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Exhaustible Resources, Economics of

This article reviews research into how an economy uses natural resources, the inputs to production and human enjoyment received as part of nature's bounty. The resources examined are termed exhaustible because, in principle, their stocks are subject to exhaustion as a result of human consumption. This is clearly evident for coal, oil, and gas, and concern that humankind will run out of these resources has provided much of the impetus for the development of natural resource economics, as a field of study. Populations of fish and other species are also depletable, in the sense that their stocks can be extinguished. Through growth these resources are capable of providing continuous flows of consumption, however, and for this reason are called renewable. Resources incapable of growth are called nonrenewable.

The fields of natural resource and environmental economics are closely connected, not just by common intellectual roots, but by a simple physical identity. Natural resource economics is concerned with the study of how naturally occurring commodities, fossil fuels, metallic minerals, fish, wood, and water, are used as inputs by an economy. Environmental economics is concerned with the emission of waste or residual products; substances that cause air pollution, water pollution, and litter from the economy into the environment. Because matter can neither be created nor destroyed, the mass of natural resource inputs withdrawn from the environment and put to work in an economy must be matched in the long run by an equal mass of waste products back into the environment. This connection makes it difficult, and sometimes arbitrary, to separate natural resource and environmental economics as subdisciplines.

This discussion is organized by individual resources. Nonrenewable resources are examined first, and the discussion here focuses mainly on fossil fuels. This is followed by a general introduction to topics in renewable resources, with specific subsections on fisheries, forestry, and water resources. (The examination of water is confined to groundwater, and excludes issues of water rights, surface water management, and water pollution. These topics arguably belong to the fields of agricultural and environmental economics.) Space limitations have forced the omission ofsome important areas of research from this survey. These are noted in Sect. 3, which also points to areas where research activity is presently most active.

1. *Nonrenewable Resources*

A natural resource is nonrenewable if it does not grow naturally, and if the sum of future consumption services it can yield is therefore bounded by the existing stock. (Nonrenewable resource theory is treated in detail in Dasgupta and Heal 1979, Chaps. 6–8, 10–12, and 15 and in Fisher 1981, Chaps. 2 and 4. A recent review of nonrenewable resource scarcity is Krautkraemer 1998.) Natural gas, petroleum, and coal are nonrenewable resources because the act of consuming a unit reduces the stock, and hence future consumption opportunities, by a like amount. Metals such as copper are also nonrenewable, although consumption must be carefully defined in such cases to account for recycling. (Recyclable natural resources are still nonrenewable, because it is impossible to completely recover scrap.)

Public concern regarding nonrenewable resource scarcity is nothing new. Concern is particularly urgent when the resources in question are the energy inputs so vital to an industrial economy and exhaustion, or even a sharp price increase, would have large macroeconomic effects. The fact that consumption must eventually go to zero leads to an obvious question: when? Common measures express scarcity as the ratio of the existing resource stock to current consumption; if consumption continued at current levels, this would represent the number of years remaining until exhaustion.

Measuring scarcity in this way is misleading for two reasons. First, as explained shortly, the basic economic model of nonrenewable resource use predicts that resource prices will rise continuously as depletion proceeds. This will cause resource users to seek substitutes, reducing consumption and mitigating scarcity. Second, there are several physical measures of the existing resource stock, and their economic relevance varies from measure to measure. The largest possible measure is crustal abundance—the physical stock in some portion of the Earth's crust. This measure surely overstates ultimate consumption, as much of the planet's endowment is technically impossible or extremely expensive to extract. A second measure is current or proven reserves—known deposits that can be profitably extracted at current prices and extraction costs. As prices rise, proven reserves will expand, so this measure surely understates ultimate consumption. 'Ultimately recoverable' reserves are proven reserves plus deposits that are currently not profitable but are expected to be in the future. Such measures depend on prices and costs, which presumably reflect scarcity. (These measures do provide a way to trace the inventory of minerals over time. The reserves-to-consumption ratio for petroleum increased over the second half of the twentieth century, indicating that discovery and cost saving innovation outpaced extraction over this period.) Economists generally prefer to assess resource scarcity from prices and costs directly. Aboveground prices, extraction costs, and mineral rights prices all reflect scarcity to some degree, as the following theoretical discussion indicates.

A nonrenewable resource deposit is an asset. To induce an owner to hold it, the deposit must generate a return that is competitive with other assets. Abstracting from differences in risk, asset market equilibrium implies that a resource stock must yield a rate of return equal to the real interest rate. Nonrenewable resource deposits do not yield a flow of consumption service, nor do they grow or depreciate physically. Thus, the only return an owner can receive from holding it rather than consuming it immediately comes from an expected increase in the asset's price. Because this capital gain is the only return a nonrenewable deposit can earn, in expectation it must be equal to the real interest rate. (As explained later, this must be amended if mineral rights ownership is monopolized to some degree.) The level of this increasing price path is determined by a requirement that prices rise to choke off demand as the resource stock approaches depletion. More precisely, demand for the resource must equal zero on the date when the resource is exhausted. (This will occur on a specific date, if there is a finite price above which the demand equals zero. It will occur only in the limit if price increases cause demand to approach zero asymptotically.) This general theory was developed by Harold Hotelling in 1931.

This result applies to prices for unextracted resources, or mineral rights, but it has direct implications for prices of extracted minerals, which are more commonly observed. If mineral extraction is competitive, the price of a unit of the extracted resource will equal the price of a mineral right plus the marginal cost of extraction. Accordingly, the Hotelling model makes the following prediction: the expected 'aboveground' price of a nonrenewable resource less marginal extraction costs will increase at the rate of interest. As exhaustion nears, the aboveground price approaches the 'choke price,' the lowest price at which quantity demanded equals zero. The exhaustible nature of such resources is socially important, as it implies that price will increase continually. The actual event of exhaustion is not a particular concern, however, because it occurs only after prices have risen high enough to reduce demand for the resource to zero.

This simple result holds only for a resource that exists in deposits of homogeneous quality. In practice, resource deposits typically vary in mineral concentrations, cost of extraction, or other attributes. Under common conditions, profit-minded mining firms will extract the most valuable deposits first, as to do otherwise would not minimize the present value of extraction costs. Suitably amended, the Hotelling rule predicts that deposits will be extracted in order of their quality or grade, with the highest grade extracted first. Within each grade, price minus marginal extraction cost will increase at the rate of interest. The lowest grade extracted is exhausted when price rises to the 'choke price.' Over time, the mineral rights price for the grade being extracted tends to rise, but mineral rights prices fall when extraction switches from higher to lower quality grades. Once the possibility of variations in quality and extraction costs is introduced, it is clear that some deposits may never be extracted, because their costs of recovery exceed their value to consumers.

Attempts to test the Hotelling model have focused on the simple uniform grade case, and the hypothesis that mineral rights prices will rise over time at approximately the rate of interest. This research, reviewed later, has found limited support at best. In hindsight, this lack of success is not terribly surprising. Hotelling's theory predicts that the entire price path for a resource will shift in response to unanticipated changes in interest rates, extraction technologies, input prices, demand conditions, knowledge about the extent of deposits, tax policy, degrees of monopoly power, and other factors. Attempts to test the theory generally have not controlled for changes in these factors. It is instructive to illustrate some of the model's predictions in this regard. An unanticipated increase in the rate of interest reduces the value of returns from future extraction relative to returns from extraction in the present. The predicted response is a reallocation of mineral extraction from future to present. This causes an abrupt drop in price and hastens the date of exhaustion. As extraction proceeds, price minus marginal extraction cost increases at the (now higher) rate of interest.

Changes in other factors will shift price paths in different ways. An increase in extraction cost should cause the aboveground price to jump, but by less than the cost change. Price starts higher and, as before, must reach the choke price at the date of exhaustion. Because price is higher on each date, consumption is reduced and the period of time over which extraction takes place is extended. Discovery of a new deposit should cause a discontinuous drop in the mineral rights price, subsequent price increases following the Hotelling rule, and a later date of exhaustion. Among the many possibilities for unanticipated shifts in demand, one case has been singled out for detailed study—discovery of a renewable energy source that is highly substitutable for fossil fuel energy. Invention of a nuclear fusion reactor or perfection of a low cost photovoltaic device are potential examples. In this case the Hotelling model predicts an immediate reduction in the aboveground rights price followed by resumption of price increases, with exhaustion occurring when the aboveground price reaches the cost of the renewable substitute.

Shifts from competition to monopoly ownership of energy resources have been studied in detail to gain insights on how OPEC (the Organization of Petroleum Exporting Countries) has affected energy markets since the early 1970s. OPEC, acting as a cartel, seeks to control petroleum prices by coordinating the production decisions of its member nations. The simple Hotelling model predicts that, under plausible conditions, monopolization will cause an abrupt jump in price followed by relatively modest price increases until the choke price is reached upon exhaustion. The overall period of extraction is longer with monopoly than with competition. While OPEC is far from a perfect monopoly, these prescriptions are broadly consistent with energy price patterns and observed OPEC behavior since the 1970s.

An important policy issue arises when there is an absence of clear ownership claims. Crude petroleum and natural gas exist under pressure in subsurface natural deposits. Extraction from one portion of a deposit can cause part of the stock to flow from other regions toward the point of extraction. This creates a management problem when portions of the land overlying the deposit are owned by different individuals. Each landowner has an incentive to extract rapidly and thereby capture part of the stock presently underlying a neighbor's property. Because all landowners have the same incentive, the result is a rush to extract, and thus there is inefficient rapid depletion. An efficient policy response is unitization, whereby the entire reservoir is placed under unified management and each landowner receives a share of the net proceeds.

Another important policy issue arises when resource use causes environmental damage. If damage results from the extraction process, as may occur with open-pit mining and offshore oil production, the correct policy response is to charge the extracting firm an amount that reflects this damage. This gives the producer an incentive to reduce such damage. The effect on resource markets is to raise price when the charge is imposed, slow the rate of production, and render some deposits uneconomic. Environmental damage sometimes cumulates with the total amount extracted. When fossil fuels are extracted and combusted, carbon dioxide is released. Carbon dioxide does not decay rapidly, but rather accumulates in the atmosphere, where it is believed to contribute to climate change. In this case, the appropriate charge for extraction must reflect the fact that emitting a unit of the gas will cause damages that persist for a long time. Also, the charge will generally increase over time as concentrations grow.

The 'strong' prediction of a uniformly increasing price path has been tested in a variety of ways, which are outlined here. But, as mentioned earlier, a proper test would require accounting for the many variables that can shift extraction and price paths. If these factors change over time, comparing price changes to the interest rate does not provide a valid test.

Neither extraction costs nor mineral rights prices are easily observed. Some studies have instead focused just on aboveground prices, while others have attempted to estimate marginal cost statistically. Much of this research has found that prices of many resources are falling over time. A falling resource price could be consistent with the Hotelling model temporarily if deposits were being found or extraction costs being reduced, but price must eventually turn back upward as depletion approaches. This suggests the possibility of U-shaped price paths for some resources and some early evidence supported this for petroleum. Subsequent evidence, however, was contradictory. Studies using estimated extraction costs to construct series of mineral rights prices (the proper object of study) have also failed to support the simple prediction of price increases.

The Hotelling Valuation Principle provides an alternative test. The Principle states that the average asset value of a unit of a nonrenewable resource reserve should equal the current price net of extraction cost. This implies, remarkably, that the average reserve value is independent of future prices and extraction costs. The value of a firm's reserve is estimated from financial data and the implication is tested by comparing the average value of firms' reserves to resource prices net of extraction costs. Again not suprisingly, tests of the strong prediction tend to be rejected.

2. *Renewable Resources*

Renewable resources are exemplified by forests, fish populations, and water. In each case the stock available for consumption at any point in time is, or can be, regenerated by a natural process. Because such resources can grow, the cumulative future consumption service that a renewable resource stock can provide is not bounded. (The general theory of renewable resources is developed in Dasgupta and Heal 1979, Chap. 5 and in Fisher 1981, Chap. 3. Brown 1999, provides a perceptive and entertaining review of management issues related to renewable resources.)

A renewable resource stock is also an asset, so it must generate a return competitive with other assets to induce an owner to hold it. The phenomenon of renewability causes the behavior of associated markets to differ fundamentally from what we observe for nonrenewable resources, however. Physical growth, as with biomass in a population of fish and in forests, represents a return to the owner. Some renewable resource stocks can also yield flows of consumption services for their owners, for example, forests can provide habitat for wild game and aesthetic benefits for those who enjoy looking at them or walking in them. A larger population of fish generally benefits the harvester by lowering search costs. Hence, the returns earned by renewable resource stocks are multidimensional, complicating the equal returns condition.

An important caveat is that equalization of returns across assets follows from the behavior of owners who rationally seek to maximize their returns. As we shall see, some important renewable resource stocks, particularly fish, tend to be unowned. In these cases the equalization of returns condition can serve as a guide for efficient management, but it will not describe how unowned, unregulated resources are used in practice.

2.1 Fisheries

A fish population is a living, mobile resource, capable (within limits) of regenerating itself if part of the stock is harvested for human consumption. If the stock performed no economic function other than supporting growth, an efficient manager would seek a stock size that equates the proportionate rate of growth to the real rate of interest. The long run efficient annual harvest would then equal the stock's annual growth. (In this simple model, a higher interest rate implies a smaller equilibrium stock and a larger annual harvest. The first implication tends to hold true in more complex settings. For simplicity, we are abstracting from the possibility of ongoing price changes or from price changes related to changes in the volume of harvests.)

As this simplified discussion shows, the natural population growth process must play an important role in any economic analysis of the fishery. Most economic treatments have adopted the simple logistic description of population growth and have specified a production technology in which the factors of production are of two sorts: (a) the inputs engaged in fishing effort, for example, crew, vessels, and gear, and (b) the stock of fish itself. A larger stock aids harvesting due to search costs—less effort need be expended to catch a ton of fish where the population is plentiful. This cost reduction is an additional return the stock earns, beyond the return it generates by supporting growth. Accordingly, the efficient stock in the presence of search costs is greater than would be implied by simply equating the proportionate rate of growth to the interest rate. The value of avoiding extinction provides another reason for a larger stock, since this generally lowers the probability of extinction. (Brown 1999, p. 22 notes that larger stocks of elephants may impose costs, rather than benefits, on some members of society by terrorizing farmers and destroying crops.)

The management strategy implied by equalizing rates of return will maximize the present value of net economic returns from harvesting the resource. Alternative management goals have often been pursued in practice. One such goal is maximizing sustainable yield (MSY), and another is management to protect stocks from falling below biologically critical levels. Economists have generally been critical of MSY as a management goal, since it amounts to maximizing output without considering either the value of that output or the cost of producing it. The economic arguments against MSY are illustrated by the fact that a doubling of fish prices, or a halving of fishing input costs, would have no effect on the management strategy this goal prescribes.

Generally, there is no private owner who controls how the population is used. This is due partly to the fact that fish are mobile and difficult or impossible to monitor. Hence, enforcing ownership to all or part of a population would be impossible or prohibitively costly. This explanation for the typical lack of ownership in fisheries is reinforced by the observation that the few instances of partial private ownership tend to be cases where the species are sedentary and harvesting is easily detected (for a general discussion of communal management of renewable resource, see Brown 1999, pp. 38 ff). The term 'open-access' is used to describe such unowned fisheries if they are unregulated. While the equal rates of return rule remains valuable for policy, the self-interest of asset owners cannot be relied upon to achieve efficient management where ownership is lacking.

Economic reasoning can characterize how an unowned fishery will be exploited by profit-minded harvesters. The structure of this analysis resembles a predator–prey system in ecology. Individual firms (boats) combine fishing inputs in a profit maximizing way, given the fish population available for them to exploit. Each regards its own catch as too small to have any appreciable effect on the stock it encounters. Positive profits attract new boats to the fishery, increasing fishing pressure. Added fishing pressure drives the stock down, increasing harvesting costs and reducing profits. When excess profits have been eliminated, entry stops and the industry is in long run economic equilibrium. The stock itself earns no economic return—fishing revenue just covers the cost of labor, vessels, and gear. While the population is clearly capable of generating a positive economic return in the form of growth and reduced search costs, this return is not realized in open access equilibrium.

This model has implications for harvesting activity in an open access fishery. Higher fish prices or lower prices of fishing inputs will increase fishing effort and reduce the stock; the harvest could either increase or decrease, depending on the initial stock level and the shape of the biological growth function. Populations exhibiting particular biological growth characteristics can face the possibility of extinction due to open access harvesting. (The presence or absence of critical depensation, which is characterized by a minimum viable population size below which the population cannot survive, is key consideration.) This is a rare outcome, but it becomes more likely if fish prices are high, fishing input prices are low, and search costs are unimportant.

Recognition that a lack of ownership is a cause of inefficiency points the way to more effective regulatory approaches. The Individual Transferable Quota (ITQ) is the most important regulatory innovation proposed by economists. It operates by transforming a fishery-wide restriction on catch into quantitative harvest rights that can be bought, sold, and owned by individual harvesters. One such right entitles its owner to harvest, for example, one ton of a particular species of fish in a designated area during a specified period of time. These rights are of obvious value, so command a positive price. ITQ prices represent an economic payment for use of the stock, and force harvesters to recognize that the stock is a valuable input. This induces efficiency in combining use of the stock with other fishing inputs in the harvesting process. ITQ fishery policies have been implemented in New Zealand, Iceland, Greenland, the Netherlands, and Australia.

Fisheries utilizing ITQs generally experience greater returns for harvesters, and no nation adopting the ITQ approach has subsequently abandoned it (Brown (1999) Table 1 and pp. 34 ff). In practice ITQs are often allocated to those who can demonstrate a historic involvement in the subject fishery, and this no doubt accounts for some of their political popularity. An alternative allocation would have government claiming initial ownership of ITQ rights and then auctioning them to harvesters. Economic theory, *per se*, gives no reason for preferring one initial allocation to another, and actual allocations are driven more by considerations of political feasibility and equity. (The ITQ operates by charging harvesters a price for each unit of the stock captured. One could charge the price directly, without the ITQ device, by imposing a fee or tax on fish landings. Policy economists proposed this long ago, but were ignored for political and equity reasons.)

The ITQ approach requires first setting an overall target catch. The correct economic criterion for choosing the target is maximization of the present value of net receipts, suitably adjusted to recognize that some values, for example, the value nonusers of the resource may place on avoiding extinction, are not matched by monetary payments. Traditionally, the goal of regulation was to avoid endangering stocks from a purely biological perspective. This goal was often approached by restricting fishing to only part of the year, by prohibiting the use of particularly effective fishing techniques or equipment, and by limiting the number of fishing boats allowed to operate. Economists have leveled two sorts of criticisms at such regimes. First, they often do not generate any economic return for society. While they do protect stocks, restricting fishing times or the kinds of gear used simply raises harvest costs. If costs had been raised by imposing a harvest fee, the resulting stock, catch and harvester profits could have been similar and the fee revenue would represent a net economic benefit for society. Second, harvesters will find ways around such regulations and this can magnify inefficiencies. When regulators limit the number of boats in a fishery, harvesters tend to invest in larger, faster boats with larger crews to increase fishing effort despite the regulation. When regulators limit the time available to fish, harvesters fish more intensively during the open season, raising costs, lowering fish quality, and expanding effort back toward its pre-regulation level.

2.2 Forestry

The study of renewable resources dates to a fundamental forest management problem first addressed in the eighteenth century. An early example of both intertemporal and biological components in economic models, this classic problem considers a decision facing an owner of a growing stand of trees: when to cut and harvest them for timber. The first proper economic treatment of this problem is attributed to Martin Faustmann in 1849, but in part because the solution is subtle, the optimal rotation age of a tree has since received a great deal more attention in economics. Other, more modern issues in forestry are outlined later, following a brief description of this basic model.

A tree is an asset whose return to the owner is assumed to derive only from the simple fact that it grows. (The logic of this problem is equivalent whether looking at a stand of trees of the same age or one tree.) If the price of timber remains constant, the rate of growth in value equals the rate of growth of biomass. A wealth-maximizing owner will harvest when annual growth in the tree's biomass (the benefit to leaving it standing) is equal to the sum of two distinct opportunity costs. This first cost is the rate of return that could be earned cutting and selling the resource and earning interest on the proceeds. The second cost is the land rent and represents the return that could be earned by the land the tree occupies. At the wealth-maximizing harvest age, the net rate of return earned by the standing biomass (the value of growth minus land rent) just equals the interest rate.

The forest's biological growth function plays a key role in determining the harvest age. When a tree is young and growing quickly, the return to leaving it standing exceeds the relevant opportunity costs. As the resource matures and the growth rate falls to the level of the combined opportunity costs, the time has arrived to cut. The reasoning at the heart of this solution is that part of the cost of waiting to harvest a stand of trees is that an older tree takes up space that a younger, faster growing tree could occupy.

Investigating how this optimal harvest age responds to changes in the price of timber, replanting costs, and the market interest rate yields useful insights. When replanting is costly (in the absence of replanting costs, the optimal rotation age does not depend on the price of timber; this, perhaps surprising, result derives from the fact that all of the costs and benefits are proportional to this price) a higher price of timber will shorten the optimal harvest age and a higher replanting cost will lengthen it. These results follow from the fact that a higher price or lower replanting cost will increase the maximum value of forest land, and therefore increase the land rent. An increased rent, by raising the opportunity cost of letting the forest stand, induces the owner to harvest earlier. A higher rate of interest tends to reduce the harvest age. Intuitively, this occurs because the forest's net rate of return (growth minus land rent) tends to fall as the forest matures. It will, therefore, reach equality with the interest rate at a younger age when the interest rate is higher. To summarize, a higher interest rate causes the forest to be cut sooner.

These results have implications for the supply of timber. An increase in the price of timber increases the value of land in forestry and therefore is likely to increase acreage in forest. This increase reduces the average quantity of timber produced on each acre, however, due to the shortened harvest age. (This is true if the optimal harvest age is less than the age that maximizes sustainable yield.) As a result, the net effect of a price increase has an ambiguous effect on timber supply. The exact opposite is found for replanting costs. An increase in the interest rate unambiguously reduces timber supply as a higher interest rate reduces both land rents in forestry and the harvest age, and both effects reduce supply.

Other management goals, particularly maximizing sustainable yield, are sometimes advanced as criteria for publicly owned timber. Economists have criticized MSY in this context for essentially the same reasons they have criticized it for fisheries. While the determination of optimal harvest age is a classic problem in resource economics, other issues of forest management have become arguably more important. These include the land use decision, especially at the margin between uses in forest and agriculture, management under imperfectly defined property rights, and the external (nontimber) value of forests. These subjects are briefly discussed in the remainder of this section.

There are, of course, competing uses for a parcel of land and efficiency requires choosing the use with the greatest discounted net benefit. Importantly, the costs and benefits appropriate for this criterion include some that may be external to the owner. Such external benefits range from the services of carbon sequestration, habitat for a large fraction of the world's species, and recreational or general aesthetic value. (CO_2 captured by a growing forest is 'sequestered' from the atmosphere, where it would contribute to a potential greenhouse effect. The value of biodiversity is in both potential medical services and less tangible human preferences.) In general, if a standing forest provides benefits not captured by the landowner, and if those benefits increase with the age of the stand, then the private owner's harvest age will be too short and there will be an inefficient bias toward nonforest land uses. This observation suggests a role for government policy related to land use and harvest age on both private and public lands.

Ownership of forest land is often incomplete. In many areas of the world the ubiquitous property rights regime is 'common property' or 'communal management,' where a village or otherwise organized group of people share ownership of land used alternatively for agriculture, fuel wood, forest products, and other services. Without collective action to regulate individual behavior, each member of the community has an incentive to clear more forest land for agriculture, and to allow livestock to overgraze common pasture, etc. An individual farmer considers the private cost of converting common forest to agriculture, for example, the reduced availability of fuel wood for him personally, but ignores the cost borne by every other member of the community. This incentive is magnified by the realization that failure to appropriate a piece of the commons today only decreases the probability that it will be available for appropriation in the future.

The difference between common property resource management and open access (a concept developed in the fisheries section) relies on the effectiveness of informal controls. Effective common property management requires a set of rules or norms, and a binding enforcement mechanism that promotes socially efficient resource use. While the requisite conditions are not well understood, informal solutions to commons problems should be more common when bargaining, enforcement, and information about resource use are inexpensive relative to the gains from efficient management. This seems more likely when the resource is small and scarce, and perhaps where the number of actors is small. Another seemingly important ingredient is a long-established community that shares traditional norms of behavior and a common technology. Empirical work suggests that actual common property arrangements internalize some, but not all, of the relevant social costs.

2.3 Groundwater

Groundwater exists in subsurface reservoirs, or aquifers, that usually are replenished by percolation of water from the surface. As with oil and gas, groundwater is mobile and does not respect the boundaries of individual parcels of land that overly it. Absent of regulation, one can therefore expect groundwater stocks to be overused.

Water in an aquifer is an asset and the problem of efficient management can again be guided by the principle that rates of return be equalized. As water in storage is depleted, the distance it must be pumped to the surface increases, raising costs. Water in storage thus earns a return by reducing pumping costs. It can also earn a return associated with the fact that withdrawing groundwater can cause the overlying land surface to subside, damaging structures or otherwise reducing the land's value. Similarly, withdrawing groundwater near an ocean shoreline can cause saltwater to intrude and degrade the quality of water in an aquifer. In both cases, leaving more water in storage reduces the damage, or makes it less likely, adding new components to the return that water in storage yields.

As with fish and unowned petroleum reservoirs, groundwater will not be efficiently managed if left to the choices made by individuals withdrawing from a common aquifer. Policies similar to ITQs in fisheries, or unitization with oil and gas are viable management instruments in principle. They have not generally been adopted, however, owing in part to the unique legal institutions that apply to property rights for water.

3. Conclusions and New Directions

Several important topics were not discussed due to a constraint on space, and some trends in the study of exhaustible resources are worthy of mention. These are briefly broached these here, and the interested reader is directed to more detailed discussions in Brown (1999), Krautkraemer (1998), and Dasgupta and Heal (1979).

The study of nonrenewables has largely shifted from optimal extraction and scarcity measurement to the environmental impacts of fossil fuel consumption. The traditional concern was that energy would become expensive as coal, petroleum, and natural gas reserves were depleted. Prices of these inputs have not risen consistently, but today it is recognized that energy consumption is expensive in a sense historically not properly accounted for. A ton of coal in the ground provides few external costs or benefits, but a ton of coal burned spreads damages widely in the form of acid rain and greenhouse gases. This link between nonrenewable resources and environmental policy is central to the field today.

There are several directions in which the theory of fisheries and fishery regulation is being extended at present. First, most economic models of fisheries do not incorporate state-of-the-art ecological models of the resource. Fisheries ecology has moved far beyond the simple logistic models of population dynamics that are still a mainstay of fisheries economics. Second, economic analyses of fishery regulation have, with a few recent exceptions, made no attempt to study the motives and the behavior of the regulator. Third, economic models of fisheries tend to ignore spatial considerations in the distribution of fish populations or fishing activity. As this very active area of natural resource economics develops, it seems likely that each of these topics will receive attention.

While the optimal harvest age is the textbook forestry topic, the total stock of forests is more sensitive to the factors that determine land use. This is particularly true as it becomes clear that the conversion of land to agricultural uses drives much of global deforestation. Recent study has focused on how ownership security, agricultural and trade policy, and the functioning of related input markets affect land use decisions. Empirical attempts to measure the external value forests provide, through the services of carbon sequestration and biodiversity habitat, are met with great interest.

This article has ignored a large and important literature incorporating exhaustible resources into the theory of economic growth. This literature has traditionally treated exhaustible resources as capital necessary for production but substitutable with other inputs. Whether exhaustible resources represent 'limits to growth' is certainly an issue that commands attention far outside the field of economics.

Nearly all of the basic models described here ignore the fact that the world is an uncertain place. An owner of a resource is assumed to know what will happen to future prices and costs. How poor an approximation of behavior is it to replace random variables with their expected values? The degree to which people are averse to, and able to insure against, risk, are key aspects of investment behavior that shed light on resource management problems. Optimal resource use is also likely affected if relevant events are irreversible, a point distinct from risk aversion. Irreversibility is key to the study of species extinction and climate change in the modern literature.

See also: Agricultural Sciences and Technology; Ecotourism; Environmental and Resource Management; Environmental Economics; Environmental Planning; Environmentalism: Preservation and Conservation; Sex Differences in Pay; Sustainability Transition: Human–Environment Relationship; Sustainable Development; Sustainable Transportation; Urban Policy: North America

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E. Balsdon

Existential Social Theory

Modernity, as the continuing project of human self-understanding and human self-making, is both the historical foundation of social theory and an existential perspective on the world. All modern social theory, thus, insofar as it reflects upon the experiential character of social life, is to some degree existentialist.

1. Max Weber's Fundamental Contribution to Existential Social Theory

The centrality of an existential perspective to social theory is nowhere clearer than in the work of Max Weber (1864–1920), who must be accounted its most formidable advocate. The existential character of Weber's perspective is most evident in his essays on politics and science and, more especially, in his methodological writings. These stress both the centrality of meaning to a proper understanding of social action, and the essential freedom of humans in relation to the values that ultimately confer meaning on events. In a radical fashion Weber insists that meaning flows from an existential 'orientation to the world' and does not inhere in any objectively given reality. Weber's sociology, thus, is concerned primarily with the typification, on a world historical scale, of an extraordinarily varied range of such meaning complexes, their historical contextualization, and the existential orientations within which they were formed and enacted.

Weber's social theory also established critical insight into the existential problems of modern society. On the one hand, he argues that modernity can be understood in terms of a specific set of values which he typifies as the 'spirit of capitalism' or 'modern rational capitalism'; while, on the other hand, he argues that modernity is characterized above all by the 'disenchantment of the world,' which involves nothing less than the annihilation of value as such. Not only are these two very different conceptions, but the notion of disenchantment seems to contradict his philosophical-methodological premise that all human activity be inherently open to meaning through its relation to extra-rational ends. This duality in Weber's characterization of modern life in fact brings to light the seriousness of the struggle in modern society to create and maintain a sense of individual human worth and dignity in the face of powerful processes of rationalization. He traces this theme substantively to the Reformation and the 'unprecedented inner loneliness' which was its religious expressions and the historical foundation of the anxiety which has become a general condition of modern existence. In this approach it is clear that Weber was influenced by Friedrich Nietzsche (1844–1900) and Søren Kierkegaard (1813–55). Indeed, a remark of Nietzsche's might well stand as an epigraph for his existential sociology;

> Man first implanted value into things to maintain himself—he created the meaning of things, a human meaning! Therefore he calls himself: 'Man,' that is; the evaluator ... Evaluation is creation.

2. Kierkegaard and the Origins of European Existential Thought

But it is to Kierkegaard that we must turn as the originating source of the varied forms of modern existential thought. Not only in his work do we find the first modern account of human reality focused directly on the elusive and difficult character of 'existence,' we also discover, linked to it, a significant social theory of modernity.

Kierkegaard's writings provide a rich exploration of all the forms of existence which have become possible in the modern world. Rather than analyze these positions in terms of an abstract analytic framework—itself presumed to be outside of any of their existential determinants—he presents them as the self-expressed orientations of a number of pseudonymous authors. This semi-fictional method draws author, subject matter, and reader into an existential complicity and Kierkegaard uses this technique to mount a powerful attack on all modern (especially Hegelian) forms of scientific abstraction and objectivity which have been misleadingly applied to problems of existence.

This method, inaugurated in the celebrated *Either/Or* (1987 [1843]), is neither a form of pure 'subjectivism' nor does it result in chaos of arbitrary life-

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