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AN INTELLECTUAL HISTORY OF ENVIRONMENTAL ECONOMICS

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■ **Abstract** From modest beginnings in the 1960s, environmental economics has grown to be a major subdiscipline of economics. It combines traditional work in the field of welfare economics and the theory of economic growth with more recent perspectives on the political economy of choosing policy instruments and the philosophy of sustainable development. The central tenets are that environmental problems have their roots in the failure of economic systems to maximize human well-being, that environmental quality matters for human well-being and for more traditionally oriented economic growth objectives, and that efficient policy can be achieved through incentive design.

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INTRODUCTION: THE ORIGINS OF ENVIRONMENTAL ECONOMICS

The origins of environmental economics lie in the 1950s when, in the United States, Resources for the Future (RFF) was established in Washington, DC. RFF is an independent research organization that has both developed and applied economics to a large array of environmental issues. The early focus at RFF was on the issue of natural resource scarcity, prompted by the U.S. President's Materials Policy

Commission (the Paley Commission). The Paley Commission was asked to review the future supply of minerals, energy, and agricultural resources in light of the formidable demands made on these resources by World War II. RFF's early work focused on the same issue, culminating in the influential and widely cited work *Scarcity and Growth*, by Barnett & Morse (1) in 1963, together with Christy & Potter's statistical analysis of historical resource price trends (2) in 1962. But it was in the 1960s that environmental economics truly came of age. The political backdrop was the first environmental revolution initiated by Rachel Carson's *Silent Spring* (3) in 1962. Carson's warnings about the effects of agrochemicals in the environment were not new, but they were cogently put and had already gained public attention earlier in the same year with a series of three articles in the *New Yorker*. That economics should have a lot to do with environmental concerns of the kind raised by Carson was not surprising. First, agrochemicals were and are big business. Second, the use of chemicals such as DDT had done a lot to raise agricultural productivity and protect human health. Third, economists were already familiar with the idea that there are likely to be costs and benefits from any form of economic activity. The costs take the form of "external effects," in this case the alleged loss of biological diversity about which people had begun to care far more than previously. It is no surprise, then, that economists began to link the theory of external effects with an economic interpretation of the rising tide of environmentalism.

Like all subdisciplines of economics, environmental economics borrowed heavily from thought of its precursors. The idea of an externality, a detrimental (or beneficial) effect to a third party for which no price is exacted, was already familiar from the work of Pigou (4) in the 1920s. Pollution damage fitted neatly into this framework. Polluters cause damage to third parties but may not be required to pay for that damage. Because market-oriented economic systems did not account for externalities (any more than planned ones such as the former Soviet Union did in practice), those systems could not be maximizing human well-being. Intervention in some form to internalize the externality—to get the third-party effect included in the internal costs of the polluter—was justified.

That policies could be evaluated in terms of their costs and benefits, with costs and benefits defined in terms of human preferences and willingness to pay, was established by Dupuit in the nineteenth century (5, 6). The body of modern-day welfare economics was established by Hicks (7, 8), Kaldor (9), and others in the 1930s and 1940s. Practical guidelines for using welfare economics in the guise of cost-benefit analysis were drawn up first for the water sector in the United States. Considerable attention was also being devoted to the wider issue of efficiency in government, especially military spending, by bodies such as the Rand Corporation. In 1958 three seminal works appeared: Eckstein's *Water Resource Development* (10), Krutilla & Eckstein's *Multipurpose River Development* (11), and McKean's *Efficiency in Government Through Systems Analysis* (12). The feature of these works was the synthesis of practical concerns with the theoretical welfare economics literature. The essential step was the justification for the benefit-cost

principle: justifying projects or policies on the basis that benefits exceed costs is wholly consistent with there being losers, i.e., those who suffer the costs. The Kaldor-Hicks compensation criterion had established that projects were nonetheless justified because gainers could compensate losers, such that losers would be no worse off, and gainers would still have a net benefit. This implies that, provided the compensation takes place, no one is actually worse off, thus meeting the long-established Pareto criterion for an improvement in overall well-being. However, actual compensation need not occur: It is necessary only that it could take place.

In a separate strand of intellectual development, the idea that any natural resource had some optimal rate of use had been established formally by Gray (13) in the early twentieth century and later by Hotelling (14). Initially, these optimal use theorems were confined to natural resource economics as opposed to environmental economics. The distinction between the two was that the former was mainly concerned with rates of exhaustible resource depletion and the determination of optimal harvest rates for renewable resources. Environmental economics, on the other hand, focused on pollution. The distinction largely broke down once it was recognized that theorems from the former were applicable to the latter contexts, especially where pollutants were cumulative, and also in the context of the theory of optimal economic growth. The growth theory contributions culminated in elegant if demanding treatises in the 1970s, e.g., Dasgupta & Heal (15). Mathematical models of economies with single exhaustible natural resources were in turn stimulated by real world issues. In 1973 the first Organization of the Petroleum Exporting Countries' (OPEC) oil price increase occurred, which prompted concerns about the stability of fossil fuel–dependent economic systems. The optimal use rate for a renewable resource, such as a fishery, was the subject of a separate literature dating mainly from Gordon's 1954 paper on fisheries as a common property resource (16). Gordon also explained why a fishery faced with open access, i.e., totally absent property rights as opposed to common property where rights exist for a defined community, could be exploited to the point where all economic rents were dissipated. By implication, if certain other conditions are present, open access may be consistent with extinction of the resource. Interestingly, the paper that commanded substantially more attention for saying the same thing (although confusing common property and open access) was Hardin's 1968 paper "The Tragedy of the Commons" (17). Hardin is a human ecologist, and "Tragedy" has been one of the most reprinted articles in the environmental literature.

Nonetheless, even today, textbooks tend to preserve the distinction between natural resource and environmental economics. For reasons of space, the rest of this paper adopts the distinction and focuses on environmental rather than natural resource depletion issues. The history of natural resource economics has yet to be written, but there is considerable historical perspective in Fisher's 1981 text (18).

Another precursor literature relevant to the birth of environmental economics is that relating to some notion of the ecological limits of economic activity. The environmental movement of the 1960s had begun to focus on the apparently wasteful

lifestyles of the occupants of modern economies, prompting a logic that said if these lifestyles were endangering the planet, then the lifestyles must change. Gradually, the unsustainable lifestyle issue became synonymous with the pursuit of economic growth, and the antigrowth movement was born. But even this movement was not new. The notion of absolute limits was central to Malthus's concerns 160 years before. Ricardo had developed a separate notion of scarcity arising from rising marginal costs of resource extraction and use. John Stuart Mill had analyzed the notion of a stationary state in which critical stocks of population and capital were perpetually constant. These concerns about ultimate constraints to economic activity surfaced again in the now neglected work of Kapp, *The Social Costs of Private Enterprise* (19), published in 1950. But probably the most celebrated paper to provoke the many questions subsequently to be analyzed in environmental economics was Boulding's 1966 "spaceship Earth" essay (20). Boulding likened planet Earth to a spaceship in which there is a finite supply of energy, which can only ultimately be replaced with solar power, and a finite supply of water and materials, which can only provide a sustainable future if they are reused and recycled. Viewed with more than 30 years' hindsight, Boulding's essay sets the foundations for what many today would still regard as a sustainable society, one that operates within the limits set by finite supplies and finite flows of materials and energy. Production and consumption cease to be good things and instead, attention has to be paid to the maintenance of stocks of assets, including the stock of knowledge that Boulding rightly foresaw as one of the means of improving the human lot without changes in physical resources.

Boulding's essay remains to this day the basis of ecological economics, where the focus is still on physical limits and where technological change through human capital formation is not regarded as an obvious and viable means of escape from those limits. Within environmental economics, however, Boulding's work prompted a different development. The theory of external effects had concluded that, when present, externalities will produce suboptimal levels of human well-being. But until Boulding's notion of spaceship Earth, externalities were generally regarded as fairly minor and manageable deviations from the optimum. *Silent Spring* had already suggested exactly the opposite—agrochemicals were pervasive to economic systems. Externalities were showing up long distances from the sources of emissions and were cumulating through time as well. Spaceship Earth similarly invoked the first law of thermodynamics to point out that whatever was taken out of natural resource sectors must reappear in equal weight as waste, which will likely affect the environment when disposed of: Matter and energy cannot be created or destroyed. As economies expand in the economic sense, so they are likely to expand in terms of physical resource extraction and hence in terms of physical waste emissions to the environment. Worse, economic activity chemically transforms materials and energy into waste gases: Carbon becomes carbon dioxide, for example. These transformations become systematically more and more diffuse, or entropic, and hence less and less easy to recapture in terms of materials reuse and recycling. Moreover, energy cannot be recycled at all, although waste gases can

be captured. But if waste is pervasive to economic systems and if environmental systems have finite capacities to receive waste, then externalities are also likely to be pervasive, as Ayres & Kneese showed formally in the first materials balance model of an economy (21).

A final important contribution was Coase's "Problem of Social Cost" (22). Coase observed that an externality context was conducive to two potential solutions. The first, familiar from the work of Pigou, was a tax on the creator of the externality (the polluter), or some form of regulation that imposed the burden of action on the polluter. The second involved the sufferer paying the polluter not to pollute. In the first case, the polluter pays and in the second the victim pays. Coase argued that, in terms of efficiency (though not in terms of distributional burdens), the solutions were equivalent. For those opposed to more state regulation, in this case in the name of environmental quality, Coase's argument opened up a substantial potential for free market environmentalism. The state was redundant except perhaps in terms of setting the conditions under which such market bargains took place. While there is a tendency to dismiss Coase's second solution as being unfair, one real world context in which it operates occurs when the polluter is a low-income agent and the sufferer a high-income agent. It is not uncommon for states suffering transboundary pollution, for example, to provide grants and technology for the upgrading of polluting technology in the polluting country.

The pieces of the economic jigsaw were now in place. Welfare economics provided the analytical foundations for determining optima in economic systems. Within welfare economics, externalities were transformed from being fairly minor deviations from the optimum to being pervasive, central, and potentially large. Economic systems could therefore be significantly inefficient. The materials balance principle, embodied in the notion of spaceship Earth, established that there could be limits of a Malthusian kind unless technological change provided an escape. Economic growth models in which resource endowments were explicitly modeled came up with the same answer—an optimal world might require significant intervention, but it might also be unsustainable without technological change. The instruments for achieving optimality had also begun to be forged. Pollution taxes and perhaps Coaseian bargains provided efficient solutions, and these instruments were soon to be joined by perhaps one of the most ingenious policy instruments of all, the tradable permit.

SUSTAINABLE DEVELOPMENT

Sustainable development has become a central notion in modern economic policy. Its most celebrated formulation comes from the World Commission on Environment and Development (the Brundtland Commission) (23):

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

- the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given, and
- the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs [(23) p. 43].

In economic terms, the definition involves the notion of an economic system in which well-being per capita increases over time on a sustained basis. A similar, far less researched notion, would apply to the current distribution of well-being. But economic growth models traditionally adopted the same temporal perspective by looking at growth paths of utility and consumption. Hence it seems appropriate to reinterpret traditional growth theory in terms of sustainable development. Growth models were concerned with what the optimal path of consumption, and hence well-being (or utility) looked like, and also, incidentally, with whether such a path is sustainable or not over long periods.

Defining sustainable development in terms of sustained per capita increases in well-being needs to be distinguished from stating the conditions for the achievement of such increases. Like traditional growth theory, the modern theory of sustainable development is based on notions of capital assets as the means of generating well-being. Along with developments in growth theory, e.g., endogenous growth theory, capital is decomposed into human-made capital, human capital (knowledge, skills), natural or environmental capital, and social capital. The condition for sustainability (or potential sustainability) is that the sum of these assets, i.e., total wealth, should increase in per capita terms over time. Intergenerational rules of behavior follow immediately, e.g., that each generation should bequeath to the next generation a capital endowment no less than the one it has now. This interpretation of sustainable consumption was debated in the 1930s, with Hicks in 1939 setting out the notion that it involved maximum consumption consistent with maintaining capital assets intact (24). The resulting *Hicksian income* measure can then be interpreted as "the interest on total wealth."

The links between sustainable development and traditional neoclassical growth theory can be illustrated. Ignoring technical change and population growth, one central equation describing an optimal path of consumption is given by the Ramsey rule:

$$\frac{\dot{C}}{C} = \frac{\alpha R^{\beta}/K_M^{1-\alpha} - d_M - \rho}{\mu}.$$

Here C is consumption, and hence the left-hand side of the equation is the percentage growth rate of consumption. The first expression on the right-hand side is the marginal productivity of human-made capital, assuming a Cobb-Douglas production function in human-made capital (K_M) and natural resources (R). The growth rate of consumption depends upon the utility discount rate (ρ), the marginal productivity of human-made capital, the elasticity of the marginal utility of consumption (μ), and the rate of depreciation on human-made capital (d_M). Following

Dasgupta & Heal (15), consider what happens to the consumption path as $R \to 0$. Since $\rho > 0$, the rate of growth of consumption becomes negative. To avoid this, let $K_M \to 0$ as well. But if $K_M \to 0$, then so does income and consumption. The implication is that the optimal path of consumption eventually goes to zero. Obviously, this is not consistent with any notion of sustainable development.

The discussion is sufficient to establish that optimality, defined in terms of maximizing the present value of future consumption streams, is not necessarily consistent with sustainability. This nonsustainability comes about because of positive utility discounting or because particular features of the depreciation of human-made capital, and despite working with a Cobb-Douglas production function in which a fair degree of substitutability between human-made and natural capital is assumed (in fact the elasticity of substitution is unity in this model).

The Ramsey growth path above is based on a highly simplistic model. The potential nonsustainability of the model can be made worse by allowing population to grow, so that the chances of bequeathing rising per capita wealth are less. But one optimistic perspective on population growth is to allow its rate of growth to be a determinant of technological change, which raises the productivity of capital assets in the sense argued by Boserup (25). How far Boserupian technological change describes real world contexts is debated in the literature. But more generally, the omission of technological change from any growth model makes the model seriously unrealistic.

One consumption path emerging from a model with technological change is:

$$\frac{\dot{C}}{C} = g - \beta\rho,$$

where g is the growth rate of the efficiency of production inputs (the growth rate of total factor productivity), and it is interpreted here to reflect technological change. The β is the exponent on R in the production function and is interpreted as the elasticity of output with respect to the rate of resource use, R. The ρ is familiar as the utility discount rate. The growth rate $\dot{C}/C$ will be positive if $g > \beta\rho$, i.e., if the rate of technical progress exceeds the elasticity of output with respect to the natural resource multiplied by the pure time preference rate. Results of this kind are familiar from the 1970s literature on optimal growth (26–28). Technological change has the potential to rescue optimal growth paths from being unsustainable.

MEASURING SUSTAINABLE DEVELOPMENT

The Earth Summit at Rio de Janeiro in 1992 gave a strong impetus to the search for measures of sustainable development. However, almost all of the resulting indicators of sustainability are simply indicators of environmental and economic change. A sustainability indicator should have the property of giving at least a first approximation of whether a given economy is sustainable or not. The Rio Summit called for the development of revised measures of gross national product (GNP) to

reflect this concern. In the 1990s, environmental economists developed indicators based on the capital theory of sustainable development outlined above. The GNP is a poor measure of well-being because it implicitly assumes there is only one capital asset—human-made (or reproducible) capital. Revising the GNP to reflect changes in other assets turned out to be intuitively simple, although debate continues on the various adjustments, and measurement problems abound. An extensive guide to modern national income theory is given in Hartwick (29).

Ignoring other forms of capital, the proper measure of well-being is net national product (NNP) rather than GNP because capital depreciation does not contribute to well-being—it merely replaces depreciated stocks. In 1976 Weitzman (30) showed that current period consumption plus investment is, if held constant and the present value taken, just equal to the present value of consumption along an optimal path. The theoretical foundations for modifying the national accounts were subsequently set out in various papers by Hartwick (31) and Mäler (32). Solow (33) also showed that increases in national product from some baseline value are equal to the discount rate multiplied by the cumulated capital wealth from the baseline period to the current period. In other words, national product becomes interest on total wealth, the Hicksian income concept introduced above. An expression that modifies NNP to be an appropriate indicator of well-being is:

$$\mathrm{NNP} = \mathrm{GNP} - \mathrm{d_M} - \mathrm{d_N} - \mathrm{d_H} - \mathrm{d_S}.$$

In each case d refers to net depreciation and subscripts M, N, H, and S refer to human-made, natural, human, and social capital, respectively. In turn GNP is made up of consumption C and gross investment, I. Since $\mathrm{I} - \mathrm{d_M} = \mathrm{I_{net}}$, or net investment, the revised measure of NNP becomes

$$\mathrm{NNP} = \mathrm{C} + \mathrm{I_{net}} - \mathrm{d_M} - \mathrm{d_N} - \mathrm{d_H} - \mathrm{d_S}.$$

In terms of measurement, $\mathrm{d_M}$ is estimated in conventional national income accounts. Thus $\mathrm{d_N}$ will be made up of any increases in environmental assets (e.g., growth of renewable natural resources) less any use rates (harvest), i.e., $\mathrm{d_N}$ will be positive if resources are used more than sustainably and are negative otherwise. By definition, $\mathrm{d_N}$ will be negative for exhaustible resources, but allowance needs to be made for the discovery of exhaustible resources. The $\mathrm{d_H}$ is likely to be negative, i.e., human capital appreciates as knowledge and skills increase through time in a cumulative fashion. The $\mathrm{d_S}$ could be positive or negative with indicators such as crime rates, family breakdown, etc., indicating depreciation of social capital.

For this measure of true or "green" NNP to be estimated, each depreciation indicator needs to be measured in monetary terms. The issue of money valuation thus arises (see below). The correct unit valuation in each case is the economic rent, i.e., price minus marginal cost. While data on rents are difficult to come by, the valuation issue for marketed products—fisheries, timber, energy, for example—is not complex in principle. But where the asset being depreciated is not marketed, the problem arises of finding individuals' willingness to pay to prevent those changes

(or to secure a gain). Probably the largest, and most controversial, research effort in environmental economics has in fact been devoted to this issue of valuing nonmarketed asset change. The focus has been on environmental assets. Only now is attention being paid to the valuation of changes in social assets. The development of valuation procedures is discussed shortly.

Empirical attempts to estimate modified national accounts predate the interests of environmental economists in green NNP [for a review see Eisner (34)]. The first set of accounts to incorporate environmental depreciation was produced in 1989 for Indonesia by scholars at the World Resources Institute in Washington, DC (35). The adjustments involved deductions for the rents foregone in the petroleum and forestry sectors and for output losses from soil erosion. The resulting "net domestic product" (a confusing term since it has a direct meaning in conventional accounts) grew at 4% per annum from 1971–1984 compared to recorded gross domestic product (GDP) growing at 7.1%; although after 1975, growth rates in the two magnitudes were almost identical, which illustrates one of the problems of interpreting modified national income measures. Essentially, a modified product measure could grow less fast, just as fast, or faster than conventional GDP. It is not intuitively obvious what this means for sustainability. Several dozen studies of modified national income have been published since the World Resources Institute study and are reviewed in Hamilton & Lutz (36).

The World Resources Institute study did in fact show an alternative illustration in terms of net "true" investment, i.e., investment minus the depreciation on environmental assets. Pearce & Atkinson (37) established that the correct measure of sustainability could be expressed in terms of "genuine" savings. Savings can be thought of as a fund set aside to cover depreciation on assets. A simple rule then emerges to the effect that savings must be greater than depreciation on all assets for an economy to qualify as potentially sustainable. Savings minus depreciation equaled genuine savings. The notion of genuine savings was subsequently extended and its theoretical underpinnings more rigorously established in a sequence of papers by Hamilton, for example (38). The concept was adopted by the World Bank, and genuine savings indicators appear for over 100 countries (and across time) in the Bank's annual publication *World Development Indicators*, [see also (39)]. By and large, economies with high ratios of savings to GNP have positive genuine savings, i.e., are in principle sustainable. This result is as one would expect from traditional development economics. That more developed economies emerge as being sustainable is not therefore surprising. But high-consuming countries, such as the United States, do not fare well on the genuine savings indicator; neither do natural resource-dependent economies, e.g., Middle East oil economies, unless depletion is compensated for by investment in other capital assets—bearing out the "Hartwick rule" for sustainability (40).

One surprising feature of the various modifications to indicators of sustainability is the omission of population change, i.e., measures have not been expressed in per capita terms, even though this is an obvious requirement if the indicator is to reflect sustained well-being. Recent efforts to measure changes in per capita total

wealth show that even modest rates of population change can put sustainability at risk (41).

Although growth theorists can legitimately argue that the economic growth models of the 1970s had already encompassed the issue of sustainable development, it seems fair to say that the wider political embrace of the concept in the 1990s has stimulated the substantial progress in conceptual models of sustainability and its measurement. This development contrasts starkly with the broader and ever-growing literature on sustainable development, much of which lacks the rigor brought to the subject by environmental economists.

ECONOMIC VALUATION

Although modified national accounting requires that asset depreciation be valued in monetary terms, efforts to develop valuation techniques arose directly, and far earlier, from project appraisal and, eventually, policy appraisal. Initial efforts to broaden the coverage of environmental impacts in investment (project) appraisal involved the addition of some form of environmental impact appraisal to statements of costs and benefits. This remains the dominant form of appraisal. Its obvious weaknesses are that environmental impacts are not fully integrated into the appraisal process and that simply conducting an environmental assessment is easily construed as having taken account of environmental concerns, without the assessment affecting project design or even the final decision.

Welfare economics had established (partly through the rediscovery of Dupuit's work) that market prices are conceptually the correct measure of the economic value of a marginal change in the supply of a marketed economy. But for nonmarginal changes, the relevant magnitude is the sum of consumers' and producers' surpluses, and to estimate these requires knowledge of demand and supply curves. The same welfare economics also established that all such changes in well-being arising from a project (later extended to policies also) should be included in a cost-benefit appraisal. In practice, the first conceptual guidance was followed and the latter ignored because environmental changes—usually referred to as intangibles—were ignored. The basic assumption appeared to be that changes in surplus for nonmarketed goods could not be estimated. Two of the triumphs of environmental economics have been to emphasize the incompleteness of appraisals that omit environmental change and to develop the means of incorporating environmental values into appraisal.

In fact, there had been early suggestions on how to value some environmental benefits. Responding to a request from the U.S. National Parks Service in 1947 about the worth of national parks, Hotelling actually set out what today is known as the travel cost method (42). The parks had no entrance fees so the problem was similar to that analyzed by Dupuit in the 1840s—there was no market for roads and bridges, but people obviously were willing to pay for them. In the park case there were expenditures associated with the recreational use of the park, notably the costs

of traveling to the park. Because people traveled different distances, the costs they faced varied. In principle, treating the differential costs as prices meant that the demand curve for recreational visits could be derived. The resulting area under the demand curve gave an estimate of the total consumer surplus accruing to visitors to the recreational site. Hotelling's response was ignored by the National Parks Service since other respondents had expressed a consensus view that the problem could not be solved although his note appeared in the Parks Service report on the issue (42). Ten years later it resurfaced, first in a study of recreational use of the Feather River in California (43) and almost simultaneously in work from Resources for the Future (44, 45). Since then, hundreds of travel cost studies have been carried out, mainly, but far from exclusively, in the United States, where various pieces of legislation have required that the benefits of sites be demonstrated. Methodologies have been refined and techniques have been extended to cover benefit estimation in the context of multiple recreational sites. Various issues remain debated: how to deal with the value of time and the treatment of joint benefits where visits are part of a broader travel experience. A significant feature of travel cost studies is that they involve surveys of users to determine their mode of travel and the starting point of the journey. Many issues of survey design and securing adequate and truthful responses arise in travel cost, just as they do in the "stated preference" procedures to be discussed below. A detailed survey and guide to travel cost techniques is given in Ward & Beal (46).

The travel cost method is a "revealed preference" approach to valuation: Individuals' preferences for a nonmarketed good are revealed through the inspection of other markets. A second form of revealed preference relates to property—land and housing—markets. The intuition is again simple. Property prices are capital values that reflect the implicit rentals arising from the asset, rentals that in turn reflect the value of the flows of services from the asset. If environmental characteristics are one feature of those services then, in principle, it should be possible to decompose the values of each of the characteristics, including the effect of the environmental variable(s) on property prices. Proofs that these relationships bear formal connection to measures of welfare change came after the first attempts to use property prices. Ridker (47, 48) established statistical links between levels of air pollution and property values in St. Louis, Missouri. Essentially, the value obtained is the coefficient on air pollution in a regression of property prices on determining factors. (His study is also of interest because it devotes one chapter to the assessment of the avoided costs of cleaning materials if air quality is improved and another to valuing the epidemiological links between air pollution and human health using forgone output and burial costs).

The obvious question, however, was whether the resulting coefficient is actually a welfare-consistent measure. The regression equation linking property prices to the bundle of price-determining characteristics became known as the "hedonic price function." Its derivative with respect to the environmental pollution is the "implicit price function," so that the value of the coefficient in the hedonic price function can vary with the level of the environmental characteristic. Although most

hedonic property price studies stop at the estimation of this implicit function, once the change in environmental quality is nonmarginal, implicit price estimation is insufficient as a measure of the change in welfare, and a complex two-stage procedure is required to estimate an actual demand curve (49, 50). As a general rule, the coefficient on pollution in the regression equation produces an implicit price, which is a theoretically sound measure of welfare change provided the environmental change is marginal, but not otherwise. Even where the estimation problem is resolved, the resulting welfare measure is incomplete because it excludes (*a*) changes in the welfare of any landlords, (*b*) effects of changes in environmental quality on supply conditions generally, and (*c*) changes in welfare accruing to nonhouseholders (e.g., visitors). Efforts to provide a more encompassing measure of the change in welfare have defined the recent contributions to the hedonic price literature (51, 52).

The notion of an hedonic price is general. Early work on hedonic models tended to focus on air pollution, as discussed above, and noise nuisance. Most studies used regression approaches to estimate the relevant implicit price, but some attempted direct estimation of the coefficient through questionnaires of estate agents (realtors). A notable attempt in the United Kingdom using the latter approach in a study of aircraft noise was the work of the Roskill Commission on the siting of London's third airport (53, 54). The early aircraft and road traffic noise studies were reviewed by Nelson (55, 56).

One other major area of research using the hedonic approach has been on the valuation of risks to life. The principles are the same as for hedonic property prices, but the dependent variable is the labor wage, and the independent variables are wage-determining factors such as skill level, unionization, and risk. Traditional approaches to valuing life risks involved estimating the forgone output due to premature death, the idea being that society forfeits the (net) product of the individual concerned. Apart from obvious anomalies, such as retired persons appearing to have no value to their remaining lives, this approach has no basis in the theory of welfare economics. Schelling appears to have been the first to note the relevant concepts of willingness to pay to avoid a risk and willingness to accept compensation to tolerate a risk (57). The resulting "value of a statistical life" is an aggregation of individual risk valuations. Assume the probability of dying next year is 0.004 for each person, and assume there are 1000 persons in the population. A hypothetical risk reduction policy reduces the risk to 0.003, a change of 0.001. If each person values this risk change at $1000, the aggregate willingness to pay is $1 million. The change in risk will result in one statistical person being saved each year (1000×0.001). Thus the value of a statistical life is $1 million in this example. What is being valued is aggregate willingness to pay (or accept, in the hedonic wage case) for the change in risk. The phrase "value of statistical life" has caused many problems for economists because it is easily shortened to "value of life," which raises moral concerns about procedures for placing money values on life itself. But the central economic proposition remains: No society allocates all its resources to life-saving, nor does any society treat lives worldwide as if they have equal monetary

value. Some of the sensitivity surrounding life valuation is avoided by noting that the policy context is one of ex ante valuation not the valuation of identified ex post deaths (58). The impossibility of avoiding monetary valuation was noted very early on in a neglected classic paper by Thomas (59).

Travel cost and hedonic price methodologies are examples of revealed preference approaches to valuation. The underlying theory of economic valuation was eloquently brought together in Mäler's 1974 classic treatise (60), which also set out some of the theorems relating to the choice of policy instruments. In addition, Mäler devoted some attention to what today would be called stated preference techniques, basically the elicitation of the willingness to pay from the use of questionnaires. Mäler was concerned with the classic Wicksell problem of misrepresentation of preferences in such contexts, i.e., whether it is possible to design questionnaires that avoid the incentives that respondents otherwise have not to tell the truth. He concluded that it was impossible to guarantee truth telling, or incentive compatibility as it has come to be known, but that directions of bias could be defined. According to Hanemann (61), the idea of using questionnaires appears to date from a suggestion by Ciriacy-Wantrup in 1947 (62) when addressing the issue of how to derive a demand curve for soil conservation measures. As with the travel cost method, however, the suggestion was not taken up, and the first, unrelated, efforts to use what came to be known as contingent valuation occurred in 1958 and 1961. The 1958 exercise related to recreationists in the Delaware River Basin (63), and the 1961 application related to recreationists in the Maine woods (64). Soon after, contingent valuation studies multiplied rapidly. Only now, in the new millennium, are there signs of shifts away from contingent valuation toward other stated preference techniques that do not involve direct questions such as "what are you willing to pay?" and "are you willing to pay $X?" This shift, which should not be exaggerated, reflects concerns that direct questions may strain cognitive abilities in respondents. Other stated preference techniques such as conjoint analysis, choice experiments, and contingent ranking and rating (terminology, unfortunately, varies) are now used on an increasing basis, but with the limitation that not all of these approaches are consistent with the underlying theory of welfare economics.

Stated preference techniques have secured a major place in the valuation armory of the environmental economist. Particular attractions are that, in principle, such approaches can elicit all the kinds of economic value relevant to a policy or project decision. In particular, they can elicit values placed on an asset by nonusers of the asset, i.e., those who may want to have the asset preserved or improved, but who do not make direct use of it. This notion of "nonuse" or "passive use" value came to be extremely important, and controversial, in the practical applications of stated preference techniques. A second reason for the use of stated preference techniques is that questionnaires elicit far more information than stated willingness to pay. For example, motivations for being willing to pay are a standard part of most contingent-valuation exercises. Such studies have served to underline the richness of human motivation. Motives such as altruism, stewardship, concern for future generations, etc., have been shown to be important. Although there is nothing in

economics that requires motivations to be of the self-interest variety, it remains the case that economists have themselves contributed to the fallacy that economic man has only selfish motives. This does not mean that a multiplicity of motives avoids all problems—the extent to which values based on altruistic motives, for example, should be included in aggregated values has been the subject of some controversy.

So important did contingent valuation, in particular, become that it resulted in several sets of guidance from practitioners. Most applications occurred in the United States because various pieces of legislation and court assessments on environmental damages allowed such methodologies to be used. In contrast, European environmental liability legislation is far more limited, and economic valuation methodologies have rarely been used in liability cases. Nonetheless, government use of contingent valuation has grown in Europe, although the United Kingdom is probably the only example where contingent valuation has been used to measure damages as the basis of environmental taxation. In the United States, Mitchell & Carson (65) produced a detailed guide to contingent valuation. Coincidentally, the same year, 1989, saw the running aground of the Exxon oil tanker, *Exxon Valdez*, in a remote part of Alaska. A contingent valuation study by Carson & colleagues (66) focused on the nonuse values of the general public and found that total damages, as measured by willingness to pay to avoid an accident, ranged from $2.8 billion to $9.3 billion. In the event, Alaska State and the U.S. Federal Government settled for around $1 billion in damages. Exxon, however, initiated an attack on contingent valuation, and the resulting controversy was partly responsible for the creation in 1992 of a distinguished panel of experts to appraise the credibility of contingent valuation. The National Oceanographic and Atmospheric Administration (NOAA) Panel itself set out an extensive set of guidelines for the implementation of a contingent valuation study. An example of one of the more important recommendations was that values must be "sensitive to scope," i.e., values must vary with the scale of the environmental effect (67). While not themselves uncontroversial, the NOAA guidelines are widely used in modern contingent valuation studies. European guidance on contingent valuation and other stated preference techniques is contained in Pearce et al. (68), and detailed guidance on choice modeling (i.e., stated preference techniques other than contingent valuation) can be found in Louviere et al. (69).

All stated preference studies have tended to be controversial, because the issue, identified as early as Wicksell, of whether respondents are telling the truth remains central to the debate. While a few efforts have been made to look at charitable donations as a means of eliciting nonuse values, it remains the case that stated preference techniques are the only means of uncovering these values. Nonuse value had been identified first by Krutilla in a seminal paper in 1967 (70). The main feature of nonuse value is that it has no "behavioral trail" and so will not appear in conventional estimates of demand curves for environmental assets. The same is true for another notion of economic value, option value, first identified by Weisbrod in 1964 (71). Although nonuse value relates to a positive valuation independently of use now or in the future, option value relates to a willingness to pay now for the option to make use of the asset in the future, regardless of whether

the option is exercised or not. Substantial debate arose over both concepts, with early lack of consensus fostered partly by different definitions and terminology. At some time in the 1980s, the notion of "total economic value" (TEV) emerged, with TEV defined as the sum of use values (the usual measure of consumer surplus), option values (seen as a premium over and above consumer surplus), and nonuse values. By and large, nonuse values have proved to be important for environmental assets with a degree of uniqueness about them.

COST-BENEFIT ANALYSIS

Although most of the conceptual foundations for cost-benefit analysis developed independently of environmental economics, the integration of environmental impacts into cost-benefit analysis did lead to some significant changes. The most obvious was that, through the techniques for measuring the economic value of changes in environmental assets, cost-benefit analysis became more complete in its coverage. Given that cost-benefit had always claimed to measure all changes in well-being with a project or policy, and given that, via the materials balance principle, all projects and policies do have environmental impacts, this process of extending cost-benefit analysis was important.

A second contribution to change came from the new focus that environmental issues gave to the choice of the discount rate. The problems with positive discounting had always been known—far-distant effects could be substantial but, expressed in present value terms, could quickly become insignificant. This raised issues of fairness through time, and later it also appeared inconsistent with sustainable development because the latter appeared to imply that current generations should not impose significant costs on future generations. An assembly in 1977 of the leading analysts on discounting, once again arranged by Resources for the Future, produced an impressive, technical volume on all the arguments about selecting discount rates (72). After nearly 500 pages of exposition, a policy analyst was not much wiser about what rate to select despite a masterly (and still widely recommended) attempt at consensus by Lind in the introduction to the volume. A more recent volume, produced as a deliberate follow-up to the first set of essays, offers more guidance, especially because of a short but incisive essay by Weitzman (73). Weitzman suggests that the apparent trivialization of large future costs by discounting arises from a confusion between discount rates and discount factors. Treating the latter rather than the former as a random variable can be shown fairly simply to produce the result that the discount rate declines over time. Weitzman even offers some rules of thumb about what appropriate short- and long-run discount rates are. No one would pretend that the issue is resolved, but there is an elegance about Weitzman's solution.

A third area in which environmental economics modified cost-benefit analysis arose from the contribution of Krutilla & Fisher (74). The problem developed from the use of cost-benefit procedures to evaluate projects that had irreversible

effects, e.g., the flooding for hydroelectricity of an environmentally important valley. It did not seem justified to commit resources to a project that yielded benefits (electricity) for a possibly very short period of time (given rates of technological change that would displace such technologies), while incurring a perpetual loss of natural amenity. One major adjustment to cost-benefit procedures had already been suggested in Krutilla's 1967 essay (70), i.e., the inclusion of nonuse values of the environmental amenity as part of the opportunity cost of the development. Option values in the sense of Weisbrod were also relevant. The second adjustment was to build in the rate of technological change as a decay factor in the benefits of development, which lowers the present value of the benefits of the electricity by effectively raising the discount rate applied to development benefits. The third adjustment involved raising the present value of the benefits of the amenity by lowering the effective discount rate applied to those forgone benefits. The rationale here was already familiar: If environmental assets are fixed in supply and demand for them grows through time, there will be a relative price effect that will inflate the conservation benefits. The end result was a modified cost-benefit algorithm that appreciated the benefits of conservation and depreciated the benefits of development, which biased the rule more in favor of conservation.

A final consideration involved the value of delaying irreversible action. Delay generates more information, and more information provides for better decisions. Because the context of most decisions is one of uncertainty and because uncertainty pervades our knowledge of the natural environment and how it provides for the life forms it supports, there is a value to be attributed to conservation over and above all the previous considerations. Essentially, conservation generates information. Also initially called option value, generating confusion with Weisbrod's concept, this notion subsequently became known as quasi-option value. Quasi-option value reflects the value of information gained from the delay in making an irreversible decision. The notion also underlies options theory, which, originally formulated in the context of financial markets, results in a modification to cost-benefit analysis as shown by Dixit & Pindyck (75). The same idea can also be utilized to make some sense of "the precautionary principle," widely adopted in national and international legislation, but which has little formal meaning. Quasi-option value suggests there is a value to caution in a world of irreversibility and uncertainty.

While the basic infrastructure of cost-benefit analysis remained intact during these developments, the modifications have proved to be very important. Environmental economics has therefore improved and extended cost-benefit analysis.

THE CHOICE OF POLICY INSTRUMENTS

The last major theme in the development of environmental economics relates to the choice of the means of achieving an environmental goal. Traditionally, environmental policy has been based on what came to be known as "command-and-control" policies. Although widely used as a piece of terminology, it is not

always clear what distinguishes command and control measures from other policy instruments. One strong form of command and control combines setting a target and telling the regulated party how to achieve the target. The most obvious example here is the technology-based environmental standard that works by telling the polluter what technology to use either in production of the good he is producing or in terms of abatement equipment. The standard (e.g., level of emissions) is whatever the technology achieves, and the means of achieving the standard is the technology itself. In other cases, standards may be prescribed with the polluter left alone to decide how best to achieve the standard. Most literature would classify this approach also as command and control, but it is clearly primarily a command with the control being left to the polluter. In contrast to these approaches, environmental economists have been concerned to advance the use of economic instruments or market-based instruments. Examples would be pollution taxes, deposit-refund schemes, and tradable pollution or resource permits. The focus of these instruments is on sending a price signal to polluters or resource users. The price can be either explicit, as with an environmental tax, or derived from a quantity control, as with the price of tradable permits.

The virtues of these approaches lie in the theoretical expectation that they will (*a*) minimize the costs of complying with regulations, and (*b*) stimulate technological change because the tax (or need to buy permits) is avoided if pollution is reduced. The notion of an environmental tax related to the money value of environmental damage dates from Pigou (4). Pigou argued that, where "marginal private net product" deviated from "marginal net social product" (i.e., when there is an externality) intervention through a tax would be justified as a means of maximizing the "national dividend" (economic welfare). While the idea of setting taxes equal to the marginal externality remains the cornerstone of the environmental tax literature, Baumol & Oates early on demonstrated that taxes still have the desirable feature of minimizing compliance costs even in contexts where an arbitrary standard is set (arbitrary from the standpoint of welfare economics, that is) (76). The intuition is simple. For any tax rate, each polluter will abate pollution up to the point where his marginal abatement costs just equal the tax. Hence the marginal abatement costs of all polluters are equal, and this is the condition for minimizing the sum of all abatement costs. If firms recognize this cost minimizing theorem, it becomes difficult to explain why they are usually hostile to environmental taxes. Some of the reasons suggested include (*a*) that they pay the tax on all pollution, optimal and nonoptimal, whereas command and control procedures impose costs only on the levels of pollution above the standard, and (*b*) the suspicion that what starts as an environmental tax can quickly become a general revenue-raising tax.

Advocacy of environmental taxation has been one of the hallmarks of environmental economics. A dominant figure in the early advocacy was Allen Kneese who, along with John Krutilla, was widely regarded as one of the fathers of environmental economics. Both were long associated with Resources for the Future. Kneese wrote one of the first textbooks on the subject in 1977 (77), just as he also contributed substantially to communicating research results on the economic value

of the environment (78). In 1964 Kneese authored an important book on regional water quality management (79), which was extended and reissued four years later (80). The volume set out to show that water management in the United States had not been informed by any balancing of costs and benefits nor by attention to cost-minimizing market-based incentives. Although critical of the management system in the Ruhr basin in Germany, Kneese & Bower reported favorably on the pioneering efforts made there to bring rational economic concepts to bear on that system.

The more recent debate on environmental taxation has centered on the so-called double dividend debate. Traditionally, economists did not concern themselves with what happened to tax revenues (although some of Pigou's work did suggest that he favored earmarking of taxes). The idea of the double dividend is that a tax on pollution yields revenues that can then be used to finance a reduction in some other distortion in the economy, a reduction in labor taxes for example. In this sense a single instrument, the tax, secures two goals or dividends—the reduction in pollution and the reduction in labor market distortion. Another way of looking at environmental taxation is that it always yields two dividends—the pollution reduction and the benefit of whatever the tax revenues are spent on. The new interest in double dividends arises because of the presence of existing distortions, i.e., the analysis concerns what happens in a second-best world. It is usual to distinguish at least two forms of the double dividend hypothesis. The weak form accepts that the environment will be better with the tax than without and that well-being will also improve relative to a situation in which tax revenues are redistributed as lump sums. The strong form says that there will be two improvements in well-being, which ignores the lump sum transfer baseline. But whether either double dividend exists is open to debate. Much depends on the interactions between the environmental tax and other distortions. For example, the environmental tax may raise the cost of polluting goods, which reduces consumers' real incomes. They may or may not be better off with the tax than without it. What is required is a general equilibrium modeling of the tax. The double dividend is thus far from assured (81, 82).

In terms of the practical relevance of environmental taxation to policy, an important event was the creation of the Environment Directorate at the Organisation for Economic Co-operation and Development (OECD) in Paris. This Directorate has been a persistent advocate of economic instruments generally; its early work focused on taxation. It formulated the "Polluter Pays Principle" in the early 1970s very much along Pigouvian lines, although, by the time of publication, the formulation had been watered down to make almost any regulation imposing a cost on polluters consistent with the principle (83).

The origins of marketable permits lies with the work of Dales (84), a Canadian economist. Again, the basic notion is a simple one. Given the need to meet some target, say X tonnes of pollution, and the source of the pollution is Y emitters, distribute permits equal to X tonnes to the emitters, and then allow them to buy and sell the permits. Because pollution without a permit is not allowed, each emitter will reduce pollution so long as the cost of doing so is less than the price that would have to be paid for a permit. High abatement–cost polluters will therefore tend to buy permits, and low-cost polluters will sell permits. The market in permits will

determine an equilibrium price for the permits. That such a system will minimize compliance costs was formally demonstrated by Montgomery (85), but the intuition is the same as that for the Baumol-Oates cost minimization theorem for taxes.

While much younger in concept than environmental taxes, tradable permits have developed rapidly in practice. They have been most widely used in the United States for the control of acidic pollutants, but they have also been used to control overfishing in several countries. Tradable water rights also exist in various countries, the goal again being to ensure that scarce water supplies are allocated to those who have the highest use value for the water. Farmers with water on (or below) their land, for example, can then sell the rights to extract the water to other users with higher willingness to pay for the water than that of the farmer. Interestingly, tradable quota systems are not confined to high-income economies—tradable water rights have been in place in Chile for two decades, and Chile also has an incipient tradable air pollution permit market. Significantly, the continuing discussions on how best to tackle global warming have led to a reasonably widespread consensus that tradable greenhouse gas permits must be an integral part of the system of control. Trading will take place not only within national borders, but also under the provisions for the "flexibility mechanisms" in the Kyoto Protocol, trading will also occur internationally. Whether a fully fledged international emissions trading scheme will develop remains to be seen, but there has already been over a decade's experience with bilateral joint implementation schemes whereby an emitting nation can offset some of its target by reducing greenhouse gas emissions in other countries.

In the cases of environmental taxes and tradable permits, what was essentially a theoretical literature a few decades ago has now become practical policy. Environmental taxes are extensive in OECD countries and are emerging fairly fast in middle-income and even low-income countries. Tradable permits extend across traditional air pollutants, fisheries, and water, and they are beginning to emerge in the solid waste sector through tradable recycling obligations and tradable landfill quotas. At one level, then, academic environmental economists have been enormously successful in getting their ideas adopted. On another level, it remains surprisingly unclear just how successful the instruments have been themselves. There is a great need for more ex post study of the effectiveness of economic instruments.

ECOLOGICAL ECONOMICS: A NEW PARADIGM?

No history of environmental economics, however brief, would be complete without reference to the dissension that pervades the subject. Probably the most substantial difference of view at the moment concerns ecological economics and the extent to which it defines a new paradigm when compared to environmental economics. Any brief survey is also bound to do a disservice to the group claiming the title of ecological economics because the literature is growing rapidly and it is far from clear that the subject is a coherent one. This is as one would expect if indeed it is a new subject.

Ecological economists probably regard environmental problems as being far more serious than do environmental economists. This shows up in fairly urgent

clarion calls for action. If so, the issue is an empirical one, and not one that can be resolved by theorizing. There is far greater emphasis on limits in the ecological economics literature; limits set by the carrying capacity of the Earth and its environments. This is evident in the work of Herman Daly who has long been an advocate of antigrowth as a means of keeping world economic systems within the biogeophysical limits of the Earth [see (86)]. Daly's work is very much in the spirit of Boulding's spaceship Earth essay and has also been heavily influenced by the work of Georgescu-Roegen (87), which has stressed the role of the second law of thermodynamics, increasing entropy, in making an economic system consistent with maximum recycling and maximum use of renewable energy. Little seems to be said by ecological economists about technological change—an introductory text by the leading advocates of ecological economics does not discuss technological change at all (88).

A second feature of ecological economics, which follows on from the greater focus on limits, is its rejection of the substitutability assumption implicit in the use of neoclassical production functions. This shows up most clearly in the debate over sustainable development. Measures such as green NNP and genuine savings assume substitutability among all forms of capital. Thus, while ecological economists would accept the notion of Hicksian income as income that can be sustained without running capital assets down, they would add a strong sustainability constraint to the effect that the existing stock of natural capital should not depreciate. Although not formally demonstrated in the ecological economics literature, it is possible to show that this added constraint further lowers the level of consumption per capita than can be sustained through time. In turn, this appears to be consistent with the ecological economists' view that overconsumption accounts for much environmental degradation and that lifestyle change is required. The notion of strong sustainability is attractive in many respects. However, it begs the question of how the optimal stock of natural capital is determined, unless what is intended is that what there is is optimal.

A third feature of ecological economics, also following from the previous points, is a rejection of the smoothness of the various production functions in neoclassical economics. If there are discontinuities in ecological systems, then comparatively small variations in economic variables may bring about collapse of ecological systems. Although this is an extension of the rejection of substitutability, it also has implications for the choice of environmental policy instruments. It would appear to suggest a preference for quantity-based command and control regulations because instruments such as environmental taxes are not certain in their effect. Equally, such a view may be consistent with the adoption of tradable permit schemes.

Fourth, ecological economists are far more suspicious of the practice of discounting future costs and benefits and of monetizing environmental damage. The stance against monetization follows logically from the view that the environment has no substitutes. However, the extent to which the literature is consistent in this respect is debatable. Some ecological economists appear, for example, to embrace modified green national accounting, which assumes substitution and monetization.

Others reject monetized national accounts in favor of satellite systems where monetized accounts have attached to them physical statements about changes in natural resource endowments. Similarly, the stance on discounting is ambiguous. Like many environmental economists, ecological economists express a concern that high discount rates discriminate against future generations and hence against sustainability. It was observed earlier that this result is not new and emerges clearly from the optimal growth literature of the 1970s. But how far discount rates should be lowered, even to zero, is not clear, and the literature sometimes reads as if one should not discount at all. But zero is a discount rate, and zero discounting would have profound implications for the distribution of well-being between current and future generations, lowering well-being now to very low levels in the name of future generations. Again, the role of technology appears to be ignored, and there is perhaps an implicit substitution of a survivability criterion for a sustainable welfare criterion.

A final issue is perhaps less significant in dividing ecological from environmental economists, but it seems fair to say that ecological economists want to revisit the well-known fact in welfare economics that what is economically efficient is not necessarily optimal from the standpoint of a social welfare function. Essentially, social welfare functions are concerned with procedures for aggregating the well-being of individuals. Rules for aggregation will depend on what constitutes a fair or deserving distribution of benefits and costs, an issue that may reflect assumed sets of rights. As is well known, there are many such rules, and there is no unique rule by which just distributions can be judged. The issue of how to weight individual gains or losses between people now and, for that matter, people across generations is not resolved in the philosophical literature nor in the economics literature. Nor, many would argue, can it be. There are as many forms of cost-benefit analysis, for example, as there are social welfare functions. Ecological economists tend to emphasize one set of social welfare functions, for example those stressing the rights of future generations. Environmental economists may not be so motivated, although many are. The issues are complex because it is not clear whether nonexistent beings can be said to have any rights at all, an issue much debated in the moral philosophy literature. Although these differences between ecological and environmental economists should not be exaggerated, they are not resolvable by logic.

It may be no surprise if ecological economics has contradictions and ambiguities; it is a new subject, and it appears to be a broad church, embracing many different persuasions. What is true is that it provides a refreshing challenge to environmental economists who might otherwise not challenge some of the fundamental assumptions underlying their own subject.

CONCLUSION

Environmental economics is remarkably young as a subdiscipline of economics. It can claim at most a 50-year heritage dating from the formation of Resources for the Future in 1952, and more probably, a 40-year duration dating from some

of the seminal works of the 1960s by the likes of Boulding, Krutilla, Kneese, Dales, and Weisbrod. The 1970s onward saw a lengthy period of theoretical consolidation in terms of valuation theory and policy instrument design, together with the most important advances in optimal growth theory in the presence of environmental constraints. The last decade has witnessed a greater effort to produce an environmental macroeconomics through the focus on sustainable development and, not covered in this essay, environment, and international trade. From humble beginnings in the 1960s and 1970s, the discipline now boasts two major international federations of environmental economists, the (North American–based) Association of Environmental and Resource Economists and the European Association of Environmental and Resource Economists. Ecological economists have formed their own association, the International Society for Ecological Economics. Perhaps more important, theoretical exercises, in what to the public are obscure journals, a few decades ago have been transformed into practical policy measures that now figure in the armory of environmental policy in the political world. Even if major obstacles remain, it is no longer necessary to explain the language of environmental economics to decision makers. That situation has been changed for ever.

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