honduras	3112	587	3004	567	9642	1820[j]	2.6	2.7	20.0	23.5	45.6
Jamaica	3532	1446	3497	1431	8966	3670[j]	1.0	1.6	5.0	43.9	53.1
Mexico	256422	2971	286628	3321	618864	7170[j]	1.5	1.2	8.0	30.7	61.3
Nicaragua	1079	283	1736	456	9708	2550	(1.4)	(1.9)	31.1	20.0	48.9
Panama	5259	2133	5544	2248	12108	4910[j]	0.3	0.5	9.9	10.0	80.1
Trinidad and Tobago	4475	3793	4939	3948	10483	8380	(3.9)	(4.4)	2.5	38.6	58.9
United States	5645415	22356	5610802	22219[n]	5588356	22130[kn]	3.1	2.6	2.0[o]	29.3[o]	68.6[o]
SOUTH AMERICA											
Argentina	129723	3966	189720	5800	167485	5120[j]	(0.2)	(0.4)	8.1	46.0	55.9
Bolivia	4808	654	5020	683	15941	2170[j]	0.5	0.3	×	×	×
Brazil	442698	2920	405771	2677	794394	5240[j]	2.5	2.5	10.0[f]	39.0[f]	51.0[f]
Chile	31582	2359	33977	2538	94512	7060[j]	3.4	3.6	×	×	×
Columbia	41207	1254	41700	1269	179421	5460[j]	3.2	3.7	16.1	36.5	47.4
Ecuador	10907	1010	11663	1080	44712	4140[j]	2.0	2.1	13.4	37.9	48.7
Guyana	242	302	349	435	×	×	(3.8)	×	×	×	×
Paraguay	5568	1266	6249	1421	15038	3420[j]	2.3	2.7	27.8	23.1	49.1
Peru	23434	1065	21899	996	68408	3110[j]	(0.4)	(0.4)	0.0	0.0	0.0
Suriname	1666	3874	1941	4513	×	×	(2.2)	×	11.1[h]	26.8[h]	62.1[h]
Uruguay	8971	2883	9804	3150	20757	6670[j]	0.2	0.6	11.3	32.1	56.6
Venezuela	53880	2728	53441	2705	160394	8120[j]	1.1	0.15	5.4	50.2	44.4
EUROPE											
Albania	×	×	1154	351	×	×	×	×	×	×	×
Austria	158054	20410	163992	21177	136991	17690[k]	2.3	2.3	3.2	36.1	60.7
Belgium	190140	19043	196873	19717	174837	17510[k]	2.2	2.1	1.8	30.1	68.1
Bulgaria	16316	1818	12687	1414	44696	4980	1.7	1.9	17.7	51.3	31.0
Czechoslovakia (former)	38810	2473	33172	2114	98565	6280	0.7	0.6	8.0[f]	56.0[f]	36.0[f]
Denmark	122484	23793	130277	25306	92046	17880[k]	2.2	2.3	50.0[f]	28.0[f]	67.0[f]
Finland	120326	24089	124542	24933	80569	16130[k]	2.9	3.0	6.0[f]	34.0[f]	60.0[f]

Table 1.2 (cont'd) Gross national product and gross domestic product—1991.

Continent and country	Gross domestic product GDP										
	Gross national product GNP 1991[a]		Exchange rate based GDP 1991[b]		Purchasing power parity PPP 1991[c]		Average annual growth rate (%)		Distribution of GDP, 1991 (%)		
	Total $US million	Per capita $US	Total $US million	Per capita $US	Total million $1	Per capita $1	GNP[d] 1980–91	GDP[e] 1980–91	Agriculture	Industry	Services
France	1166992	20486	1199287	21053	1049865	18430[k]	2.3	2.3	3.4	29.0	67.6
Germany	1533932	19204	1574317	19709	1579168	19770[k]	2.3	2.3	1.5	38.7	59.8
Greece	66300	6530	70572	6951	77975	7680[k]	1.6	1.8	17.0[f]	27.0[f]	56.0[f]
Hungary	28436	2700	31593	3000	64035	6080[g]	0.5	0.6	12.6	32.4	55.0
Iceland	5994	23324	6490	25252	×	×	2.4	×	12.0[p]	29.0[p]	59.0[p]
Ireland	39279	11245	43432	12434	39925	11430[k]	2.4	3.5	11.0[f]	9.0[f]	80.0[f]
Italy	1703075	18588	1150517	19930	983702	17040[k]	2.4	2.4	3.2	33.3	63.5
Netherlands	283798	18858	290725	19319	253124	16820[k]	2.1	2.1	4.0	29.3	66.7
Norway	102684	24065	105922	24824	73264	17170[k]	2.5	2.7	3.1	35.6	61.3
Poland	68439	1787	78031	2037	172382	4500[g]	1.2	1.1	8.4	54.2	37.4
Portugal	58636	5944	65103	6599	93224	9450[k]	3.2	2.9	8.7[o]	37.1[o]	54.2[o]
Romania	32120	1380	27619	1187	160584	6900[j]	0.3	0.1	18.0	53.9	28.1
Spain	487150	12482	527284	13510	494485	12670[k]	3.2	3.2	5.3[m]	35.0[m]	59.7[m]
Sweden	217438	25254	236947	27520	150589	17490[k]	2.0	2.0	3.0[f]	34.0[f]	63.0[f]
Switzerland	228926	33850	232000	34304	147298	21780[k]	2.2	2.2	3.6[q]	35.5[q]	60.9[q]
United Kingdom	955828	16606	1009499	17538	940530	16340[k]	2.8	2.9	1.7[o]	36.3[o]	62.0[o]
Yugoslavia (former)	×	×	×	×	×	×	(0.7)	0.8	12.0[f]	48.0[f]	40.0[f]
USSR (former)											
Armenia	6583	1928	701	205	15739	4610[i]	2.9	×	×	×	×
Azerbaijan	8866	1232	×	×	26417	3670[i]	1.9	×	33.0	35.0	31.0
Belarus	33795	3288	×	×	70411	6850[i]	4.0	×	×	×	×
Estonia	6200	3914	×	×	12825	6090[i]	2.8	×	15.6	46.8	37.6
Georgia	9778	1788	×	×	20071	3670[i]	2.9	×	×	×	×
Kazakhstan	34227	2062	×	×	78850	4490[i]	2.1	×	×	×	×
Kyrgyzstan	5183	1163	6727	1509	14619	3280[i]	4.1	×	33.7	38.3	28.0
Latvia	10342	3850	×	×	20252	7540[i]	3.4	×	18.1	47.4	34.5
Lithuania	9046	2415	×	×	20266	5410[i]	3.4	×	27.7	43.3	29.0
Moldovia	7422	1700	14171	3246	20258	4640[i]	2.7	×	30.7	39.4	29.8
Russian Federation	515989	3469	×	×	1030851	6390[i]	2.0	×	17.0	49.0	34.0
Tajikistan	3793	697	×	×	11861	2180[i]	2.9	×	×	×	×
Turkmenistan	5419	1439	×	×	13328	3540[i]	3.2	×	×	×	×
Ukraine	114052	2191	168800	3243	269598	5180[i]	2.7	×	×	×	×
Uzbekistan	20510	978	×	×	58523	2790[i]	3.4	×	33.3	31.1	34.4
OCEANIA											
Australia	296051	17068	300900	17348	289315	16680[k]	2.8	3.1	3.3	30.9	65.8
Fiji	1423	1945	1475	2015	×	×	1.5	×	×	×	×
New Zealand	42106	12301	42233	12338	47819	13970[k]	1.0	1.5	8.4[m]	26.9[m]	64.8[m]
Papua New Guinea	3693	932	3787	955	7254	1830	1.7	2.0	29.0	30.4	40.6
Solomon Islands	226	684	217	656	×	×	6.7	×	×	×	×

Source: IMF (1995). *Data sources:* The World Bank and United National Population Division.
Notes: a. Current US dollars (Atlas methodology). b. Current 1991 US dollars. c. Current 1991 international dollars. d. Constant GNP. e. Constant GDP f. From the World Development Report 1993. g. Extrapolated from 1985 International Comparison Programme (ICP) estimates and scaled up by the corresponding US deflator. h. Data are for 1990. i. These values are subject to more than the usual margin of error. j. Extrapolated from 1980 ICP estimates. k. 1991 ICP estimates. q. Data are for 1985. r. Source: World Resources 1994–5, Table 15.1.
0 = less than half of the unit of measures; × = not available; negative numbers are shown in parentheses.

Box 1.3 Exchange rates, purchasing power parity and international comparisons

Currency exchange rates tend to be very volatile. They respond in the short run to changes in interest rates, political events, and other noneconomic events that cause expectations to fluctuate. Over the long run, however, exchange rates should be determined primarily by the relative prices of goods. They should work to equalize the cost of buying tradeable goods domestically and abroad. Accepting this theory, economists have designed and estimated purchasing power parity (PPP) rates of currency exchange to reflect this market-based tendency toward relative price equalization and to provide more stable conversion factors.

The PPP for any country is defined as the number of units of its currency that are required to purchase the same quantities of goods and services in the domestic market as US$1 would buy in the United States. There are obviously an infinite number of ways of spending a dollar, though, so the quantity bundles for each country comparison are based upon implicit quantities of goods and services that are drawn from national income accounts. The procedure is designed to give international comparisons the same sort of stable footing as is achieved over time by using constant dollars; and, as a result, intercountry comparisons of GDP can reflect differences in quantities of the goods and services that generate economic welfare without being distorted by intercountry price differentials.

Comparisons of the level of economic activity across national boundaries rely explicitly on the conversion of all statistics to a common currency, of course, and the more stable PPP rates are thought to be more reliable. The choice is, however, more than an academic artifact of little interest in the real world. The table below reports GDP statistics for a select group of countries computed in billions of dollars using average exchange and PPP rates. GDP in countries with relatively low incomes tends to be understated using exchange rates, and so they rank higher under the PPP conversion scheme. The reason is simple. Most of the output of these countries comes from nontradeable and labor-intensive services that are generally inexpensive in low income (i.e., low wage) economies. So, for example, China ranks far down the GDP list when exchange rates are used, but second in the world when PPP rates are used.

Comparison of GDP using market exchange and PPP rates.

Country	GDP using market exchange rates (billion US$)	GDP using PPP exchange rates (billion US$)
United States	6378	6398
China	520	2596
Japan	4260	2536
Germany	1869	1412
France	1257	1092
India	255	1045
United Kingdom	941	994
Mexico	391	633
Indonesia	139	616
Nigeria	30	178
Malaysia	63	171
Philippines	55	151

Source: DRI/McGraw-Hill adapted by Samuelson & Nordhaus (1995) for their table 21–2.

and relative to each other. Regardless of the environmental benefits involved, governments will carefully monitor the effects of climate change policies on GNP and GDP.

The impact of climate change policies on economic growth must be calculated relative to baseline growth rates and differences among countries in rates of growth. Different standard measurements may produce different results, thus altering the baseline comparisons.

Comparisons of the recent experiences of China and the United States can be a case in point. Per capita GNP and GDP (computed using exchange rates) both increased in China at an average annual rate of 7.2 percent over the decade from 1981 through 1991. Measured in terms of exchange rates, per capita GNP rose from US$179 to US$364 and per capita GDP rose from US$156 to US$317. By way of comparison, per capita GNP in the United States rose from US$18324 to US$22356 over the same period—an annual rate of 2.0 percent. GDP meanwhile climbed at an annual rate of 1.5 percent to grow from US$19154 to US$22219. The disparity in growth rates is enormous; China's growth over the decade of the 1980s exceeded that of the United States by more than 250 percent when measured in GNP (7.2 percent compared with 2 percent) and a staggering 380 percent in terms of GDP (7.2 percent vs 1.5 percent). Nonetheless, the absolute magnitude of the difference between per capita GNP and GDP in the United States and China increased by more than US$3800 and US$2900, respectively. These are comparisons whose qualitative import can survive any quarrel with the statistical accuracy of the data.

Historical trends in international trade

Trade among countries has grown dramatically over the past several decades—a trend reflected in the opening of domestic markets across the globe, a corresponding reduction in tariffs and other (nonprice) barriers to trade, and the explosive growth in multinational enterprises. Trade is a factor in computing emissions and in projections of energy-efficient mitigation paths; so, again, establishing a baseline is important.

Table 1.3 shows the trend from 1980 through 1990 in both exports and imports for the major geographic and economic regions and nations defined by the International Monetary Fund in its monthly publication, *International Financial Statistics*. The table shows that relatively stable flows of goods and services marked the beginning of the decade, but that increased trade took hold of the international marketplace in 1985. Indeed, more than 16 percent of total world economic activity of US$21196 trillion was exported across a national boundary in 1990. Clearly, international trade will play a vital role in global change as the future unfolds, and alternative regulatory strategies will need to be cast in the context of expanding internationalized sectors.

Table 1.3 Global exports and imports, 1980–90.

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
EXPORTS											
World	1875.9	1844.0	1708.5	1661.9	1767.7	1784.5	2002.9	2355.3	2695.0	2907.3	3332.0
Industrial countries	1239.5	1218.5	1155.5	1139.4	1214.6	1258.5	1485.3	1735.8	1985.5	2126.2	2457.6
United States	220.8	233.7	212.3	200.5	217.9	213.1	227.2	254.1	322.4	363.8	393.6
Canada	67.7	72.7	71.2	76.5	90.3	90.6	90.3	98.2	116.6	120.2	131.7
Australia	22.0	21.8	22.0	20.6	24.0	22.8	22.6	26.5	33.0	37.7	39.8
Japan	130.4	151.5	138.4	147.0	169.7	177.2	210.8	231.3	264.9	273.9	287.6
New Zealand	5.4	5.4	5.6	5.4	5.5	5.7	5.9	7.2	8.8	8.9	9.5
Austria	17.5	15.8	15.6	15.4	15.7	17.2	22.5	27.2	31.0	31.9	41.3
Belgium–Luxembourg	64.7	55.7	52.4	51.9	51.9	53.7	68.8	83.1	92.1	100.0	117.7
Denmark	17.0	16.1	15.4	16.0	16.0	17.1	21.3	25.7	27.7	28.1	35.1
Finland	14.1	14.0	13.1	12.5	13.4	13.6	16.4.	20.0	21.7	23.3	26.6
France	116.0	106.4	96.7	94.9	97.6	101.7	124.9	148.4	167.8	179.4	216.6
Germany	192.9	176.1	176.4	169.4	171.7	183.9	243.3	294.4	323.3	341.2	410.1
Greece	5.2	4.2	4.3	4.4	4.8	4.5	5.6	6.5	5.4	7.5	8.1
Iceland	n/a	n/a	n/a	n/a	n/a	n/a	1.1	1.4	1.4	1.4	1.6
Ireland	8.4	7.7	8.1	8.6	9.6	10.4	12.7	16.0	18.7	20.7	23.7
Italy	77.7	75.3	73.5	72.7	73.3	79.0	97.2	116.7	127.9	140.6	170.3
Netherlands	73.9	68.7	66.3	64.7	65.9	68.3	80.3	92.9	103.3	107.8	131.8
Norway	18.5	18.2	17.6	18.0	18.9	20.0	18.1	21.5	22.4	27.1	34.0
Portugal	4.6	4.1	4.2	4.6	5.2	5.7	7.2	9.3	11.0	12.8	16.4
Spain	20.7	20.3	20.5	19.7	23.6	24.2	27.2	34.2	40.3	44.5	55.6
Sweden	30.9	28.7	26.8	27.4	29.4	30.5	37.3	44.5	49.7	51.5	57.6
Switzerland	29.6	27.0	26.0	25.6	25.9	27.5	37.5	45.5	50.7	51.2	63.8
United Kingdom	110.2	102.2	97.0	91.6	93.8	101.2	107.1	131.3	145.2	152.3	185.2
Less industrialized countries	616.7	603.0	531.0	497.4	523.7	495.3	517.6	619.5	709.5	781.1	874.4
Africa	95.3	78.8	62.2	59.8	61.1	62.5	54.7	63.7	61.9	61.9	73.7
Asia	144.3	153.9	153.5	155.3	179.9	179.9	227.0	295.3	363.9	406.5	453.6
Europe	42.8	45.2	46.0	46.0	48.2	49.6	66.7	71.1	76.5	74.8	71.1
Middle East	230.6	216.3	171.2	134.9	130.3	105.6	88.9	99.2	n/a	n/a	n/a
Western Hemisphere	103.7	108.3	97.6	97.7	103.7	98.4	80.6	91.6	104.6	117.4	127.8
IMPORTS											
World	1928.1	1908.2	1800.4	1737.6	1842.7	1879.3	2066.2	2418.1	2767.6	3005.6	3450.0
Industrial countries	1369.4	1298.6	1219.5	1200.3	1309.2	1361.4	1545.5	1829.5	2067.6	2238.8	2571.2
United States	257.0	273.4	254.9	269.9	341.2	361.6	382.3	424.4	459.5	492.9	517.0
Canada	62.8	70.3	58.4	65.1	79.8	81.1	85.5	92.6	112.7	119.8	122.0
Australia	22.4	26.2	26.7	21.5	25.9	25.9	26.1	29.3	36.1	44.9	42.0
Japan	141.3	142.9	131.5	126.4	136.2	130.5	127.6	151.0	187.4	209.7	235.4
New Zealand	5.5	5.7	5.8	5.3	6.2	6.0	6.1	7.3	7.3	8.8	9.5
Austria	24.4	21.0	19.5	19.4	19.6	21.0	16.9	32.7	36.2	39.0	49.1
Belgium–Luxembourg	71.9	62.5	58.2	55.3	55.5	56.1	68.6	83.2	92.4	98.5	119.7
Denmark	19.4	17.6	16.7	16.3	16.6	18.2	22.9	25.5	25.9	26.7	31.8
Finland	15.6	14.2	13.4	12.8	12.4	13.2	15.3	19.6	21.3	24.4	27.0

Table 1.3 (continued) Global exports and imports, 1980–90.

	IMPORTS										
	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
France	134.9	121.0	115.7	105.4	103.7	108.3	129.4	158.5	178.9	193.0	234.4
Germany	188.0	163.9	155.4	152.9	153.0	158.5	190.9	228.4	250.5	269.7	346.2
Greece	10.5	8.8	10.0	9.5	9.4	10.1	11.4	13.2	12.3	16.2	19.8
Iceland	n/a	n/a	n/a	n/a	n/a	n/a	1.1	1.6	1.6	1.4	1.7
Ireland	11.2	10.6	9.7	9.2	9.7	10.0	11.6	13.6	15.6	17.4	20.7
Italy	99.7	91.1	86.2	80.4	84.2	91.1	99.4	125.7	138.6	153.0	182.0
Netherlands	78.0	67.2	63.8	61.7	62.3	65.2	75.5	91.3	99.5	104.3	126.1
Norway	16.9	15.7	15.5	13.5	13.9	15.5	20.3	22.6	23.2	23.7	26.9
Portugal	9.3	9.8	9.6	8.2	8.0	7.7	9.6	14.0	17.9	19.1	25.3
Spain	34.1	32.2	31.5	29.2	28.8	30.0	35.1	49.1	60.5	71.5	87.7
Sweden	33.4	28.8	27.6	26.1	26.4	28.5	32.7	40.7	45.6	49.0	54.4
Switzerland	36.3	30.7	28.7	29.2	29.5	30.7	41.1	50.7	56.4	58.2	69.7
United Kingdom	115.5	102.7	99.7	100.1	104.9	109.0	126.3	154.4	189.3	197.7	223.0
Less industrialized countries	538.9	588.4	562.1	516.9	511.4	497.9	520.7	588.6	699.0	766.7	878.7
Africa	82.8	89.7	79.6	69.1	64.9	55.9	54.2	57.6	64.0	64.8	72.1
Asia	160.8	177.6	174.0	178.8	192.3	200.8	231.3	293.7	367.2	418.0	473.3
Middle East	113.3	135.2	148.7	133.1	120.2	102.0	91.2	90.5	101.1	97.7	n/a
Western Hemisphere	113.8	119.2	94.4	75.9	74.9	72.2	71.8	81.3	91.1	100.6	111.5

Notes: In billions of US dollars using current exchange rates averaged over the cited year.
Source: IMF (1995).
Data source: International financial statistics, International Monetary Fund, 1980–95. Statistics for specific countries, as well as regional definitions, can be found in these publications.

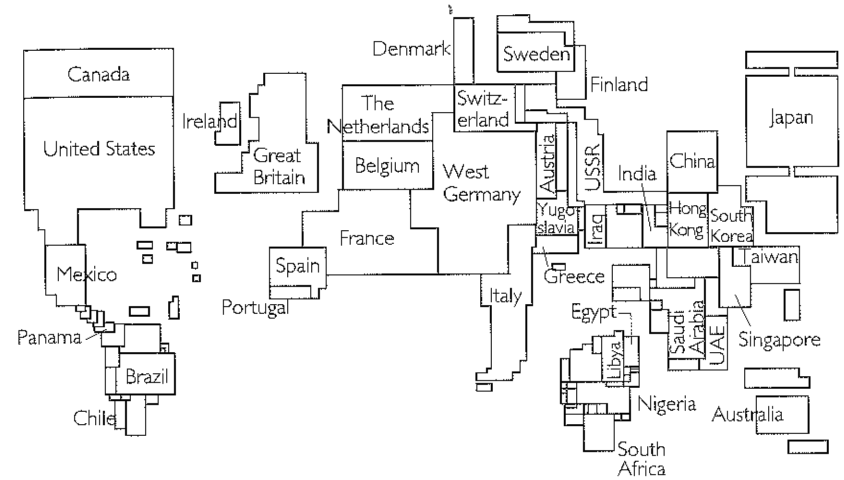

Figure 1.2 Countries of the world, scaled to their international trade. In this map, the area of each country is drawn proportional to its share of total world trade in 1985. Compare the size of the advanced industrial countries with that of Africa and Asia. (Adapted from M. Kidron & R. Segal, *The new state of the world atlas.* New York: Simon & Schuster, 1987.)

Figure 1.2 offers a graphic depiction of international trade patterns. The area of each country drawn there is proportional to its share of total world trade (exports) in 1991; and so it depicts not only the OECD nations that dominate the current international marketplace, but also Asian and African nations where the potential for future expansion and growth is the largest. Table 1.4 offers an

Table 1.4 Major categories of United States exports and imports (1993).

Commodity classification	Share of each commodity as percent of total: Exports	Imports
Industrial supplies		
Oil, coal, and other fuels	3	11
Food	10	5
Other	23	16
Manufactures		
Capital goods		
Computers and related equipment	13	11
Aircraft	9	3
Other	19	12
Motor vehicles	11	18
Consumer goods	12	24
Total	100	100

Source: Samuelson & Nordhaus (1995).

aggregated view of the composition of trade for the United States in 1993—one of the world's most advanced economies in a year of continued trade expansion. It reveals that the United States still exports a large volume of primary commodities, notably food and coal—evidence of an ample resource base. At the same time, the United States imports large quantities of capital-intensive manufactured goods such as automobiles and various types of electronic equipment. Perhaps most surprising, although actually quite typical of advanced economies, some industries (e.g., computers and motor vehicles) show sizable quantities of exports *and* imports. Similar data can be found routinely in another monthly International Monetary Fund publication, *Direction of trade statistics*.

The important question is, of course, what this expansion of international trade means for global climate change and for policies to deal with it. The standard economic models can provide some insights into the relationship of trade to economic growth and its implications for climate policy.

International trade can, for the most part, be explained in terms of conventional market constructions of supply and demand, but there are limits to economists' ability to straddle international borders with simple translations of domestic market analyses. International transactions must deal with multiple currencies, a variety of domestic policies that influence transactions in one but not all sovereign nations, and a complex litany of international trading restrictions, even as they seek to deliver the elusive gains from trade. However, the data suggest that international trade is growing, so the economic gains must be there for the taking.

Trade among nations reflects the diversity of tastes and productive possibilities that span the globe. On the supply side, different countries are endowed with different natural resources, so countries find it beneficial to trade the fundamental inputs of production. Countries also differ in their productive potential, so that they seek to exploit their economies of scale that lower the average cost of production of some good as the volume of output expands: they sell such goods abroad. On the demand side, tastes vary and drive any nation's citizens to seek expanded trading opportunities.

The result of all of this complication can still best be understood in terms of the Ricardian notion of comparative advantage—each country should benefit from trade if it tends to specialize in the production and potential export of those goods and services that it can offer to the world marketplace at relatively lower cost and import those goods and services which it finds both attractive and relatively costly to produce.

Comparative advantage has its limitations, though. It is based upon classical assumptions of smoothly working competitive markets within and between nations; and so it is based explicitly on the assumption that labor markets will adapt to any change to maintain full employment. But what if labor markets do

not adapt, and trade causes dislocation and unemployment? Significant opposition to trade can emerge, and barriers to trade can be constructed. Even if labor market response can be anticipated, expanded trade does not mean that everyone will be better off unless some of the gains from the expansion are distributed to workers whose real wages might fall in its wake. The opening of trade tends to harmonize wages across national boundaries, in short, so that the gains from trade are not ubiquitous. Exchange rates muddle the workings of international markets even more.

The links between economic growth and international trade are complex and potentially very confusing. Indeed, even basic trade theory texts (e.g., Gray 1978) go to great lengths to explain that there is simply no straightforward correlation between one and the other. For example, economic growth might be expected to be an engine for expanded trade. However, this need not be the case. The correlation of trade and growth depends upon:

- the effect of growth on the relative (world) prices of exportables and importables (prices dubbed the "terms of trade" in the literature)
- the degree to which growth favors the domestic production of exportables over the domestic production of importables
- the degree to which growth increases domestic demand for exportables relative to the domestic demand for importables.

Scenarios in which growth works to retard trade and to produce a drag on future growth are just as easy to create as those in which growth works to promote trade and to ignite a second spurt of future growth. In the first scenario, growth in one country favors its exportables (so that they become relatively less expensive as world markets adjust to new supply conditions), turns the terms of trade against those exportables (so that importables become relatively more expensive), and nonetheless produces income effects that cause the demand at home for imports to rise even as the demand for exportables falls. In the second type of scenario, growth moves everything the other way.

Trade, growth, and the environment

How do these insights about economic growth and international trade relate to environmental concerns? The standard presumption in the political economy of international trade is that domestic environmental questions should remain in the hands of domestic policymakers. The argument is that any attempt to force a country to move in either direction from its self-selected environmental stance would be inefficient and would make that country worse off. This argument has been raised in the context of wage rates, where markets exist to facilitate adjustment, but the idea is the same: the harmonization of national environmental policies (by policy decree) can be just as weak as the harmonization of wages (by market adaptation). The fundamental question, then, is whether or not the argument against harmonization holds for regional pollutants and, perhaps more fundamentally, for global pollutants (Box 1.4).

Box 1.4 Harmonizing climate change policies

The European Union (EU) has since the early 1980s been engaged in a process of *harmonization* of economic and environmental goals, regulations, and practices.

The EU pursues its agenda of greater uniformity through two policy instruments. First is the EU Directive, which sets a goal (such as maximum permitted levels of nitrates in drinking water), but under the principle of *subsidiarity*, permits member states to determine how they will meet that goal.

The second category of instruments comprises uniform European regulations. For example, standards specify which varieties of fruits and vegetables may be offered for sale. Bans, such as a proposed ban on heavy motorcycles, prohibit the use of certain products within the entire EU. However, efforts to introduce community-wide taxes, such as an EU-wide carbon tax, have been defeated because of sovereignty concerns on the part of member states such as the United Kingdom.

One of the characteristics distinguishing the EU from other international organizations is its ability to adopt legislation that is directly binding on member states without further review or ratification by their national legislatures. Harmonization, particularly in relation to product and production standards, is widely viewed as essential to the EU's goal to establish a single market. However, there is considerable breadth of opinion about the effectiveness of such policies. For example, problems may arise from widespread variation in the institutionalized meanings of apparently common terminologies. In attempting the harmonize its handling of hazardous waste, the EU stumbled across a morass of different understandings even of the terms *hazard* and *waste*. On the other hand, the EU has adopted several hundred items of environmental legislation, most having a narrow technical content.

Nordhaus (1994b) reviewed the first principles of the economic paradigm as applied to international trade to argue that the answers to these questions are "yes" for regional pollutants and "no" for global pollutants. For the first case, the trade literature supports what many hold to be a contentious result. Nordhaus noted first that local or national pollutants can be viewed as nontradeable goods (bads) in the Ricardian sense that they cannot (do not, actually, by definition) move across national borders. Then, assuming that environmental quality is priced correctly within any nation or region and that the standard assumptions of classical trade theory hold, all of the apparatus of classical trade theory applies to show that the full set of internal, national competitive equilibria are optimal. Global efficiency in these cases therefore requires that countries do not harmonize their environmental policies. It follows that any attempt to do so (e.g., uniformly holding local emissions to 1990 levels) would reduce potential economic welfare. Any move toward harmonization would increase

the economic cost of achieving any specific set of environmental objectives by forcing countries with high costs of meeting a given set of environmental objectives to meet the same requirements as countries with low costs.

This is a result that runs counter to the perspective of many who see harmonization as a nonnegotiable objective on grounds of simplicity or equity; and it also runs counter to the perspective of many who support free trade and see differential environmental standards as hidden barriers to trade.

The first group fundamentally questions whether or not local environmental quality can be correctly priced internally. To assume so rests on the notion that governments can be relied upon to value their environmental resources correctly from a social perspective; that is, that governments have both the desire and the wherewithal to try to maximize social welfare. To the extent that they do, the assumption stands; to the extent that governments fail, the assumption falters. However, this analysis begs the question of how to persuade governments to set internal prices correctly; and it does not offer any convincing argument that harmonized policies would do any better.

The supporters of free trade do not really question whether or not the classical assumptions required in the result hold. Rather, they worry that the power of these assumptions might be exploited by governments that would lower environmental standards in a race toward increased international competitiveness. To do so would, of course, be to pursue a "beggar thyself" policy that would be difficult to sustain over the long term. Another issue involves adjustment and the degree to which local or national competition might ultimately stimulate countries to find increasingly cost-effective ways of mitigating environmental damage (Box 1.5).

The case of global pollution is entirely different. Nordhaus is not alone in noting that global efficiency in controlling a global pollutant requires that countries harmonize their environmental policies in the sense of equalizing the marginal cost of emissions reductions across all sources. Why? Because to do otherwise would leave the most efficient solution unrealized. But this result does not support equal (proportional) quantity standards any more than the result for local pollution did. Although such policies have the advantage of simplicity, they are excessively costly even for a global pollutant, except in the improbable case in which the level and rates of growth of all marginal cost functions were identical.

Cost–benefit analysis applied to growth and climate

As suggested by even a casual reading of the Nordhaus (1994a,b) treatment of trade and the environment, economists like to evaluate the relative efficacy of

Box 1.5 Industrial location and the environment

The links between the location of economic activity and environmental issues run both ways. If economic activity generates localized pollution, then those areas with the most concentrated activity will tend to be more polluted. If environmental regulation imposes costs on business and regulations differ across locations, firms might choose to go where regulations are least strict. Economists have concentrated on the latter; the former appears to most to be more of an engineering question. Careful application of economic principles can nonetheless allow researchers to concentrate on the location decision.

As with most economic decisions, issues of location can be treated as optimal choice problems: many potential sites differ in terms of various characteristics (including environmental regulation), and a firm chooses the best location, where "best" is usually assumed to mean "profit-maximizing." The cost minimization procedures that produce cost curves are therefore implicitly assumed, and so environmental regulation could influence the location choice if regulatory stringency raises production costs. Firms will tend to leave high-regulation areas, or locate fewer new plants there, as long as any beneficial effects of regulation (e.g., a cleaner environment allowing the firm to attract better workers) are outweighed by the costs of complying with the regulation. Analyses of the respective costs and benefits might include concepts that would be familiar to a wide range of social scientists, but the economic perspective puts the greatest emphasis on dollar-denominated factors such as wages and taxes.

Considering the interactions among a variety of decisions broadens the applicability of the economic perspective. Oates & Schwab (1988), for example, identified the straightforward pressures on regulators to relax stringency in order to attract new businesses, leading to environmental standards that are too lax. In a more complex model, Markusen et. al. (1994) expanded the scope to three "players": two areas and a firm. Decisionmakers in each area must decide how stringent their regulations will be; decisionmakers in the firm wait to find out the level of stringency before deciding where to locate the firm's productive activities. The model captures the two opposing pressures on regulators: a desire to gain the jobs and income associated with the plant and a desire to avoid the associated pollution. Economic analyses show that regulators will tend to set excessively stringent standards, trying to encourage the firms to locate in the other area, if the pollution would be severe and/or very local. This is the classic NIMBY ("not in my back yard") response. However, if the pollution effects would be more general, standards would tend to be set too loosely, since the costs from the pollution are partially borne by the other area.

Empirical economic studies of location generally develop quantitative measures of actual location decisions and try to relate those measures to the measured characteristics of the areas chosen. These studies typically work with relatively large sample sizes (larger than the survey samples employed in other approaches, for example), but many have had trouble quantifying differences in environmental regulation across areas. Their results, therefore, may be very sensitive to the estimation method actually employed.

The most common statistical approach, for instance, uses plant-level data on locations of new plants to look at how differences in regulation across areas affect which area is chosen. It embraces the idea of competition between states for new plants, but it treats the number of new plants as given. As a result, an equal increase in regulation across all areas should have no impact on plant location, because the differences in regulation across areas are unaffected and, by assumption, so is the total number of new plants.

More direct regression analyses, and those based upon specific (e.g., Poisson) distributions for the creation of new firms, have the advantage of capturing the impact of a general increase in regulation, but they give up most of the sense of competition. In these approaches, an increase in regulation for a given area has the same impact on new plant location, regardless of whether or not other areas have the same increase in regulation.

Most studies seem to show some effect of regulation on plant location, but the estimated effect is generally small (especially compared to other economic factors such as wage differentials, unionization, or product demand). Direct measures of regulation (attainment status, enforcement activity, or indices of stringency) tend to show a more negative impact than do measures of regulatory spending (either by state regulators or by manufacturing firms). Studies using new plant openings in a conditional LOGIT framework seem less likely to find a significant impact. Some evidence shows a feedback effect of industrial location on air quality.

Although most of the empirical results to date are based on US data, there are implications for international differences in regulatory stringency. The results may suggest that it might make economic sense for developing countries to relax regulation. Poorer workers in poorer countries might place a high value on the jobs and a low value on the reduced pollution; and so, the argument goes, they might see some real advantage to such a trade. Calibrating this advantage so that the net global effect would be positive is, of course, difficult. Global insulation from the local cost would be certain only if the pollution were local, so that the same people who would reap the benefits lower regulation would bear the corresponding higher (environmental) costs. Aside from the ethical issues involved in endorsing such a trade, localized pollution is not universal. Researchers and decisionmakers seeking solutions to global environmental problems that require global regulatory solutions are thus warned that local incentives designed to influence industrial location decisions could easily hinder their ability to reach global regulatory goals.

many decisions, including decisions on how to manage the environment, in terms of their costs and benefits. Reaching beyond the traditional bounds of simple project analysis, modern cost–benefit analysis has investigated optimal provisions of public goods, the efficient level of ambient air and water quality, and other complex environmental issues. Many studies have been completed on these issues. The results of these studies would be reliable so long as they are guided by markets in their computation of costs and benefits and they have the welfare properties of competitive equilibria to use as benchmarks. Market demand and supply curves (or at least marginal cost schedules) support the specification of benefit and cost schedules, and decisions are made with an eye toward maximizing net benefits.

Cost–benefit analysis can lead the way toward allocations of resources that equate marginal costs with marginal benefits, just like a competitive market; and so the promise of improved if not maximized welfare is offered. The key assumption underlying this promise is that policies that produce benefits in excess of costs allow for the possibility of Pareto improvement; that is, enough economic surplus is created to permit full compensation of individuals who bear the cost of the policy by those who reap its benefits. Compensation schemes designed to accomplish this transfer are seldom part of the plan, of course; but it is enough for the paradigm that they could be.

The Intergovernmental Panel on Climate Change (IPCC) offered a chapter on cost–benefit analysis and its strengths and weaknesses (Munasinghe et al. 1996), which will not be repeated here. The cost–benefit analysis techniques can be adapted to a variety of types of data, with techniques varying from traditional project level cost–benefit analysis through cost effectiveness, multicriteria analysis, and decision analysis. Insights from such an expanded cost–benefit analysis are exemplified by the Richels & Edmonds (1995) findings that carbon dioxide stabilization could be achieved at a much lower cost if emissions were not stabilized immediately. The techniques of cost–benefit analysis, because they force at least semiquantitative thinking about climate policy, have highlighted the issue of uncertainty. Nordhaus (1994a) has used the framework to calculate the value of information on various aspects of the climate problem.

The integrated assessment community has, for the most part, adopted the cost–benefit paradigm in its portrayal of how best to design mitigation policy in the face of the threat of global change (see Ch. 5). At least ten models with varying degrees of sectoral detail and (dis)aggregation weigh global costs against global benefits to compute optimal mitigation policies. Each model sets marginal cost against marginal benefit and assumes that winners will compensate losers across international and intergenerational boundaries.

In dealing with global climate policy, some observers treat the emissions of greenhouse gases and the potential impacts of climate as if they were fixed physical relationships. For example, several vulnerability assessments of potential sea level rise have estimated potential damages as the (growing) value of resources placed at risk. A survey of such studies appears in Bijlsma et al. (1996). Yet standard economics reminds that markets and adaptive behavior can play a major role in modifying these effects through the real estate market. Economic damage that might be attributed to future sea level rise (in the absence of any decision to protect threatened property) must be calculated in terms of the value of that property at the (future) time of inundation. This value will include any adaptation that might have occurred naturally and efficiently prior to flooding and abandonment.

Satisfactory descriptions of how future development might affect coastline real estate values can be derived from empirical market analyses of driving socioeconomic variables such as population and real income. Changes in these variables will be reflected in fluctuations of real estate values over the same timeframe. Applied with care in the absence of any anticipated fundamental structural change in the real estate marketplace, the resulting development trajectories offer representative portraits of the evolving value of real estate vulnerable to sea level rise.

However, to determine the likely actual losses, this information must be combined with an assessment of how real estate markets actually work. Satisfactory descriptions of how real estate markets might respond on a more micro, local level in the face of threatened inundation from rising seas are difficult to create. Yohe (1990) provided some insight into how to proceed in his preliminary construction of vulnerability estimates for the United States. Yohe et al. (1995) later calculated economic cost. Land and structures had to be considered separately because the adaptation options open to the market differ. On the one hand, the value of the land lost to rising seas should, in most cases, be estimated on the basis of the value of land located far inland from the ocean. Any price gradient that placed higher values on parcels of land in direct correlation with their proximity to the ocean would, in a very real sense, simply migrate inland as shoreline property disappeared under rising seas.

Ignoring what could be significant transfers of wealth between owners, the true economic cost of inundation would be captured in most cases by the value of the land that was lost in an economic sense—interior land equal in area to the abandoned and inundated property. The exception to this procedure occurs when rising seas threaten a barrier island where the property value gradient encroaches from two sides. It is still possible to use the value of interior land to reflect costs, but care must be taken to note when interior values begin to reflect the higher values that define both gradients from the inside out.

In contrast to the case of lost land, the economic value of structures that might be lost to sea level rise would depreciate over time as the threat of impending inundation and abandonment became known. Structures would be lost at the moment of inundation, to be sure, but their true economic value at that point could be zero with enough advanced warning and with a complete understanding that the property would, indeed, be abandoned when the time came to retreat from the sea. Despite stories of individuals' reluctance to abandon threatened property in, for example, floodplains, the literature that records the results of investigations into how markets react to low probability and high cost events strongly supports the assertion that market-clearing real estate prices do indeed decline over time in response to the pending cost of a growing threat.

Brookshire et al. (1985) examined the validity of the expected utility hypothesis as a model of homeowner behavior in the face of low probability and high severity risk—earthquakes in this case. They found evidence to support the hypothesis in peoples' response to expert and legal descriptions of risk, even when the same people did not respond privately by purchasing disaster insurance. The Brookshire work was reinforced by MacDonald et al. (1987) after an analysis of homeowner behavior in the face of the threat of flooding. All of this work offers evidence to suggest that market values should accurately process information provided by experts on low probability natural hazards.

The assumption made in the sea level application extends that conclusion and argues that property prices should, over the very long term in the face of gradual manifestations of global warming, internalize the threat of rising seas, given some validating informational authority (provided perhaps as informally as some loosely documented history of sea level rise).

True economic depreciation (TED), modeled to start at some fixed time prior to inundation and to finish just when inundation would occur, is an appropriate representation of the maximally efficient market response to (known) risk of future sea level rise. TED is, by definition, a representation of how the value of an asset declines over time as it moves toward its retirement from service. Samuelson (1964) introduced the notion in a different context, but it applies equally well here. Its application to the cost of sea level rise supports the position that the true economic cost of structures lost to rising seas could be as low as zero, with sufficient warning.

Uncertain abandonment, caused by imprecise understanding of the rate of future sea level rise or a disbelief that existing property would actually be abandoned, would affect efficiency. Either a source of imperfect information or an incomplete reaction to the threat of rising seas could, for example, shrink the time period over which markets could react to the threat of rising seas. The value of lost structures under these conditions would not be zero; it would, instead, equal the remaining value of (shoreline) structure at the time of inundation. True economic depreciation takes a mirror-image trajectory over time, compared with the more familiar concept of accelerated depreciation. The actual trajectory depends upon the discount rate, but (for example) ten years of depreciation against a 30-year time horizon would, for all positive rates, mean that more than 67 percent of the true economic value of the structure would remain.

The worst case of imperfect information and uncertain abandonment would allow absolutely no warning and thus no time for any structural depreciation at all. Consideration of this case takes the lack of information to an extreme, caused more by a sudden realization that the policy of abandonment would be followed than a sudden realization that the oceans have risen. It would, however, capture the situation in which the cost attributed to rising seas would be maximized in either case.

The importance of taking efficiency-based adaptation actions can hardly be overstated. Table 1.5 replicates table 6 in Yohe et al. (1996). It shows that cost estimates for the United States along two selected sea level trajectories are a full order of magnitude lower than previous estimates based upon vulnerability calculations. However, these new estimates assume market adaptation in anticipation of inundation and protection decisions based upon a cost–benefit calculation that ignores the redistribution of wealth associated with the planned abandonment of property.

Table 1.5 The potential cost of sea level rise along the developed coastline of the United States (1990 billion US$).

Amount of sea level rise and source cited	Type of estimate	Amortized	Cumulative	Transient (2065)
4.6m				
Schneider & Chan (1980)	Vulnerability	n/a	$347	n/a
7.6m Schneider & Chen (1980)	Vulnerability	n/a	$474	n/a
100cm				
Yohe (1990)	Vulnerability	n/a	$321	$1.37
EPA (1989)	Protection	n/a	$73–$111	n/a
Nordhaus (1991)	Protection	$4.9	n/a	n/a
Cline (1992)	Protection	$1.2	$240	n/a
Fankhauser (1994a)	Protection	$1.0	$62.6	n/a
Yohe, et al. (1996)	Protection	$0.16	$36.1	$0.33
	Abandonment	$0.19	$45.4	$0.38
50cm				
Yohe (1990)	Vulnerability	n/a	$138	n/a
Cline (1992)	Protection	$3.6	$120	n/a
Fankhauser (1994b)	Protection	$0.57	$35.6	n/a
Yohe et al. (1996)	Protection and abandonment	$0.06	$20.4	$0.07

Note: All of the cumulative estimates but Fankhauser's are undiscounted; His are discounted effectively by the annual rate of growth of per capita GNP (expected to average approximately 1.6% for the US through 2100).
Source: Yohe et al. (1996).

Institutional structure and environmental consequences

The economic theory of how environmental resources are used centers on the notion of incomplete markets and externalities. Ordinary market activity uses natural resources, removing them from the natural environment for use as inputs, and then returns residual byproducts of production and consumption back to the environment. This process often degrades the quality of amenities and services that environmental media provide for their inhabitants. Such degradation is generally excessive, in the sense of imposing net costs that exceed the net benefits of degradation, because environmental costs are largely unrecognized in private economic decisions. They are unrecognized because the environmental resources affected are unowned—no owner can demand compensation when the service flow provided by an environmental resource is impaired. This theory prescribes the role for government as either to institute effective ownership, for example, by adopting regulations or marketable permit systems to regulate use, or to adopt policies that mimic the outcome a market would achieve, for example, by imposing a tax or fee on resource use.

This view of how environmental resources are used is incomplete, in large part because it does not recognize the imperfection and costliness of the enforcement process for ownership rights. Whether a particular environmental resource is owned, and hence whether the costs and benefits of using it are internal or external to the user, is taken as given, determined outside the policy analyst's model. One source of important variation, however, is in the form and stability of government from country to country, as the form of government is one determinant of the pattern of ownership in a country. More complete economic analysis has recognized that variation in government form and stability has implications for the policies that will be effective in controlling externalities. Policy prescriptions designed with country A's context in mind may make no sense in country B, either because they are not politically compatible with B's system of government or because they require a degree of policy continuity not present in B.

Empirical evidence relating to the effect of political regimes on environmental outcomes is scanty at best. It is consistent with anecdotes and casual observation of levels of environmental protection in the former Soviet bloc nations. Pollution control, a public good that generally benefits the population at large, was largely neglected by these regimes. One relevant statistical test was performed by Grossman & Krueger (1993) as part of a study of international variations in air pollution levels. The partial effect of a communist government was found to be statistically significant for sulfur dioxide and for one of the two measures of particulates. Moreover, the effect was large, ranging from one-third to four-fifths of the mean concentration level for the entire sample. A dummy variable for communism is, of course, only a rough measure of the degree of government representation.

Another hypothesis is that investments in manufactured capital and natural resource conservation will be most extensive in countries ruled by stable laws, precedent, and impersonal institutions, because ownership security is greatest (transactions costs associated with enforcement of ownership rights and contracts are lowest) in these circumstances. The idea here is that the incentive to invest or conserve is diminished if the individual who bears the cost of such actions cannot be sure of enjoying the ultimate payoff.

Ownership insecurity (whether individual or social) has implications for the use of forests, for example, because allowing a forest to grow and provide a stream of output or services in future years, rather than consuming it immediately, is a form of investment. Insecure ownership rights might induce short rotations on land used to grow timber or biomass for shifting cultivation, or eliminate incentives to replant land that has been cut over. Insecurity also weakens incentives to develop plantation forests and village wood-lots for timber and fuelwood—investments that would reduce pressure on natural forests. These considerations indicate a possible link between insecure ownership and loss of forest cover (see the discussion of land tenure in Vol. 2, Ch. 2). This is a

significant issue for global change, because emissions from land clearing could increase, carbon uptake from forests could be reduced, and the resiliency of human and natural systems affected by climate change could be reduced.

The political factors that might be associated with ownership risk are arguably of two sorts. The first are instability and general lawlessness—indicators that government lacks the power, stability, and popular support to enforce ownership laws. Specific indicators might include the occurrence of guerrilla warfare, armed revolt, and the frequency of major constitutional changes. The second set would indicate whether a country is ruled by specific individuals and dominant elites rather than by laws and anonymous institutions. They might indicate whether the head of government is a military dictator, whether a legislature exists, and so forth. By hypothesis, the average citizen's ownership claim is weaker and less predictable when it depends on the favor of a specific individual, and upon the individual's grip on power, rather than the persistence of established (and more predictable) legal institutions.

A simple way to examine and test these hypotheses is to compare the political attributes of countries experiencing high versus low deforestation rates. Data on deforestation rates, investment rates, and political attributes were collected, and countries in the sample were partitioned in two ways. The first partition places countries into high versus low deforestation rates, depending on whether their percentage reduction in forest cover over the period 1980–85 was greater or less than 10 percent. The second partition depends on whether their investment was greater or less than 10 percent of GDP during 1980–1985.

Table 1.6 reports mean political attributes for both partitions. Twenty high-income countries were excluded from all comparisons to deflect the potential criticism that these nations are not comparable to less industrialized countries. All of the measures of government instability are higher in high deforestation countries (see Deacon 1994 for additional political measures). Three of the four instability measures also are higher in low investment countries. The single exception, more frequent government crises in the high investment group, has no ready explanation except that two countries (Bolivia and Liberia) dominated this political indicator during the period examined. Tests for associations with measures of nonrepresentation in government also are as expected—deforestation rates are high and investment rates low where the country's chief executive is a military dictator, where no legislature exists, and so forth.

These results reinforce findings from an extensive body of empirical research on the relationship between political insecurity, investment and economic growth. Barro (1991) examined crosscountry data and found certain measures of political turmoil to be negatively related to growth and investment rates, suggesting the influence of incomplete ownership in volatile political regimes. Persson & Tabellini (1990), Ozler & Rodrik (1992), Alesina et al. (1991), and

Table 1.6 Deforestation, investment and political attributes (means of political attributes, 1980–85).

	Deforestation rate		Investment rate	
	High	Low	Low	High
Measures of government instability				
Guerrilla warfare	.333*	.205*	.326	.184
Revolutions	.326*	.186*	.410*	.150*
Major government crises	.144	.068	.035*	.089*
Major constitutional changes	.114*	.070*	.118*	.064*
Indicators of nonrepresentation				
Government executive is military	.242*	.094*	.230*	.070*
Nonelected executive	.439	.318	.490*	.310*
Executive is not a premier	.614*	.412*	.640*	.370*
No legislature exists	.174	.141	.320*	.130*
Legislature is elected	.788	.842	.660*	.820*
Number of countries	22	78	24	86

*Difference in mean political attribute between high and low deforestation, or high and low investment countries, is significant at 10 percent.

Definitions:

Guerrilla warfare is the presence of any armed activity, sabotage, or bombings carried on by independent bands of citizens or irregular forces and aimed at the overthrow of the present regime. A *revolution* is an attempted illegal or forced change in top government elite, or armed rebellion intended to gain independence from the central government. A *major government crisis* is a rapidly developing situation that threatens to bring the downfall of the present regime–excluding revolt aimed at such overthrow. A *major constitutional change* is a basic alteration in a state's constitutional structure, e.g., adoption of a new constitution that alters roles of different branches of government (minor constitutional amendments are excluded.) *Government executive is military* indicates that the individual who exercises primary influence in shaping the country's major internal and external decisions is in the armed services. *Executive is not a premier* indicates that the executive is not drawn from the legislature of a parliamentary democracy. *Legislature is elected* indicates that a legislature exists and that legislators are chosen either by direct or indirect election. Other measures are self-explanatory.

others corroborated the importance of political factors in the investment behavior of countries. Keefer & Knack (1994) and Clague et al. (1995) have found significant associations between property rights measures and systems of government that are stable and representative.

These results also lend support to recent work on the role of nominal ownership rights in determining environmental outcomes. Southgate et al. (1991) showed that security of tenure, as measured by the prevalence of adjudicated land-claims, is negatively related to deforestation rates in Ecuador. Alston et al. (1994) presented evidence from Brazil that the existence of adjudicated land-claims enhances incentives for agricultural investments, and that land-claim adjudication is slower and less complete in areas where government jurisdiction is disputed. Pearce & Bann (1993) summarized other empirical research on the determinants of deforestation.

Limitations and critiques of the standard paradigm for climate policy analysis

Earlier sections have emphasized that the interpretation of economic activity is highly dependent on the organization and specification of particular economic models. Although these models are well established, they are not universally accepted, and they certainly have a long and rich history of controversy.

Global change is part of a class of policy problems that tend to exacerbate the shortcomings of the mainstream approach in economics. Examining policy in the context of global change brings attention not only to methodological or analytical component, but also to certain scope or domain considerations. The complex interactions of highly interdependent systems and the long-term nature of the decision problem are features that analysts have recognized as particularly important for global environmental problems. Concepts such as intergenerational equity, stewardship, and sustainability are often at odds with the growth and efficiency paradigm that has dominated the traditional models.

This section discusses various criticisms, and extensions to the traditional economic perspective that are particularly important for the type of complex, long-term, and far-reaching decision problems inherent in global change policies. The discussion emphasizes key model components that have been somewhat minimized in standard treatments and key extensions to the scope of the models that emerge from consideration of the relationships between economic and environmental systems.

For clarity, we separate the list of issues into two general categories: measurement problems, and concept and domain problems. The first category is one where we expect better methods and data might eventually lead to resolution of the problems. The second category, however, is more problematic, and we anticipate that resolving scope problems will require substantial theoretical and conceptual changes in the traditional approach.

Measurement problems

Many goods and services are traded or otherwise made available in every part of the world through nonmarket mechanisms. For example, neighborhoods populated by individuals who are excluded from formal market share developed trading and exchange systems for goods and services employing a variety of skills (Whyte 1955, Liebow 1967, Dow 1977). Studies of low-income neighborhoods showed that these trading networks serve to integrate the community and provide a social fabric of mutual aid and support (Lowenthal 1975, 1981). Other studies showed that not only the poor trade in informal exchange structures. Disillusion with established helping services and declines in the traditional systems of social support, such as the family, have led to expansion of nonmarket exchange structures that provide self-help and mutual aid among group members (Katz & Bender 1976, Robinson & Henry 1977).

Many important relationships, which are actually economic or have important economic attributes, are transacted through nonmarket institutions and arrangements. For example, the dominance of Hassidic Jews in the New York wholesale diamond market significantly reduces transaction costs to the extent that the entire business is conducted by passing packets of stones from trader to trader, tracked only by handwritten slips of paper. Although cheating would be easy, it would probably result in ostracism from the community, that is, social death. This gives rise to measurement problems because economic measurements are done best when those things measured are traded in markets.

Informal economic activity and national income accounting

The contributions of informal sectors to the economies of industrialized and less industrialized nations can be huge—often as large as the official sectors of some smaller nations. Consequently, informal sectors influence the transmission of macroeconomic policies and can sometimes cause those policies to produce contrary results. Global modelers and decisionmakers must begin to understand the workings of informal sectors and to incorporate their dynamics explicitly into an overall view of economic activity. This subsection will examine the problem in industrialized and less industrialized countries.

All activity that lies beyond the pale of official regulation and control is considered informal. In less industrialized nations, the informal economy also includes many activities in traditional and rural sectors that continue to lie outside the bounds defining systemic linkages with formal institutions. Searching over both sets of activities, researchers have identified four broad classes of informal economic activity:

- activities that generate goods, services, and income that are not recognized in the official estimates (such as subsistence agriculture)
- activities that are recognized for official accounts and are not intrinsically unlawful, but are nonetheless arranged so that no official record is reported (such as unlicensed and unrecorded extraction of coal from open-pit mines as far afield as Appalachia and India)
- illegal activities (such as narcotics trading, prostitution, or theft of electricity through illegal hookups and distribution networks)
- myriad activities in the rural traditional sector and in the urban periphery of less industrialized countries, activities that occur outside the domain of established institutions (such as fuelwood extraction from forests and woodlands).

Table 1.7 records some estimates of the size of the informal economy in several less industrialized countries and in some specific urban areas. The measures reported there are not exactly comparable, but their dimension is nearly as impressive as the diversity of the activity that they reflect.

Informal activities in urban areas include, for example, street trading, unregistered factories and shops, informal housing, self-employment in private transport, scavenging, casual labor transactions in urban construction, and domestic service. Traditional sectors meanwhile include activities such as artisan work, cattle tending, household employment by women (including collecting fuelwood, dung, and drinking water; see Cecelski 1991), irrigation transactions among farmers (see Kolavalli & Chicoine 1989 or Shah 1993), and subsistence agriculture. Table 1.7 also shows that informal financial markets can play a large role in less industrialized nations. Informal credit transactions take place between family members and friends, to be sure, but informal lending mechanisms provide significant credit to small enterprises and households across the less industrialized world.

Regardless of its form, informal activity in less industrialized countries can generally be viewed in terms of the response of economic agents to their economic environments. Informal markets serve varied purposes. Lowenthal (1975, 1981), for example, argued that informal markets integrate the community and provide a safety net. In the informal sector of less industrialized countries, moreover, the information embodied in the operation of product and factor markets is thin and the underlying institutional structure is weak. Consequently, the market does not resemble the smoothly operating institution

Table 1.7 The informal economy in less industrialized nations.

Country/location	Estimate	Year	Source
India	80% of GDP	1990	Bose (1993)
Zambia	95% of GDP	1990	" "
Argentina	98% of GDP	1990	" "
Calcutta	40–50% of employment	1971	Sethuraman (1981)
Jakarta	45% of employment	1976	" "
Bombay	45% of employment	1961	Heather & Joshi (1976)
Latin America	30–57% of urban employment	1975	Lubell (1982)
India	Black income = 51% of GDP	1987	Gupta (1992)
Cameroun	Informal institutions hold 58% of total savings	1988	Lubell (1982)
Sri Lanka	40% of credit informal	1980s	Montiel (1993)
India	40% of credit informal	1980s	" "
Bangladesh	33–67% of credit informal	1980s	" "
China	" " " "	1980s	" "
Malaysia	67–75% of credit informal	1980s	" "
Nepal	" " " "	1980s	" "
Pakistan	" " " "	1980s	" "
Thailand	" " " "	1980s	" "

Source: Shukla 1994

assumed by simple neoclassical economics. Geertz (1978) saw the resulting personalized and informal contracts as ways to deal with imperfect information and institutional gaps.

Cantor et al. (1992) noted that exchange rules of the traditional and informal economies are often different and deserve separate consideration. Traditional sectors in less industrialized nations are typically decentralized and isolated; the economic activities that they support are therefore performed within localized, mainly rural, and effectively isolated spheres. Linkages among these localized economies are weak, and so the exchange of goods, services, and technological innovations is minimal. Difficulties in establishing a credible and widely accepted currency, and feeble financial institutions act as barriers to the flow of finance across sectors and regions. Interest rates in traditional sectors are thus generally higher than in the formal sector, and so the penetration of efficient technologies is retarded even more. Characteristics of technological progress in traditional sectors of less industrialized nations must therefore be very different, both from their counterparts in the industrialized nations and from other more modern segments of their own economies. Inasmuch as the results of the models of energy and greenhouse gas abatement policy analysis currently in vogue depend critically on the assumptions about future technological progress and market penetration, the technological relationships assumed for less industrialized nations can be misleading.

Finally, informal economic activity is not confined to less industrialized economies. Several studies report estimates of the size and growth of the informal activity within a few industrial nations. The estimates recorded in Table 1.8 vary widely—owing in large measure to inaccurate data and differences in the ranges of activities included in the estimate.

Table 1.8 The informal economy in industrialized economies.

Country	Estimate (% of GNP, except USA)	Year	Source
United States	$270 billion	1988	IRS (1988)
Canada	10	1982	Mirus & Smith (1989)
Sweden	3.8–6/8	1988	Hansson (1989)
Italy	9.4	1977	Contini (1989)
France	6.7	1979	Barthelemy (1989)
Netherlands	1.8–9.1	1979	Broesterhuizen
United Kingdom	3	1977	Dilnot & Moris (1981)
	15	1979	Feige (1981)
	7.5–9.3	1982	Bhattachryya (1990)
West Germany	8–12	1980	Kirchgaessner (1983)
Japan	3.9	1980	Langfeldt (1989)
European Community	12	n/a	Manasian et al. (1987)

Source: Shukla (1994).

Measuring inequality in the global distribution of income

Much of global climate policy is concerned with equity—the measurement and sharing of the burdens of impacts and mitigation costs across countries, regions, and income and ethnic groups. For example, Bruce et al. (1996) recognized costs related to damages, to protection or adaptation, and losses from extreme events. They devote a chapter to equity considerations. The impacts of each of those sources of cost could be distributed quite differently across regions and groups, but the parties to the FCCC disagree concerning even the appropriate burden-sharing principles (see Vol. 1, Ch. 4). Social welfare analysis has not been attempted.

Measurement of equality or inequality across the distribution of any economic variable is a difficult problem under the best data conditions. There are enormous methodological difficulties to overcome, but these are only part of the problem of comparing international and intertemporal income inequality. Issues of scale, comparability of data, and quality all come into play in that arena.

Scalar measures of equity are popular and convenient, but they can also prove to be difficult to interpret. Sen (1975) argued that any single measure can conceal information about the structure of inequality and the way it might change over time and distance. Many others have observed that different measures are liable to produce different and potentially conflicting results.

The technical annex to *Investing in health* (the 1993 World Development Report) notes that different measures fail to produce similar results for magnitude and sometimes even the direction of changes in inequality, because they assign different weights to different parts of the income distribution. Three of the more widely applied measures are applied to historical data collected and analyzed by Berry et al. (1983) in Box 1.6. The measures are drawn from a Lorenz curve, which is a plot of the cumulative percentile share of national income against cumulative percentile share of population. If plotted as a 45° line, income is equally distributed.

The first measure, the Gini coefficient (GINI), is the ratio of the area between the plotted Lorenz curve and a 45° line, divided by the area under a 45° line (equal per capita income). GINI measures the degree of inequality. It is really a variance measure and is particularly sensitive to changes in the neighborhood of the modal income.

A second common approach tabulates the ratio of the income received by the wealthiest x percent of the population to the income received by the poorest y percent of the population. Growing inequality would be indicated by an expansion of the ratio, but interpretation of exactly what is going on is often difficult. In particular, ratio measures are extremely sensitive to small changes around the critical x and y percentage thresholds.

Box 1.6 Measuring inequality in the global distribution of income

Berry et al. (1983) constructed statistics from per capita GNP data, assuming that income for every resident in every country matched their country's per capita average and that imprecisely registered growth in the People's Republic of China was moderate over the 27-year period from 1950. Shares of world income received, and consumption enjoyed, by people were reported for a selection of years; consumption shares were recorded for 1950, 1960, and 1977. However, since all of the entries were constructed using national averages, inequality in the distribution of income within countries was omitted. There are, nonetheless, a few observations that can be drawn from even these restricted estimates.

First of all, the lowest 60 percent of the world's population saw their share of income fall from 1950 through 1977 by 1.3 percent, the upper-middle 30 percent of the population enjoyed a 1.8 percent increase, and the uppermost 10 percent of the population felt a 0.5 percent decline. The first change worsened the distribution of income, of course, but the second improved it so that no unambiguous conclusion can be drawn about the overall trend. However, the distribution of income did worsen unambiguously over the 2-year period from 1970 until 1972; the cumulative percentage of income received up through every decile was smaller in 1972 than in 1970. The consumption data tell the same discouraging story even over the longer term from 1950 through 1977. The upper 30 percent of the world's population increased its share of world consumption from 79.2 percent to 81.5 percent at the expense of the lower seven deciles—an unambiguous worsening of the overall distribution.

Berry et al. went further with their analysis of the data, looking empirically for explanations of the trends that they observed. It should be clear, however, that more sophisticated measures of inequality are required if summary data such as these are to be instructive. Studies of changes in the distribution of income, for example, rely heavily on the measures chosen to reflect that change. This is certainly true of any comparative methodology or analysis, but the difficulties posed by international and intertemporal comparisons of income inequality are particularly acute.

A third scalar, developed by many economists, including Sen (1974), deflates average per capita income by the Gini coefficient to produce a theoretically rooted measure of the economic cost of income inequality (essentially aggregate costs incurred by individuals because they may place poorly in future income distributions). Termed GINI2, this measure is technically equal to average per capita income multiplied by a factor that varies with the Gini coefficient. GINI2 equals zero under perfect inequality and average per capita income under perfect equality. Yitzhaki (1979) and Hey & Lambert (1980) showed that GINI2 is really a special case of a relatively general welfare function in which there is no correlation between the welfare achieved by any individual and the distribution of income across national boundaries. In other words, no one's welfare depends upon the opportunities offered to citizens in other countries. In addition, reliance on GINI2 means that the researcher is implicitly assuming that the value of the last dollar earned is the same for citizens of the poorest countries as it is for the citizens of the richest counties. These are obviously very strong assumptions, but they do provide the foundation for a benchmark

measure that is distorted neither by jealousy and envy across national boundaries nor by the value judgments of researchers who might arbitrarily assign different weight to different changes in income.

Lovell (1994) used the *Penn world table* and *World development report* data to estimate, on the basis of GINI2, that the cost of inequality across the world was more than US$5400 per person in 1990—a value derived in equal proportion from inequality within and between nations and equal to more than 60 percent of the average world per capita GDP during 1981–90 .

Many other measures of income inequality can be developed axiomatically from a theoretical structure that relates welfare functionally to per capita income. Atkinson (1970) echoed some of the insights first offered by Dalton (1920). Gastwirth (1972), Sheshinski (1972), and Dagum (1992) made notable contributions to a body of highly technical literature based entirely on utility theory and the notion of aversion to risk. All of the competing measures still produce the same comparative results under the simple case that one society's income inequality is more severe than another's for the full range of population percentages (0–100 percent). When relative income inequality is worse only for some portion of population percentages, comparative results for two such countries can be contradictory—in part because of technical reasons embodied in the underlying functional forms and in part because they must deal with enormous differences in scale from one nation to another.

Lovell (1994) explored the scale dimension after noting that large inequality in the distribution of income does not necessarily mean lower welfare for even the least advantaged citizens. Disadvantaged citizens in wealthier countries may be better off than their counterparts elsewhere simply because they receive smaller shares of larger pies. He shows, for example, that it is better to be in the lowest quintile in the United States than it is to be in the same class in all but ten other countries, including some, such as Hungary, that have a more egalitarian distribution of income.

Broadening the perspective, Lovell also considered a concept termed *Pareto dominance*, which is based on the relative standing of income classes in two or more countries. Pareto dominance of one country by another seems to be most likely when there is a great difference between their respective average income levels; and Pareto dominance undermines the implications of some Lorenz curve comparisons. The US Pareto dominates 44 of the 55 other countries included in the Lovell analysis, whereas the US Lorenz curve lies unambiguously above only 15 different nations, indicating that the US distribution of income is unambiguously more egalitarian than these 15 countries only. In all other cases, results depend on what part of the income distribution is under discussion.

Studies concerning climate change effects on income mostly have concentrated on average effects or per capita income. Little has yet been done concerning the distribution of the costs and benefits of climate change among groups or the distribution of mitigation and adaptation costs (Banuri et al. 1996).

Additional concerns about the quality and the coverage of data have also been noted. Summers & Heston (1990), for example, offered subjective ratings of the quality of the data from 134 countries. Such overviews show that the data are, for the most part, not very good. Researchers can, as a result, rely on these data as perhaps the best available; but they should certainly be cautious to avoid overstating precision in making international comparisons or fine tuning modeling parameters.

Nonmarket valuation

To conduct policy analysis where standard signals of market value are missing or suspect, environmental economists have had to devise methods to derive values for many environmental resources and service flows. The resulting nonmarket values are sometimes taken to be those accruing to current users of a resource, but they are not usually confined to these individuals or to their individualistic motives. If climate change were to cause a wetland to deteriorate, for example, then those currently fishing or hunting in the wetland would certainly be affected; but other individuals might register losses, too. Some might want to fish some day, and that opportunity would be lost. Others might want their children to be able to fish the wetland in ten years' time, and they would feel a loss. So would people who just like knowing that high-quality wetlands exist. The US National Oceanographic and Atmospheric Administration (NOAA 1993) and Larson (1993) have been particularly forceful in their assertions that acknowledging the validity of adding these option and existence values to more standard use values has been a major step in nonmarket valuation.

Economists have followed two largely separate routes, dubbed direct and indirect valuation, in trying to estimate nonmarket values for the environment. A survey of methods can be found in Freeman (1993). For a rare example of a combining the two, see Adamowicz et al. (1994). In both methods, individuals are assumed to come to the table equipped with utility functions that include both market-valued private goods and nonmarket environmental goods, such as clean air and the stock of white rhinos. A central feature of this utility function is that the individual is assumed to be prepared, in principle, to trade more or fewer environmental goods against more or fewer market goods to maintain a certain level of utility. Stevens et al. (1991) and Spash & Hanley (1994) both provided counterexamples to this assumption, so care will need to be taken to investigate when it makes sense, when it does not, and whether it will matter much.

In direct valuation, individuals are asked, in a carefully structured way, to specify the greatest amount that they would give up to secure more of an

environmental good or to prevent a loss of the environmental good. This is their maximum *willingness to pay* (WTP) for environmental gains and losses respectively. In other cases, individuals are asked to specify the least they would willingly accept in compensation to forgo an increase or to accept a decrease in the environmental good; this is their minimum *willingness to accept compensation* (WTAC). Either question is usually framed so that individuals are paying or receiving money income to offset the environmental change and hold them on a constant level of utility. *Contingent valuation*, *contingent ranking*, and *stated preferences* are all methods that have been devised to make direct valuation assessments.

Indirect valuation, on the other hand, seeks to infer environmental values from individuals' expenditures on marketed goods and standard assumptions about the complementarity or separability of environmental and market goods within their utility functions. For example, if it were necessary to spend money on a marketed good to offset an increase in pollution, then the change in expenditure on the marketed good might be used as a money measure of the cost of environmental change. If expenditure on travel were necessary to enjoy fishing on a salmon river in the Scottish Highlands, then this cost might be used to value a day's salmon fishing. If it were known that forest planting would cause the number of salmon to fall, then an economist would know how to place a money estimate on this cost. Principal indirect valuation methods include the *travel method*, *hedonic pricing*, *averting expenditure*, and *dose–response models*.

Valuations produced by the methods of environmental economists seem likely to take more and more prominence in public decisions over environmental management. Assessment of how accurate and reliable these values are is a subject for debate. For example, Morey (1994) noted unresolved difficulties over the valuation of travel time, multipurpose trips and the unit of activity being valued in the travel cost approach. Hedonic pricing suffers from heavy data demands, statistical problems over the choice of functional form, multicollinearity, and the unconvincing assumption that housing markets are always in equilibrium for each environmental characteristic. Finally, averting expenditure only measures welfare changes accurately if this expenditure is a perfect substitute for the environmental good in question and if it generates no other benefits. But how likely is that to be the case?

Most empirical methods in the social sciences are problematic in use, and cataloging shortcomings for one particular set of methods does little to help assess the validity of the results. Hanley & Spash (1993) have proposed three criteria that might be used more productively in that assessment:

- How repeatable are results gained from any method?
- How valid are these results?
- In what esteem are the methods held by the academic community?

Loomis (1989) and Laughland et al. (1991) have used repeatability as a test for the *contingent valuation method* (CVM), and their results have, by and large, been encouraging. Testing repeatability in travel cost models has proven to be more difficult, but some encouraging evidence can be found in the meta-analysis of travel cost studies presented by Smith & Kaoru (1990). Validity can be interpreted in several ways. *Convergent validity* compares the valuation results from one method with results from another method; d'Arge & Shogren (1989) and Smith & Desvouges (1986) are examples. By way of contrast, *theoretical validity* can be claimed if empirical results are in line with theoretical predictions, but that is only as good as the theory. Carson & Mitchell (1993) noted clearly and accurately, for example, that one group of economists claims that empirical evidence that confirms the embedding hypothesis undermines CVM, since theory suggests that it should fail. Meanwhile, a second group claims that the success of the embedding hypothesis supports CVM, because theory suggests that it should be so. Obviously, the two camps rely on different theory, but which is correct? Finally, *construct validity* refers to how well the method's results can be explained statistically. In CVM, this involves estimating an equation relating WTP to those variables thought a priori to influence it. If this equation has the right parameter values and explains well (in terms of the goodness of fit), then the construct validity criterion is satisfied.

At the present time, however, whether nonmarket values can be shown to be repeatable and valid or not is not really the heart of the issue. The real question still remains: should society use nonmarket values in making decisions over the environment? Using nonmarket values implies accepting the philosophical basis that underlies them: that anthropocentric values are all that matter and that they can be represented effectively in a utilitarian framework. The utilitarian framework comes into play because it lies at the heart of the cost–benefit structure into which nonmarket values are thrust, and so even the incorporation of nonuse values builds on the notion that individuals are prepared to trade off environmental goods against other goods or income. Spash & Hanley (1994) noted all of this, and warned that using nonmarket values might be wrong if this is not how individuals think about the environment. Traditional economic reasoning counters their cautionary note by asserting that making decisions on environment issues necessarily involves making tradeoffs so that cost–benefit analysis does little more than force those tradeoffs into the open.

Although environmental valuation makes decisionmaking through cost–benefit analysis more efficient by making it more inclusive, it does not guarantee that environmental quality will be improved or even maintained. Some analysts argue that including environmental values into the cost–benefit calculus elevates them to the same level of importance as more conventional costs

and benefits (such as labor costs and the value of electricity). Nonmarket valuation also reduces environmental values to the common currency metric, so no special treatment is necessarily accorded to the environment. Environmental quality is treated in the same way as labor hours, kilowatt hours, and bags of cement. Listing environmental impacts as intangibles in the past may have led to their being ignored or downgraded in the eyes of policymakers, but that might not have been the case. Keeping environmental impacts out of the cost–benefit calculus might have allowed them to retain a special status, which could make their safeguarding more likely.

Concept and domain problems

One of the difficulties of much of the work done on the policy of climate change is that it has assumed a single decisionmaker with a rational view of the benefits and costs of climate change (see Ch. 3 for additional discussion of the rational actor paradigm). The reality is much more complex and it undermines the standard paradigm. The non-economics social science literature suggests some approaches that take account of this more complex reality and expand on the standard approach.

Methodological individualism and aggregation

The discussion of nonmarket valuation raises the issue of grounding environmental decisionmaking in individual or societal preferences. Neoclassical welfare economics and the cost–benefit framework derived from it are grounded in the principle of consumer sovereignty. The implication for a normative theory of government behavior is that the government is merely an agent of its citizens. Institutional or societal preferences have no role in the welfare calculation, except perhaps to the extent that they may influence individual preferences.

Formal conditions and particular behavioral assumptions establish the fundamental linkages among individual preferences, individual utility, and social welfare, based on the view that self-interested individuals employ a rational decision process over final wealth states and personal changes in utility. The philosophical positions of consumer sovereignty and the rational pursuit of self-interest in consumer decisionmaking have stimulated many theoretical and empirical debates in the social sciences. Many of these debates turn on the validity of the behavioral assumptions. Others rest on the ethical proposition that social decisions should always be grounded in individual preferences. Both sources of criticisms are particularly relevant for addressing the role of government in global environmental problems.

In conventional microeconomics, rationality involves two major components: the basic motivation for action and the decisionmaking process by which actions are selected. The first component, the motivation underlying choice, refers to whether or not economic agents are motivated primarily by self-interest in their decision behavior. Alternative motivations would be altruism and malevolence (i.e., the presence of purposeful maliciousness in actions). The underlying assumption of motivation is important, since it bears directly upon the perceived gains from choice. Analytical approaches characterized by self-interest assumptions emphasize the influences of perceived personal and social payoffs from behavior and choice. Not surprisingly, health risk and costs for one's descendants are a significant part of what people fear in the absence of environmental protection (Hays 1987). Kempton (1991) found that his subjects defined most environmental value in economic and anthropocentric terms.

Economists have preferred the self-interest assumption on the grounds that the other explanations can be made consistent with it by redefining gain. Although recognizing the tautological implications of this position, Aaron (1994) argued that the central issue for economic modeling of behavior is not the assumption of self-interest, but rather how interests are defined and conveyed in the modeling of preferences and utility. Accordingly, economists have felt much more challenged by concerns about the second component of rationality: the decisionmaking process by which people maximize their self-interest. This component directly addresses the relationships among preferences, utility, and choice. Global environmental change is problematic for the standard behavioral assumptions about decisionmaking because it reflects an unusually complex and uncertain decisionmaking problem. In economics, such problems are commonly studied within a framework that relies on the *expected utility theory* (EUT) of decisionmaking under uncertainty (see also Ch. 4).

Although the EUT model does fairly well in predicting common decisions under risk where consequences are well understood and the decisions repeated often, it performs poorly at predicting the results of rare or complex decisionmaking (Schoemaker 1982, Harless & Camerer 1994). Consequently, EUT seems particularly ill suited to describe decisionmaking behavior for problems like global environmental change (see also Munasinghe et al. 1996).

More recent models of decisionmaking under uncertainty have emerged that build upon the parsimony of EUT models and psychological insights into rationality. In general, these economic–psychological models reflect subjective probability–consequence estimates elicited from individuals or individuals' heuristics (editing practices) for dealing with very high or low probability events. In spite of their greater attention to actual risk behavior and less stringent axioms of rationality, the focus of economic–psychological models has remained on numerical assessments of risk by individual decisionmakers. Therefore, without rejecting the self-interest paradigm, risk modelers have

concentrated their efforts on developing models that are less mathematically elegant than the EUT model but more empirically based for assumptions of rational behavior. One example is Kunreuther et al. (1990), who contrasted a benefit–cost model with one that explicitly includes several psychometric factors.

Another approach to making models more responsive to exotic or highly complex decisionmaking problems involves enlarging the scope of possible costs and benefits to include irreversibilities and morbidity health effects. If greater concerns about environmental risks are linked to greater perceived costs, individuals should be willing to pay some amount to reduce their risk of exposure. However, this modification may continue to indicate risk preferences poorly. Gardner & Gould (1989) showed that expanded definitions of perceived benefits and costs account for no more than a third of the variance in risk preferences. As another example of this approach, Fischer et al. (1991) used a phased procedure to elicit important risk concerns and WTP amounts from respondents. Although environmental risk was mentioned most often by the 460 respondents, it evoked the smallest WTP amount. On the other hand, health risks, which are very directly tied to self-interest but mentioned only half as often as environmental risk, evoked the highest WTP value.

In addition to the arguments about economic rationality and its role in actual decisionmaking, Sagoff (1988) argued that the links between unobservable preferences and operative utility functions are tenuous at best, and, for many environmental risks, nonexistent. Behavioral research strongly challenges the underlying assumptions of a single, stable set of preferences over many environmental goods, especially where there is little personal familiarity with the good in or outside of markets (Fischhoff 1991). Psychologists reject the notion of stable and well-ordered preferences in favor of models that view preferences as adaptable and constructed as needed in particular contexts (Kahneman et al. 1993).

These criticisms have led to something of a crisis for the welfare paradigm. If individuals have labile or constructed preferences for many environmental goods, then it is unlikely that the technical conditions tying preferences to individual welfare will be met. Under these circumstances, results from economic models of behavior and choice seem a particularly inappropriate source of information about improvements to social welfare. Aaron (1994) rescued the welfare paradigm by suggesting that the crisis is not about utility maximization, but rather about assumptions regarding the utility function. He argued that a more realistic model of human behavior is based on a pluralism of motivations that lead to separate utility responses that must be weighed by the individual decisionmaker. Aaron's argument preserves the relationship between preferences and individual welfare, by suggesting a much richer view of utility, that is, multiple sets of preferences that reference personal satisfaction, selfreference, altruism, spite, and the regard of others, a view consistent with Sen (1977) and Schelling (1984).

Another criticism on aggregate welfare was made by Sagoff (1993), who disputed that social welfare is measured or varied by the satisfaction of individual preferences. Although preference satisfaction comprises the core of utilitarianism, Sagoff suggested that "happiness depends more on the quality of our desires than on the degree to which we satisfy them" (1993: 5). Social norms often shape perceptions of satisfaction from the acquisition of wealth, producing a constraint on wants that Marshall (1961) called "material plenty," with a low standard of living, or what Sahlins (1972) called the "zen road to affluence." Like hunter–gatherers, the Amish Mennonite communities of Pennsylvania restrict the wants of their members, with respect to consumer goods, both to maintain group solidarity and to guarantee availability of capital for essential resources (Hostetler 1963). Social groups are able to shape the utility functions of their members even when they are constantly exposed to the wide range of goods that entice members of neighboring communities (Cantor et al. 1992). The variety and pervasiveness of such norms would seem to support Sagoff's position. A related argument was raised by Berndt (1985), whose analysis of the energy theory of value suggested that there may be a collective preference to limit the use of individual preferences for certain policy areas.

Similarly, preferences of economists for market-based incentive solutions to environmental regulation often clash with preferences of environmentalists, who favor a stronger signal about the moral illegitimacy of polluting behavior (Kneese & Schulze 1985). Which preference actually dominates in a welfare sense is a question that has not been addressed empirically.

In summary, many arguments raise questions about the role of consumer sovereignty and the welfare view:

- conceptual shortcomings in the preference–utility–social welfare linkages in the case of complex and uncertain environmental problems
- the absence of explicit treatment for social norms or welfare that is greater than the sum of the parts
- evidence that social preferences predominate over individual preferences.

However, consumer sovereignty remains at the core of the neoclassical framework.

A technical reality of the welfare paradigm is that individual preferences and societal preferences are not likely to coincide in the presence of market failures. Most environmental problems are permeated by market failures, generally involving public goods, health and safety externalities, intergenerational consequences, and high levels of government intervention. Thus, it would be unrealistic to assume that individual and collective preferences coincide for

most environmental problems.

Economists have responded to the problem of missing or incomplete markets by relying on implicit or explicit valuations of hypothetical scenarios. On the other hand, Sagoff (1993) argued that applying the welfare model and substituting hypothetical preferences for actual choices is in fact an imposition by economists of institutional sovereignty on the policy model.

Welfare economists have long been perplexed by the problem of social decisionmaking and representing individual preferences with a social decisionmaking rule. Arrow (1951) demonstrated that the principle of consumer sovereignty cannot be satisfied with a single rule that reflects the preferences of all individuals for all options in the choice set. Realistically, social decisions that impose institutional or expert sovereignty are made all the time, some with little or no public conflict.

Recognizing the many drawbacks of the pure individualistic framework, analysts have developed other frameworks for social decisionmaking that, although falling short of satisfying the Arrow criteria, appear reasonable compromises. Common to all these frameworks is the process of using a subset of the population to decide an issue for the larger group.

For example, Keeney & Raiffa (1976) suggested using the supra-decisionmaker approach. In this approach, the preferences of a small set of public decisionmakers are used to represent the societal preferences and the public interest. The preferences of the decisionmakers can be combined by using a multiattribute utility model, where attributes are weighted by rankings elicited from the public decisionmakers. This approach has been extended as a process to capture the objectives, values, and weights that characterize different stakeholders in an environmental decision problem (for a summary, see von Winterfeldt 1992).

Another approach to construct the social decisionmaker is to use social preferences as revealed by past policy decisions. This approach is consistent with decisionmaking in judicial processes that rely heavily on the precedent of past rulings. In the United States, court rulings have stated that current risk acceptance levels should be determined by reference to past regulatory decisions that deemed a particular chemical or hazard as safe (NRDC 1987).

A third approach to social preferences is to use collective preferences as revealed in social decisionmaking processes (Cox 1986). Such processes include voting, arbitrated negotiation and settlement, and tort-law adjudication. The value of this approach is that it is a distributional rather than point decision framework. Social decisions are not evaluated in isolation, based on the costs and benefits of each alone; rather, each decision is seen as part of a sequence of decisions generated by a socially beneficial decision process or mechanism, possibly involving implicit compromises in which those who lose on one round win on the next, and all win on average in the long run. Fairness and efficiency are evaluated for the sequence, rather than for each decision in it (Cox 1986).

Approaches that reject consumer sovereignty either explicitly or implicitly vary greatly in theoretical sophistication and methodological development. It would be naïve, however, not to recognize the pervasiveness of their use in actual decisionmaking in public policy as well as business and household contexts. In fact, decision processes that violate the spirit of consumer sovereignty are probably the rule and not the exception. One of the more intriguing approaches to bridge the individual and social influences on welfare is the substitution of such concepts as well-being for utility (see Vol. 1, Ch. 3).

Social and cultural influences

In stark contrast to methodological individualism, sociology reminds us that societies are complex ecosystems in their own right, and these societies may be every bit as fragile as tropical rainforests or the delicately balanced atmosphere. Simplistic formulations of the interface between these human ecosystems and the biosphere implicitly assume that society can and must change rapidly to avert disaster, but this assumption renders them inappropriate and perhaps useless.

The real problem here involves the unit of analysis. Although human–ecological frameworks (e.g., Ehrlich & Holdren 1971) and other such schemes apparently focus on society-level effects, in fact they are reductionist in their approach to society. According to this dominant view, population impacts the environment because each person makes sustenance demands on the environment. Affluence and technological development are important because they allow excessive individual consumption of natural resources, greatly increasing the social carrying capacity and thus the population while producing wasteful (and sometimes poisonous) byproducts. Unfortunately, nowhere in this framework can we find an appreciation of sociological forces that both shape our consumption and elimination of resources and mediate our personal relationships to the natural environment. That is, the most important variable that intervenes in the interactions among population, affluence, technology, and environmental impact is poorly represented in the equation: social structure or, more broadly, *social organization*.

Not only are population and economic growth indirectly related to environmental impacts via social organization, but also (net of population and economic development level) social organization exerts a direct (or unique) impact on such phenomena as the global climate or biodiversity. Social organization reflects the institutional and demographic matrix that constitutes any society. Social stratification and the social division of labor; population size, density, and demographic regime; the spatial distribution of human activities; and complex political economy are among the properties of social organization. None of these properties can be attributed to individual human beings, but all shape individual consumption and regulate our personal connection to the environment.

However, most contemporary analysts in this area ignore sociology (the study of social organization), and this may cripple the policy relevance of research on environmental degradation for two reasons. First, a concentration on proximate determinants as an explanation for atmospheric pollution (e.g., the influence of energy consumption on carbon dioxide emissions) is a valid model of the situation, but its policy relevance is limited, since policy actually must affect social, economic, and political processes that in turn affect the proximate determinants. Phenomena such as infrastructural inertia (e.g., sunk investments in "automotive" urban configurations), political or class alliances (e.g., working classes wedded to energy-intensive, state-owned industries), or patterns of social mobility that demand a certain energy regime (e.g., quaternary-services economies) may render both the visible and invisible hands (governments and markets) impotent to change a nation's impact on natural ecology. That is, energy consumption is a symptom of a fundamental set of social processes that heavily condition both the political and economic calculations of rational actors. Climate policy analysis, if it is to prove useful, must begin to gauge (quantitatively, if possible) the degree of influence of these sociological phenomena and analyze their malleability to policy instruments.

A severe decline in a society's key functions (perhaps through a severe energy crisis or ecological disaster) may be met with unemployment, an outward rippling of economic decline, and (eventually) a smaller population. This serves to lower the social carrying capacity permanently in many unpredictable ways. No one chooses the fall of civilization; decline is seldom manageable or predictable, as is demonstrated by the histories of the Mesopotamians, Mayans, or Easter Islanders.

Time, effects across generations, and discounting

Discounting is the technique designed by economists to make tradeoffs, not only between goods in the present and goods in the future but also between the aggregate personal satisfaction of having those goods in the two time periods. For long time periods, researchers are dealing with the problem of overlapping, or perhaps even mutually exclusive, generations. In other words, in addition to a concern that goods are delivered at various points in time, a more challenging modeling complication involves wholly changing economic conditions.

One reason that discounting techniques do not work well over long time periods is an artifact of the mathematics involved: since the present value of future net benefits declines exponentially with time, a large benefit enjoyed 100 years (let alone 1000 or 10000 years) from now can have a negligible present value. To illustrate the point dramatically, a complete loss of the today's world GDP in a hundred years would be worth about a million dollars if discounted at something close to the present prime rate of interest (6–7 percent); the loss of 100 percent of the GDP that the world might support in a hundred years would, however, be worth much more. The choice of the discount rate used also makes a great difference: Employing the usual formula, US$1 billion received two hundred years in the future discounted with a 1 percent discount rate has a present value of US$137 million; at a 10 percent discount rate, the present value is only US$5.27.

Several arguments claim that discounting is ethically inappropriate for decisions that affect future generations. Spash (1994) has argued that climate change could have serious impacts upon future generations while actually benefiting their predecessors. The standard application of cost–benefit analysis to the greenhouse effect, even if all costs and benefits could be calculated from individual preferences, would give the impression that the future is almost valueless, largely because of discounting. Nordhaus (1991) argues that, in the case of high costs, low damages, and high discounting, no greenhouse gas control is justified; whereas, with no discounting and high damages, the efficient degree of control is 30 percent of greenhouse gas emissions. Cost–benefit analysis as commonly applied would use a positive social discount rate. For closely reasoned arguments among economists on the appropriateness of discounting, the effects of long time horizons, appropriate discount rates, and environmental consequences, see Lind (1982), Cline (1992), Nordhaus (1994a), Schelling (1995), Toth (1995), Manne (1995), Bruce et al. (1996), and especially Lind (1995), who addressed several of the objections raised in this section.

Spash (1993) emphasized four common assumptions being made within the standard model that are critical to the normative case for giving less weight to the expected future damages of long-term environmental pollution, than to the same damages in the present. These assumptions address who constitutes the electorate, uncertainty over future preferences, the extinction of the human race, and uncertainty over future events.

In contrast, Adams (1989) opined that our responsibilities to future generations for global climate change are alleviated by higher material standards of living from current investments in technology, capital stocks, and other infrastructure. However, future generations being better off is not equivalent to societies consciously deciding to compensate the future. Undertaking investments with the express purpose of compensating future generations for climate change would imply that the extent to which the future will be better off has in some sense been balanced against all environmental damages. Each case of long-term damage implies compensation that is distinct from catering to the

general needs of future individuals.

Yet the suggestion has been made that spreading the costs of climate change equitably across generations is an acceptable solution (Crosson 1989). This approach relies upon the economic view that changes in units of welfare are equivalent, regardless of their direction. However, doing harm is not necessarily canceled out by doing good. If an individual pays to have a road straightened and saves two lives a year, he or she cannot shoot one motorist a year and simply calculate an improvement (Barry 1983). This argument can be extended beyond the right to life. For example, assume individuals of a nation have an accepted right to live in their own homeland. If the Maldavians are relocated and compensated for greenhouse-gas-induced sea level rise that destroys their homeland, this right has been violated.

The appeal to the *safe minimum standard* can be viewed as an example of constraining economic tradeoffs by introducing rights. In the case of climate change, Batie & Shugart (1989) argued that the safe minimum standard would support emission reductions despite apparently high costs. However, tradeoffs are still allowed once costs become too high.

Along these lines of thought, the literature on discounting contains several suggestions for addressing intergenerational equity and stewardship. According to Howarth (1993), all projects that affect future generations should be examined under the conditions of the precautionary principle before discounting occurs. As articulated by Howarth (1993: 40), this principle holds that "inhabitants of today's world are morally obligated to take steps to reduce catastrophic risks to members of future generations if doing so would not noticeably diminish their own quality of life." Perrings (1989) advocated using the precautionary principle when both the level of fundamental uncertainty and the potential cost or stakes are high—where science is inadequate and ethical judgments are ubiquitous.

Following Howarth's advice, the first question to be addressed is: "Will the project impose catastrophic risks or damages on another generation?" In the case of no catastrophic risk, Burton (1993) advocates a method whereby different intergenerational and intertemporal discount rates are applied to material/commercial and ecological benefits and costs. However, in the case where there is catastrophic risk, then another question must be asked: "Can we take steps to substantially reduce risk without compromising our well-being?" If the answer is yes, we may proceed as above. If the answer is no, then serious consideration should be given as to whether the project should be undertaken and whether discounting or cost–benefit procedures should be used at all.

Others believe that intergenerational discounting is acceptable under some circumstances. Farber & Hemmersbaugh (1993) believed that society's concern should focus on the well-being of future persons, being careful not to expose them to serious deprivation. Even in this case, however, economists disagree about the magnitude and type of discount rate to use (e.g., social discount rate or the shadow price of capital). Nordhaus (1994a) offered a succinct description of the normative economic approach to determining the appropriate discount rate. Using the Ramsey optimal growth model, he derived the discount rate on goods and services (more precisely the real rate of interest) from a combination of time discounting, aversion to inequality, and growth in per capita consumption.

Many discussions of discounting ignore the distinction between discounting goods and discounting utility. The concept of discounting growth follows from a recognition that, if future generations are wealthier than the current one, then current consumption is, in a sense, more precious. It further follows that current costs and benefits should be weighed more heavily than future ones. Arguments suggesting that it is inappropriate to discount significantly the welfare of future generations are based on the position that social rates of time preference (the tradeoff between current and future welfare) should be low. However, this does not imply that the discount rate to be employed in cost–benefit analyses for discounting goods and services should be low. A risk averse society that is growing could still support a large discount rate for goods; low time discounting would simply combine with high discounting for growth to support such a rate.

Burton's (1993) discounting technique incorporated a personal discount factor for the present generation's concerns, and a generational discount factor for matters affecting future generations. Both factors are incorporated in calculations and they interact, producing an lower overall discount factor.

A question that has not been adequately answered is whether, as a result of adopting a widely held environmental ethic, the market-determined discount rates would decline toward the rate preferred by those advancing the stewardship agenda. The question of the impact of the use of a positive discount (or interest) rate on resource exploitation decisions is somewhat more complex than is often implied in the literature. High rates of resource exploitation can be consistent with either high or low interest rates (Norgaard 1991, Price 1991). As an alternative to lower discount rates, Mikesell (1991) suggested taking resource depletion into account in project cost–benefit analysis. (For a useful commentary on the debate about the effects of high and low interest rates on sustainability, see Lipton 1991.) Or it may be necessary to impose sumptuary regulations that constrain current consumption, in an effort to induce society to shift the income distribution more strongly toward future generations.

Many observers clearly feel that, in most countries, efforts to achieve sustainable growth must involve some combination of higher contemporary rates of saving—that is, deferring present in favor of future consumption—and more

rapid technical change—particularly the technical changes that will enhance resource productivity and widen the range of substitutability among resources. Norgaard & Howarth (1991) and Norgaard (1991) argued that decisions regarding the assignment of resource rights among generations should be made on equity grounds rather than efficiency grounds. When resource rights are reassigned between generations, interest rates will change to reflect the intergenerational distributions of resource rights and income.

We can interpret these arguments as saying that, if present generations adopt an ethic that causes them to save more and consume less, the income distribution will be tilted in favor of future generations. However, this is not the end of the story. A decline in marginal time preference has the effect of lowering the interest rate. Improvement in investment opportunities resulting, for example, from technical change will have the effect of increasing the demand for investment and thus raising interest rates (Hirshleifer 1970). But will this be enough?

What should be done, given the inability of economic theory to provide satisfactory tools to deal analytically with obligations toward the future? One answer is that we should take a strategic approach to the really large issues—how much should be invested to reduce the probability of excessive climate change, for example. At the same time, we can continue to employ conventional cost–benefit analysis to answer the smaller questions, such as when to develop the drainage systems needed to avoid excessive buildup of waterlogging and salinity in an irrigation project.

Sociopolitical views of growth

Traditional development theories that relate social structure to industrial development have given little attention to ecological impact. Only the neo-Malthusians have made this a central concern. Some argue that development sociology and economics are irrelevant and that a "new sociology" has to be created before these problems receive the attention they require. Other disciplines, which emphasize different frames of reference (sociopolitical or environmental) provide critical insights into some of the climate-related problems that macroeconomics is trying to solve. In some cases, the problem is completely redefined. An alternative approach is to modify existing development theories to address ecological impact, thereby building on existing knowledge. There are five major approaches to development: neo-Malthusianism, modernization theory, dependency/world-systems theory, ecological evolutionary ideas, and state-centered approaches.

The core neo-Malthusian contention (discussed in more detail above) is that population growth is outstripping ecological limits and hence is the key source of greenhouse gas emissions, but studies such as Bongarts' (1992) analysis shed doubt on this assertion. Population growth may have a simple additive effect, but economic development is more central. However, increased energy consumption tied to development may be offset by increased efficiency which works against the thesis of a development multiplier.

The relationship between population and development suggests the need for macrosocial theory linking the two. The first, the convergence theory of modernization, posits the driving forces of development to be industrialization and global diffusion (Rostow 1960, Moore 1978). Following the painful accumulation of capital necessary for initial industrial takeoff, technological progress forces a gradual shift in the division of labor from primary to secondary sectors and, with the era of high consumption and the huge increase in labor productivity (which expands carrying capacity), the growth of tertiary or service industries. Less industrialized countries develop primarily by global diffusion, that is, borrowing and adapting technologies and the social structures and social psychologies that go along with them. Educational expansion and the building of modern institutions (especially schools, the mass media, and the state) are central facilitators of this process. The logic of industrialism is therefore viewed as the great transformer of traditional societies. Following productivity gains in agriculture, agricultural labor becomes redundant and several changes occur:

- Population shifts from rural to urban residence.
- Social organization becomes more complex and formal.
- Social psychologies evolve to grasp "modernity" (e.g., cause-and-effect).
- Demographic transition occurs as children become less economically essential to the family.

This theory offers several hypotheses. First, energy usage may be a symptom of sectoral evolution. As economies mature, the need for heavy industrial products (e.g., iron and cement) decreases, so infrastructural maturity may place lower stress on the natural environment. Second, sectoral evolution entails a shift from heavy to light industrialization and services, with concomitant shifts in energy requirements. That is, postindustrial societies have passed their dirty industrial stages and should therefore generate lower per capita greenhouse gas emissions. Third, modernization is usually associated with market economics. As economies increase in complexity, competition forces producers and consumers to minimize factor costs, one of which is energy. Complex markets should therefore encourage technological progress that is less hostile to the environment. Fourth, industrial societies are urban societies, and cities can be viewed as economic engines that help producers and consumers enjoy efficiencies of agglomeration. Accelerated communications, centralized consumer and labor markets, and reduced transport and warehousing costs (Henderson 1988) are among the benefits of urbanization that should reduce natural resource extractions and toxic byproducts over time, so highly concentrated space economies should reduce stress on the ecosystem relative to equally developed but less concentrated systems. Finally, modern individuals enjoy high levels of education, private resources, and social proximity to others (via urbanization and telecommunications). Political mobilization in the form of environmental social movements should therefore be much more prevalent in advanced industrial or postindustrial societies. Moreover, given the much greater level of social surplus, these movements should also be more successful, as producer elites can afford to comply with environmental regulations.

Evidence for these hypotheses is scattered, and little of it has been interpreted in the light of modernization theory. The idea of an inverted U-curve of energy intensity is well documented, however. Newly industrialized countries and those at middle levels of industrialization have lower greenhouse efficiency (greenhouse-related emissions per unit of GNP) than their less industrialized and fully industrialized counterparts, whether the analysis be normalized per capita or on GDP (Minzter 1990, Owata 1990). Studies of particular industries and technologies have also found that energy intensity and carbon emissions are greater in heavy industries (especially energy production and cement manufacture) that are strategic to early industrialization (Schipper et al. 1992). Dietz & Rosa (1994) also found an inverted U-curve for development in their cross-sectional analysis of carbon dioxide emissions. Ameen et al. (1994) found negative effects of literacy and urbanization on the growth of industrial energy intensity. Of course, the central criticism of modernization theory is its neglect of sustainability. Traditional modernization ideas have assumed that economic growth is potentially infinite with no ecological limits. The central question is therefore whether modernization processes produce effects that offset environmental impacts. Clearly, much more research needs to be done on the socioeconomic "metabolism" of nations and how this relates to ecological degradation.

In many respects, world systems and dependency theories offer an alternative framework. The central idea is of a global stratification system shaped by uneven political and economic power, with the industrialized countries (the *core*) at the top and underindustrialized countries (the *periphery*), controlled by coercion, international measures, and the inherent logic of capitalism at the bottom (Frank 1967, Wallerstein 1974, Bornschier & Chase-Dunn 1985). A set of newly industrialized countries (the *semiperiphery*) is undergoing a distorted form of development shaped by the core. A central premise is that world capitalism has a developmental logic characterized by unequal exchange, uneven development, and growing ethnoracial and class inequalities. Hence, social structure is largely determined by capitalist relations, which determine the effects of technology, population, and ecological constraints. Like modernization theory, this approach assumes an unlimited ecosystem but, unlike it, places primary emphasis on economic rather than technological determinism.

The theory focuses on the impact of world capitalism on less industrialized countries, and several hypotheses can be derived about the ecological impact of international stratification. First, this approach encourages the view that core countries control the capital and technology and treat less industrialized countries as simple production inputs whose costs must be minimized (i.e., they are "dependent") This means that less industrialized countries have to make economic concessions to attract foreign investment, such as relaxing environmental regulations or providing energy subsidies to multinational corporations (Repetto 1985). A critical precondition is that less industrialized countries have more need for economic integration than industrialized countries have need for resources, or else that the costs of coercion to the industrialized countries are less than the benefits they receive.

Extending this, greater integration of less industrialized countries into the world capitalist system implies weaker environmental controls and greater subsidies to multinational corporations, both of which should reduce their greenhouse efficiency. By this logic, middle income countries should have fewer environmental controls than their poorer neighbors. Second, peripheral economies often experience distorted development, or economic disarticulation. Such economies exhibit a small, modern export sector atop a much larger preindustrial subsistence sector, and this mismatch truncates multiplier effects, lowers mobility across economic strata, and therefore produces a poorer overall rate of national–regional integration (Amin 1976). Ironically, then, some versions of dependency theory might posit lower levels of greenhouse-related emissions in response to lagging industrialization, but higher levels of phenomena such as deforestation as poor populations struggle to obtain subsistence through primary commodity extraction. According to this view, equalizing access to technology and wealth could reduce deforestation and similar phenomena, and allow more rapid and high-quality industrialization earlier (bypassing the dirty early development phase of industrialization).

Little systematic research has been conducted on these questions. Ameen et al. (1994) found that commodity concentration in exports slowed the growth of energy intensity. In another study, Grimes et al. (1994) claimed that a country's position in the world system is indeed related to greenhouse efficiency in an inverted U-shaped curve, which is to say that semiperipheral societies generate on average more greenhouse gas emissions per unit of GNP than do core and peripheral societies. This study is flawed, however, because the authors do not control for industrialization. Their findings support the modernization hypothesis that societies at intermediate levels of industrialization (the heavy industrial stage) emit higher per capita greenhouse gas emissions. In other

words, Grimes et al. provided no critical experiment to differentiate world systems theory from modernization theory. Finally, there is the historical thesis that noncore countries were forcibly incorporated into the world system, thus creating severe inequalities that continue to shape social structures and institutions. Peasant "land hunger" is partially a result of this legacy, leading to deforestation pressures. A close-grained analysis in the Amazon basin showed that severe land inequality was a factor that could be traced to earlier colonialism, although current settlement regulations could be blamed just as easily (Rudel 1989).

A third theory of economic development is ecological evolutionary theory. It can be viewed as complementary to modernization and world systems theories in that it posits the existence of preindustrial social structures that facilitate industrial takeoff and incorporation into the world economy. The adoption of plow agriculture and the resulting increased population densities gave old agrarian societies an evolutionary advantage that facilitated their ready adoption of industrial technology (Lenski & Noland 1984, Nolan & Lenski 1985). These societies had agricultural surpluses that allowed population growth. This, in turn, led to greater urbanization, occupational specialization, administrative growth, and social integration between rural and urban areas, which in turn predisposed these societies toward rapid development once world industrialization was under way (Crenshaw 1992). Rapid industrialization also facilitates occupation of labor-intensive industrial niches within the international division of labor, allowing countries to be upwardly mobile within the world system.

Existing research indicates that agricultural density (net of development) contributes to energy efficiency and thus lowered greenhouse gas emissions. Ameen et al. (1994) found that agrarian population density raised energy efficiency in both manufacturing and services. Jenkins & Crenshaw (1992) also demonstrated in cross section how population densities reduce carbon dioxide emissions per capita. Obviously, much more research is needed on the institutional and demographic inheritances of contemporary nation states. Greater predictive power in forecasting which regions are likely to experience more rapid economic growth, accelerated adoption of new technologies, and concomitant effects on the natural ecosystem might allow some degree of policy intervention.

The fourth set of arguments focuses on the state. Research on the role of different types of state regimes is limited, yet this factor is critical to understanding the social structural constraints on environmental change. Many ideas about the state role are eclectic, some arguing that strong and politically responsive states increase economic efficiency and, by implication, greenhouse efficiency. Others argue that states shelter dominant groups against market competition, reducing economic (and thus energy) efficiency. Recent empirical research suggests that the political regime may have profound implications for environmental concerns, as illustrated by Table 1.6 above.

One line of argument is that stronger states (in the sense of having more centralized authority, decisionmaking power, and enforcement powers) contribute to economic development, thus promoting economic and energy efficiency (Rueschemeyer & Evans 1985, Migdal 1988). This should translate into greater greenhouse efficiency. A related idea centers on the policy responsiveness of the state. Political opportunities facilitate the mobilization of groups to press their interests, including protection from environmental risks. In a comparative study of the nuclear power industry, Kitschelt (1986) argued that strong responsive states provided the greatest possibilities for environmental protection, since the state is able to implement policies and is also responsive to citizen concerns about environmental risks. Strong but unresponsive states, such as France, have weak environmental movements and large, inefficient, and risky energy sectors, whereas weak (decentralized federal system) but responsive states, such as the United States, have strong environmental movements but cannot get the state to effectively provide protection. For Kitschelt, the German state represents the best mix, strong enough to intervene and also responsive. These propositions could be seen as further specifying the political side of modernization theory or as capturing the repressiveness of peripheral states.

A competing line of argument focuses on the inefficiencies created by state interventions. The older and more institutionalized the state, the more it has been captured by organized groups that use the state to protect themselves against market competition (Olson 1982). This means greater inefficiency, which should lead to greenhouse inefficiency. No direct research bears on this question, but the extensive evidence on comparative energy efficiency strongly suggests that state subsidies and market protections reduce energy efficiency (Bates 1993, Schipper et al. 1992, Kosmo 1987). The former Soviet Union exposed its citizens to major environmental risks and still displays one of the world's lowest energy efficiencies at its level of industrialization (Goldman 1972, Owata 1990). Repressive peripheral states among the less industrialized countries have displayed many of the same features, protecting large inefficient industries against market forces (Bates 1993, Kosmo 1987).

In summary, little systematic research has attempted to sort out the importance of different macrosocial theories of development. The best evidence bears on energy efficiency, which is assumed to be a strong determinant of greenhouse efficiency. Although neo-Malthusian ideas and some of the modernization and world system hypotheses have attracted scrutiny, very little work on the ecological evolutionary or state-centered ideas has yet been done. It is too early to forecast what such research might suggest, but it seems obvious that a more complex model of the social structural sources of global change will

eventually develop, incorporating the insights from multiple theories. One of the most promising lines of inquiry may be the interplay among state economic policies, industrialization, and energy paths, as these shape greenhouse efficiency. Existing theories present clear rival hypotheses, suggesting the need for critical tests. They also present points of possible convergence and hence possible synthetic models.

Sustainability ideas

A significant distinction for sustainability concepts is the one between *growth* and *development*. Growth refers to the quantitative increase in the scale of the physical dimension of the economy, the rate of flow of matter and energy through the economy, and the stock of human bodies and artifacts; whereas development refers to the qualitative improvement in the structure, design, and composition of physical stocks and flows, improvements that result from greater knowledge, both of technique and of purpose (Daly 1987). The potential for a more efficient use of natural resources, recycling, and reduction of waste and pollutants means a potential for economic progress based on development (qualitative improvement) rather than growth (quantitative improvement)—an economic progress that is not at the expense of the environment. On the contrary, this concept of progress tries to fit economic activity and human skills into biogeochemical cycles and adjust the economic system within the framework of the overall finite global life-supporting environment (Gilliland & Kash 1994, Viederman 1994).

Sustainability has become a transdisciplinary field of study that addresses the relationships between ecosystems and economic systems in the broadest sense, in order to develop a deep understanding of the entire system of humans and nature. In particular, ecological economics views the socioeconomic system as a part of the overall ecosphere, emphasizing carrying capacity and scale issues in relation to the growth of the human population and its activities, and the development of fair systems of property rights and wealth distribution (Carson 1991). The belief of many that humans can continue on the same path of expansion, that technological progress will eliminate all energy, resources, and environmental limits, and that infinite substitutability can be made between human-made and natural capital is considered by ecological economists to be a dangerous one. Blind faith in technology is viewed as similar to the situation of the man who fell from a ten-story building, and when passing the second story, concluded, "So far so good, so why not continue?"

The emergent paradigm of ecological economics seeks to address the distinction between growth and development, while retaining many of the useful features of neoclassical economics, such as the clarity with which arguments can be made; the emphasis on opportunity costs, and price and profit signals; and the rent-seeking literature. The main features of this new approach, according to Klaasen & Opschoor (1991), are co-evolution, an emphasis on physical limits to recycling and technological improvements (limits that derive from the first and second laws of thermodynamics), and community values that count for more than individual preferences.

Solow (1991) placed sustainability in the context of development by referring to two distinct cases of future economic activity that allow future generations the opportunity to be as well off as their predecessors. The first involves unique resources: irreplaceable assets that should be preserved for their own sake. The second case refers to more mundane assets, and sustainability here does not impose the requirement to bequeath to posterity any particular asset. Sustainability holds each generation to endowing the future with whatever it takes to achieve a standard of living that is at least as good as its own. No generation can consume "humanity's capital," but that capital needs to be defined in its broadest sense. The economic definition of that sense is clear. Except for the unique assets of the first case noted above, resources are not valued for what they are. They are, instead, valued for the goods and services that they provide; and once that perspective is accepted, then the debate over what to do is conducted in the context of ordinary substitutions and tradeoffs.

Key to distinguishing the cases of unique resources from those involving mundane assets is scientific knowledge about the role of technology in widening the substitutability among natural resources and between natural resources and reproducible capital. Economists and technologists have traditionally viewed technical change as widening the possibility of substitution among resources—of fertilizer for land, for example (Solow 1974, Goeller & Weinberg 1976). The sustainability community rejects the "age of substitutability" argument. The loss of plant genetic resources is viewed as a permanent loss of capacity. The elasticity of substitution among natural factors and between natural and manmade factors is viewed as exceedingly low (James et al. 1989, Daly 1991). Considering the production of a particular commodity—for example, the substitution of fertilizer for land in the production of wheat—is an argument over the form of the production function. But substitution also occurs through the production of a different product that performs the same function or fills the same need—of fiber-optic cable subsitituted for conventional copper telephone wire or the replacement of coal by fuels with higher hydrogen-to-carbon ratios, for example.

The argument about substitutability, although inherently an empirical issue, is typically argued on theoretical or philosophical grounds. Historical experience or advances in futures modeling may lead toward some convergence of perspectives. But the scientific and technical knowledge needed fully to resolve disagreements about substitutability will always lie in the future. The issue is

exceedingly important. If a combination of capital investment and technical change can continuously widen opportunities for substitution, imposing constraints on present resource use could leave future generations less well off. If, on the other hand, real output per unit of natural resource input is narrowly bounded, that is, it cannot exceed some upper limit which is not too far from where we are now, then irreversible damage, or perhaps even catastrophe, is unavoidable.

A well-known operating principle for researchers at the interface of ecology and economics is that the scale and rate of throughput of energy and matter passing through the economic system is subject to an entropy constraint. Intervention is required because the market by itself is unable to reflect this constraint accurately (Pearce & Turner 1990). Daly (1984) found no more reason to expect the market to find the optimum scale than there is to expect it to find the optimum income distribution. Just as the market adjusts to ethical constraints imposed on income distribution, so the market will adjust to ecological constraints imposed on the scale of throughput. Daly's analogy with the Plimsoll line on a boat clearly illustrates this. Suppose economists want to maximize the load that a boat carries. If they place all the weight in one corner of the boat, it will quickly sink or capsize. They need to spread the weight out evenly and, to do this, invent a price system. The higher the waterline in any corner of the boat, the higher the price for putting another kilogram in that corner, and the lower the waterline, the lower the price. This is the internal optimizing rule for allocating space (resources) among weights (alternative uses). This pricing rule is an allocative mechanism only. With lack of information and true uncertainty, the rule keeps on adding weight and distributing it equally until the optimally loaded boat sinks to the bottom of the sea. What is lacking is a limit (albeit dynamic) on scale, a rule that says "stop when total weight is one ton, or when the waterline reaches the red mark" (Daly 1984).

Figures 1.3, 1.4, and 1.5 illustrate this concept in relationship to two other prevalent visions of the future. Figure 1.3 shows the conventional economic optimistic view of ever-continuing growth (in terms of the above definitions) of the human-made components of capital at the expense of natural capital. Environmentally minded individuals within the conventional camp argue that this growth can be used to fund preservation of some of the remaining natural capital, but only as a luxury, since natural capital is not necessary to operate the economy and could be driven to zero without causing collapse of the economy. Figure 1.4 illustrates a more realistic (but pessimistic) view that shows overexpansion of the human economy, causing collapse of the ecological life-support system and ultimately collapse of the economy that depends on it. The collapse may be more or less severe and allow for recovery afterward, but this is still not a very desirable vision of the future. The third vision (Fig. 1.5) indicates the distinction between growth and development, the ecological "Plimsoll line" (including uncertainty) and the possibility for continued development (in terms of the above definitions), if the physical dimensions of the economy are maintained below the planet's carrying capacity. This vision of the future encapsulates the essential characteristics of ecological economics.

Ecological economists speak of natural capital, human capital (and/or cultural capital), and manufactured capital when categorizing the different kinds of stocks that produce the range of ecological and economic goods and services used by the human economy (Daly 1994, Berkes & Folke 1994). The latter two are sometimes referred to together as human-made capital (Costanza & Daly 1992). These three forms of capital are interdependent and to a large extent complementary (Daly 1994). As a part of nature, humans with our skills and manufactured tools not only adapt to but modify natural capital, just like any other species in self-organizing ecosystems (Ehrlich 1994, Holling 1994, Jansson & Jansson 1994).

Ecological economists argue that natural capital and human-made capital are largely complements (rather than substitutes), and that natural capital is increasingly becoming the limiting factor for further development (Costanza & Daly 1992, Daly 1994). Therefore, to sustain a stream of income, the natural capital stock must be maintained. This does not mean an unchanged physical stock, but rather an undiminished potential to support present and future human generations. A minimum safe condition for sustainability (given the huge uncertainty) is to maintain the total natural capital stock at or above the current level (Turner et al. 1994). An operational definition of this condition for sustainability means that (Barbier 1989, Costanza & Daly 1992):

- the physical human scale must be limited within the carrying capacity of the remaining natural capital
- technological progress should be efficiency increasing rather than throughput increasing
- harvesting rates of renewable natural resources should not exceed regeneration rates
- waste emissions should not exceed the assimilative capacity of the environment
- nonrenewable resources should be exploited, but at a rate equal to the creation of renewable substitutes.

Carrying capacity depends on the resilience of ecosystems and the behavior of the economy–environment system as a whole (Common & Perrings 1992, Perrings 1994, Holling 1992, 1994, Jansson & Jansson 1994, d'Arge 1994, Costanza 1991).

In the context of biological conservation and human welfare, the major challenge from the ecological economics perspective is to maintain the amount

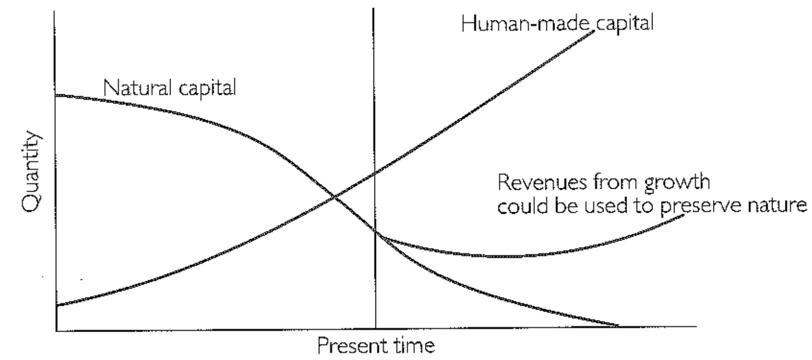

Figure 1.3 The economic optimist vision.

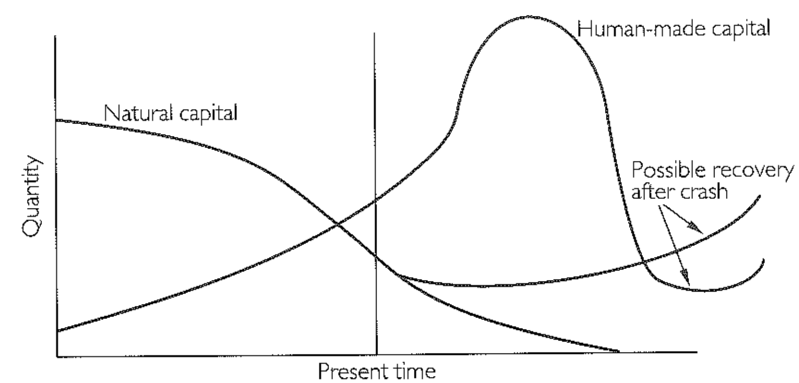

Figure 1.4 The environmental pessimist vision.

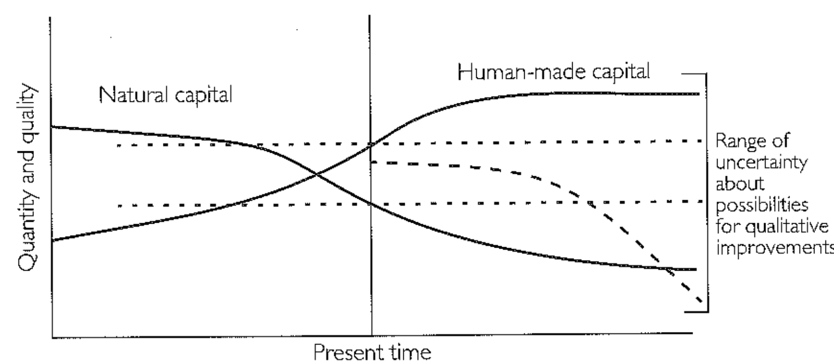

Figure 1.5 The ecological economic vision.

of biodiversity that will ensure the resilience of ecosystems, and thereby the flow of crucial renewable resources and ecological services to human societies (Perrings et al. 1992, Perrings 1994). This perspective maintains the importance of ethical and moral concerns for biodiversity conservation (Norton 1986) or people's preference value for particular species even when they do not know the species' role in the system (d'Arge 1994). Such a hierarchy of values has to be explicitly stressed in discussions of biodiversity conservation and sustainable development.

In economic modeling, a hierarchy of values is relevant for estimating opportunity costs. Ecological economists assert that natural capital is rapidly becoming scarcer, and it is inappropriate to calculate the net benefits of a project or policy alternative by comparing it with unsustainable options. The economic allocation rule for attaining a goal efficiently (maximize present value) cannot be allowed to subvert the goal of sustainability that it is supposed to be serving (Daly & Cobb 1989). When project appraisal raises development versus conservation conflicts, decisionmakers may require that cost–benefit analysis be used to choose between alternatives only within a choice-set bounded by sustainability (ecosystem stability and resilience) constraints (Bishop 1993, Turner et al. 1994).

In addition, Solow (1991) noted the recent attention paid by many economists to the depletion of nonrenewable resources and recurring threats to the very existence of other environmental assets. He has joined others to suggest also how a new *net national product* (NNP) might be constructed by subtracting a measure of their depreciation. He noted that the logic of the economic theory of capital allows construction of a net national product, but he has taken this argument a step further by suggesting that the creation of such a measure of net economic activity might provide the sound logic upon which to base the more elusive notion of sustainability. Solow argued that calls for sustainability must amount to injunctions to preserve productive capacity for the indefinite future if they are to be more than emotional slogans that rapidly lose intellectual and practical content. For Solow, the calculation that produces an adjusted net national product is essential for placing a strategy of sustainability on a firm footing.

Tobin & Nordhaus (1972) advocated an approach called *new economic welfare* (NEW), which would subtract items such as the unmet cost of pollution and the disamenities of urbanization. More recent attention paid to the environment has suggested adding the value of environmental services and the appreciation of natural resources (e.g., carbon fixing in forests) and subtracting government expenditure for preserving environmental assets, defensive expenditures by households against environmental threats, environmental damage more broadly defined, and the depreciation of natural resources

(Serageldin & Steer 1994, US NRC 1994).

Proper accounting, in other words, would turn any nation's capital stock into an indefinite retirement annuity for the future. If reasonably accurate measures of the value of each year's depletion of nonrenewable resources were available, then economies could see that they owed themselves a certain volume of investment to compensate for that year's withdrawal from the inherited stock. The appropriate policy would then generate an economically equivalent amount of net investment so that the broadly defined capital stock would be sustained for another year.

Table 1.9 provides insight into more aggregate measures that speak directly to national sustainability. It shows estimates of the proportion of national income devoted to saving in select economies (private plus public saving), the proportion of income devoted to depreciation on human-made capital (the NNP adjustment), and estimates of the proportion of income reflected in damage or depreciation to natural resources or the environment. If the computed net savings rate is positive for an economy, then it can be judged by this measure to be sustainable; the conclusion is opposite if savings turn out to be negative.

No real surprises in the locations of the various nations are recorded in Table 1.9. Highly industrialized countries populate the sustainable category, although not exhaustively; and less industrialized countries come up short. The United States is listed as sustainable, but only to a limited degree because its base savings rate is relatively low. High savings are no guarantee, though. Indonesia saves proportionately more than the United States and the same as Brazil, but the Indonesian economy falls below the line. Comparing the United States and Indonesian cases with other countries therefore shows clearly that this is entirely an economic measure. The likelihood of sustainability can be improved by either preserving natural resources and the environment or by maintaining a high national savings rate, and the linearity of the sustainability index implicitly assumes that the two are perfect substitutes in its calculation.

Ecological economics stresses that uncertainty is fundamental, large, and irreducible, and that particular processes in nature are essentially irreversible (Clark & Munro 1994, Costanza 1994). Instead of locking the world in development paths that may ultimately lead to destruction and despair, humans need to conserve and invest in natural capital, in the sense of keeping life support ecosystems and interrelated socioeconomic systems resilient to change (Hammer et al. 1993, Holling 1994, Jansson & Jansson 1994, Perrings 1994).

One of the primary reasons for the problems with current methods of environmental management is the issue of scientific uncertainty—not just its existence, but the radically different expectations it engenders and the ways that have been developed to deal with it. If people are to successfully manage the environment, they must understand and expose differences about the nature of

Table 1.9 Sustainability of selected national economies.[a]

Economies	S/Y −	δ_M/Y −	δ_N/Y =	Z
Sustainable				
Brazil	20	7	10	+3
Costa Rica	26	3	8	+15
Czechoslovakia	30	10	7	+13
Finland	28	15	2	+11
Germany (pre-unification)	26	12	4	+10
Hungary	26	10	5	+11
Japan	33	14	2	+17
Netherlands	25	10	1	+14
Poland	30	11	3	+16
United States	18	12	4	+2
Zimbabwe	24	10	5	+9
Marginally sustainable				
Mexico	24	12	12	0
Philippines	15	11	4	0
Unsustainable				
Burkina Faso	2	1	10	−9
Ethiopia	3	1	9	−7
Indonesia	20	5	17	−2
Madagascar	8	1	16	−9
Malawi	8	7	4	−3
Mali	−4	4	6	−14
Nigeria	15	3	17	−5
Papua New Guinea	15	9	−7	−1

Note: S = national savings; Y = national income; δ_M = depreciation on manmade capital; δ_N = depreciation and damage to natural resources and the environment; Z (weak) = sustainability.
Source: Pearce (1993).

uncertainty and design better methods to incorporate it into the policymaking and management process (Costanza & Cornwell 1992, Costanza 1994).

To understand the scope of the problem, analysts must distinguish between risk (which is an event with a known probability, sometimes referred to as *statistical uncertainty*) and true uncertainty (which is an event with an unknown probability, sometimes referred to as *indeterminacy*).

Risks and uncertainties abound in reducing natural capital because of very imperfect understanding of the life-support functions, the inherently limited predictability of ecosystems and social systems (Holling 1994), and a limited capability to invent technical substitutes for natural functions. Such complex systems as ecological and economic systems are fundamentally evolutionary and nonlinear in causation and of limited predictability (Costanza 1991, Holling 1994). Therefore, policies that rely exclusively on social or economic adaptation to smoothly changing and reversible conditions lead to reduced options, limited potential, and perpetual surprise.

Ecological economists stress the need to remember that substituting for

natural capital in one place requires natural capital from elsewhere, and that losses of life-support functions are often irreversible. In the face of uncertainty and irreversibility, the approach favors conserving natural capital and designing management instruments that are adaptive, flexible, and acknowledge uncertainty as a sound risk-averse strategy (Pearce & Turner 1990, Ludwig et al. 1993, Costanza 1994, Duchin & Lange 1994, Arrow et al. 1995).

However, we are very far from being able to design either an adequate technological or institutional response to the issue of how to achieve sustainable growth in economic development—or how to achieve sustainable growth in both the sustenance and the amenity components of consumption.

For example, in spite of the large literature in agronomy, agricultural economics and related fields, no package of technology is available for transfer to producers that can assure the sustainability of growth in agricultural production at a rate that will enable agriculture, particularly in less industrialized countries, to meet the demands that are being placed on them (Board on Agriculture, US NRC 1991, 1992, Rosenberg & Eisgruber 1992). The value to be placed on such studies is limited by the absence of clarity about the concept of sustainable agricultural development, suggesting that researchers approach the issue of technological and institutional design pragmatically.

Sustainability is appropriately viewed as a guide to future agricultural research agendas rather than as a guide to practice (Ruttan 1994). As a guide to research, a useful definition would include the development of technology and practices that maintain or advance the quality of environmental resources, improve the performance of other production inputs, and facilitate the substitution of nonpolluting technology for less environmentally benign technology. The research agenda on sustainability needs to explore what is biologically and technically feasible without being excessively limited by present economic constraints.

At present, the sustainability community has not been able to advance a program of institutional innovation or reform that can provide a credible guide to the organization of sustainable societies. Humans have yet to design the institutions that can ensure intergenerational equity. Few would challenge the assertion that future generations have rights to levels of sustenance and amenities that are at least equal to those enjoyed (or suffered) by the present generation. They also should expect to inherit improvements in institutional capital—including scientific and cultural knowledge—needed to design more productive and healthy environments.