NATURAL RESOURCE ECONOMICS

Jason F. Shogren
University of Wyoming, Laramie, USA

Keywords: natural resource, natural resource economics, non-renewable resource, renewable resource, biodiversity, non-market valuation

Contents

Summary

Natural resource economics examines how society can more efficiently use its scarce natural resources, both non-renewable resources, such as minerals and fossil fuels, and renewable resources, such as fisheries and forests. Theory and empirical research explores alternative models on how people and societies choose to use and manage their limited resources. For non-renewable resources, natural resource economics suggests that the efficient path to extract such resources over time is to balance the market price with both the marginal extraction costs and the opportunity cost, or shadow price of extracting the resource sooner rather than later. This shadow price is also called the user cost, resource royalty, or scarcity rent. User costs capture the idea that there is an additional cost for extracting a resource today since it cannot be extracted tomorrow. Theory also suggests the scarcity rent should grow at a rate equal to the rate of interest. This is called Hotelling's rule, which says that a unit of resource extracted in any period should yield the same rent, in present value terms.

For renewable resources, theory suggests an efficient harvest should balance the marginal benefits one can get elsewhere in the economy with the extra growth of the resource and the cost savings from not harvesting the resource now, but later. This stock

externality effect captures the idea that having more of the resource around at the time of harvest implies lower per unit harvest costs. Some renewable resources like fisheries are still characterized by overexploitation because of weak property right systems and lax enforcement. Regulations considered to address these property right failures include assignment of rights, use fees, liability rules, and tradable quotas. Natural resource economics also examines how societies could save more of their stock of biological diversity at lower cost by addressing basic economic principles such as relative economic circumstances, opportunity cost, and incentive design. The field also explores how to design cost-effective strategies to reduce risks from stock pollutants, such as the concentration of carbon feared to cause climate change. Natural resource economics also considers how to value the non-market natural resource services not bought and sold in the market-place. Non-market valuation methods like stated preference, revealed preference, and production functions are discussed.

1. Introduction

Economics has long been concerned with the efficient use of its scarce natural resources. Adam Smith examined the nature of capital for land, mines, and fisheries; Ricardo explored how land quality matters for economic rent; Malthus worried about population, poverty, and the limits of agricultural resources; Jevons feared the social consequences of the depletion of coal quantity and quality. These classical economists treated natural resources as a factor of production provided freely by nature, which made it distinct from costly capital and labor. The general mindset framed the problem as one in which a resource owner made extraction choices to maximize the net present value of the natural resource.

At the start of the twentieth-century, economics started to treat natural resources as something more distinct than just as a free factor of production. The US government report *What About the Year 2000?* prepared in 1920 by economist George Peterson noted that "[o]ur national greatness and individual well-being is in a large measure due to the natural resources of this country". Theorists like Gray and Hotelling made this point more precise by addressing the dynamic nature of natural resource use. They made the case that an additional intertemporal cost to extracting or harvesting natural resources existed. They argued that a resource owner should account for an additional cost above and beyond the cost of extraction and processing—the opportunity cost of depletion or harvesting sooner rather than later. After the Second World War, fishery economists explained how weakly defined property rights can lead people to overexploit resources that inhabit the commons (Note: *commons* refers to the resource.) In the late 1970s and early 1980s, the economics literature began to examine the social inefficiencies associated with stock pollutants, such as carbon emissions and climate change, the loss of services from reductions in the stock of global biodiversity, and the risks to life support and aesthetic services provided by natural resources left un-priced by the market.

Today, natural resource economics continues to expand on these early insights by developing theories that help explain how people and societies choose to manage and use their limited resources, both non-renewable resources like minerals and fossil fuels, and renewable resources like fisheries and forests. The field considers how societies make choices to (mis)manage their stock of biological diversity cost-effectively, to reduce risks from climate change efficiently, and to value natural resource services that are not bought and sold in the market-place. The goal is to look systematically at the demand for natural resources and at their supply, both to recommend efficient use today and to foresee impending challenges tomorrow. This understanding often leads economic theory to recommend greater resource conservation than rules based on biological criteria alone.

Examined here are some lessons from natural resource economics, on how people can develop and conserve their scarce renewable and non-renewable resources. Topics addressed include the efficient path to extract non-renewable resources; the scarcity of natural resources; the optimal harvest of renewable resources; property rights structures that promote the efficient use of natural resources; and how economics values the non-market services provided by natural resources. When considering how economic theory and empirics addresses these questions, one must remember that natural resource economics is not synonymous with financial and commercial concerns. The economic theory of natural resources economics addresses both the commercial consequences from developing a resource, and the benefits from its preservation and conservation. As economist, Henry Hazlitt noted, "[t]he art of economics consists in looking not merely at the immediate but at the longer effects of any act or policy; it consists in tracing the consequences of that policy not merely for one group but for all groups". Natural resource economics is no different. The field is concerned with the costs, benefits, and incentives of alternative strategies for resource use, including the choice of preservation.

The first section considers non-renewable resources: optimal depletion, measures of resource scarcity, and energy supply and demand. The next section examines renewable resources: the rate of harvest, the commons, and regulation options. We then consider the economic protection of climate change, biodiversity, and the methods of non-market valuation.

2. Non-renewable Resources

Non-renewable resources are those that will eventually be exhausted. These resources include the fossil fuels, such as coal, oil, and natural gas; and mineral resources, such as iron ore and gold. This section focuses on the economic theory of efficient extraction, measures of resource scarcity, and energy supply and demand.

2.1 Optimal Depletion

We first consider the economic theory of optimal extraction on a non-renewable resource like oil or coal. The simplest setting is the so-called "cake-eating" problem, in which society must select the optimal strategy to use a resource over time. Consider a society that has a non-renewable resource like oil. For simplicity, assume the resource quality is uniform across the reserves. Society's goal is to choose an extraction path to maximize the present value of total net profits over time. Recall present value is the discounted sum of all future net profits. The society must decide how much oil to supply in each time period given the opportunity cost of keeping the oil in its reserve. The opportunity cost of delaying oil extraction is the financial return that could earn elsewhere in the economy.

Economic theory treats a non-renewable resource as capital. In general, capital is a basic building block in the production of goods and services, and therefore has economic value over time. Harold Hotelling developed the seminal theory on the optimal rate to extract a non-renewable natural resource through time. Consider a basic model to illustrate. Let x_t represent the level of resource extracted at time t; T is the end of the planning time; $p(y)$ is the demand curve for the resource; y is a variable of integration, $c(x_t)$ is the cost function for extraction, and r is the rate of discount. The objective is to maximize the net present value of social benefit from a resource deposit, in which social benefit is measured by the total gains from exchange: the sum of consumer surplus and producer surplus, which is written as

$$\underset{\{x_t\}}{\text{Max}} \int_0^T \left[\int_0^{x_t} p(y)dy - c(x_t) \right] e^{-rt} dt \tag{1}$$

subject to the constraint: the finite stock of the resource,

$$\dot{z}_t = -x_t \tag{2}$$

where z_t is the stock of the non-renewable resource at time t.

Necessary conditions for an interior solution are

$$p(x_t) - c'(x_t) - \lambda_t = 0 \tag{3}$$

where $p(x_t)$ is the market price, or marginal revenue for a unit of the resource, $c'(x_t)$ is the marginal extraction costs, and λ_t represents the shadow price on a unit of the resource in the stock, and

$$\dot{\lambda} / \lambda = r \tag{4}$$

The first condition says that an efficient allocation of resource extraction over time is when the price (marginal revenue) is equal to both the marginal extraction costs and the opportunity cost (or shadow price) of the resource in the ground. This shadow price is also called the user cost, resource royalty, or scarcity rent. This user cost captures the idea that there is an additional cost for extracting a resource today. Since it cannot be extracted tomorrow, your opportunity set is smaller in the future, which provides less flexibility to respond to market conditions.

The second condition says that the scarcity rent grows at a rate equal to the rate of interest. This is the so-called Hotelling rule, the most well known result in natural resource economics. The rule says that a unit of resource extracted in any period should yield the same rent, in present value terms. That is, if resource allocation is efficient, society cannot gain any extra benefits from shifting a unit of extraction from one time period to another. This implies that the lower the discount rate, the slower the extraction of the resource, holding all else constant. This occurs because the opportunity cost of keeping the resource in the ground is low, that is the relatively low rate of return elsewhere in the economy is not tempting the owner to extract the resource, sell it, and invest the proceeds in the market. If the discount rate increases due to changes in the economy, the owner now increases the rate of extraction because the opportunity cost of not doing has increased.

The Hotelling rule holds for a competitive firm as well, but only when the private discount rate equals the social discount rate. Private and social discount rates can differ, however, if people believe the private rate set by market conditions does not accurately reflect the broad unpriced social desire for resource preservation. Other useful extensions in the literature include the efficiency of investing the returns from a non-renewable resource into the production of man-made capital that would act as a substitute for the resource, how market structure like a resource cartel affects the rate of extraction, and how market uncertainty about price and costs affects optimal extraction rates.

2.2 Resource Scarcity

People often wonder whether the world is running out of resources. Clearly our use of any non-renewable resource reduces its stock. But the relevant question is to define what this stock actually represents: the actual and potential physical quantity of the stock, the economic viability of the stock, the value of the stock and potential reserves, and how to measure the scarcity of the stock. Consider now four alternative measures of resource scarcity.

First, a common measure of resource scarcity is the lifetime of a resource. Resource lifetime is the economic reserve of a resource divided by its current annual consumption rate, often with an allowance for a predicted growth in this rate over time. For example, some have estimated that the world will run out of copper in around 2020, holding real price constant. But the problem is that if one divides a resource base by annual consumption, he is assuming real prices remain constant. But if a resource becomes scarcer, its real price will increase. This will reduce consumption as people find substitute material. These behavioral responses alter the lifetime measure. In addition, higher prices induce producers to explore for more reserves, which can increase its stock. Evidence suggests that lifetime measures for many resources are approximately constant over time, which might say more about firms' desire to hold inventories of minerals than about scarcity.

A second measure of scarcity is unit cost. Depleting a mine, forces miners to dig deeper underground or wider on the surface to recover coal. This increases the labor costs/unit of output, which also can be of lower quality. Cumulative production thus increases average costs, which is the second indicator of resource scarcity. In a classic 1963 study later supported by others, Barnett and Morse studied trends in average costs over the time period 1870–1957. With the exception of forestry, they found that an index of real unit costs declined over the period, indicating decreasing scarcity. People have challenged the validity of the unit cost measures by noting that technology has progressed over the years, which has reduced unit costs and increased the size of economic reserves. They also point out that firms do not always deplete the lowest cost deposit first, as presumed by the unit cost measure. Unit capital and labor costs might have declined due to substitution of some other input for capital and labor. Finally, unit costs are based on past experience, which makes it a weak predictor of future scarcity.

Real prices are a third measure of resource scarcity. Economists commonly use market prices as indicators of scarcity. An increase in a real price is a useful measure of scarcity when prices signal all future and current opportunity costs of using a non-renewable resource today. In the Hotelling model, the price of a resource increases at the rate of interest until it equals the price of its best substitute: the backstop resource. Empirical studies suggest that real prices had remained approximately constant from 1870 to 1957. Another study showed that real price seem to be u-shaped, where an initial decline in prices due to technological progress is eventually replaced by cumulative production and rents increasing at the rate of real interest. Critics, however, argue that real prices as a scarcity measure are limited by market structure restrictions like mineral and fuel cartels, government interventions through price ceilings, taxes, subsidies that distort the price signals, and negative social impacts to the environment that are left unaccounted for by the market price. Natural resource prices might not accurately reflect scarcity if cartels artificially keep prices high, governments subsidize output to keep prices low, or if the environmental services forgone to society are not accounted.

The fourth measure of scarcity is scarcity rent, or user cost. Scarcity rent is the difference between price and marginal extraction cost. Many economists argue that scarcity rent is the best scarcity indicator, since it shows the gap between what society is willing to pay for one more unit of the resource and the cost of extracting that unit. Rents represent the rate of return from holding a non-renewable resource deposit. This rate should equal the return on holding any other kind of asset elsewhere in the economy, like a savings bond. As we saw in the Hotelling model, theory predicts that an efficient depletion path involves rents rising at the rate of interest. One can, however, question whether firms actually follow Hotelling's rule of optimal depletion. And even if one presumes they do, empirical data is scarce. Measuring scarcity rents is a challenge since firms and governments do not keep this data, forcing empirical studies to use proxy measures like exploration costs.

2.3 Energy

Economists care about scarcity because these natural resources provide the energy that drives the modern economy. Energy is a consumer good. The energy derived from renewable and non-renewable resources like petroleum, natural gas, coal, hydro, nuclear, biomass, geothermal, solar, and wind helps grow and cook our food, warm and light our homes, and powers our cars. Energy is a factor of production. Energy, combined with capital, labor and land, is an essential input in the production of nearly all goods and services around the globe. Energy also has enormous strategic value for a nation, and the threat of its loss has led to war. People and governments follow energy prices with intense interest because it is so vital to our daily lives.

Today the world produces and consumes nearly 400 quadrillion British thermal units (Btu) of power. As a comparative benchmark, energy use in 1970 was about 200 quadrillion Btu. China, Russia, and the US are the biggest producers and consumers of world energy. Together these three countries account for about 40% of the world's total supply and demand for energy. Five nations currently produce about half of the world's energy—Canada, China, Russia, Saudi Arabia, and the USA. The USA alone produced over 70 quadrillion Btu of energy; Russia and China produced over 40 and 33 quadrillion Btu. And, five nations consume nearly half of the world's energy—China, Japan, Germany, Russia, and the USA. The US consumes nearly 95 quadrillion Btu, three and four times that demanded by China and Russia at 34 and 26 quadrillion Btu, respectively. Over the last two decades, the largest regional change was in the Far East and Oceania region, where energy production increased by over a 100%, and energy consumption doubled. All other regions except for the former Soviet Union all witnessed an increase, albeit smaller, in overall energy production and consumption.

What is the current mix of primary energy supply around the world? The non-renewable resources of petroleum, coal, and natural gas are the big three energy sources today. Petroleum remains the most important source, producing nearly 40% of energy today. Saudi Arabia, the USA, and Russia are the three largest suppliers. Coal is second, capturing 23% of production. China and the USA are the leading producers. Natural gas ranks third, supplying about 22%, increasing its share over the last decade. Russia is the leading producer. The remaining energy sources, hydro, nuclear, biomass, geothermal, solar, and wind accounted for the remainder.

What does the future of energy demand look like? One estimate is that world energy demand will increase by about 60% over the next two decades, to over 600 quadrillion Btu in 2020 from 380 quadrillion Btu in 1997. So what does the mix of energy sources look like into the future? Oil currently supplies the largest share of world energy consumption, about 70 million barrels/day, which could increase to 110 million barrels/day by 2020. Natural gas should remain the fastest growing component of world energy demand, and is projected to more than double. Coal will continue at its historical share, about 22 to 24% of energy demand. Nuclear power use in the future is less clear. Nuclear power could expand in developing Asian nations, but decline in developed nations. Renewable resource development will be slow if the expected price of fossil fuels remains relatively low in the near future.

Given these projected trends in energy use and natural resource reserves, the open question is whether an economic rationale exists for more or less governments' intervention in energy markets. If the net gains are positive, the government has three intervention tools in energy markets: to change incentives by taxing fossil fuels and subsidizing renewable fuels; to expand technological options by promoting and subsidizing research and development (R&D), and provide information about options that promote energy efficiency. First, governments that wish to alter the energy mix can change the relative prices through taxes on fossil fuels and subsidies for renewable energy resources. Second, a government could intervene by subsidizing the R&D of new technologies that address the environmental problems associated with fossil fuel use. Third, a government can also try to alter the energy market by providing information that promotes the market penetration of new technologies, including information and outreach programs, green programs, market identification and targeting. Economists note that people are often reluctant to switch to new technologies because they are unwilling to experiment with new devices at current prices. Also, factors other than energy efficiency matter to consumers, such as quality, features, and the time and effort required to learn about a new technology.

3. Renewable Resources

Renewable resources are those that can be maintained forever, provided they are not destroyed by neglect and misuse. These resources include soils, forests, wildlife, natural scenery, and water. Economic theory also treats renewable resources as capital. We begin by considering the efficient harvest of a fishery, and then discuss how this changes for forests. Next we consider the problem of weak property rights and the commons, and explore different options to regulate the overexploitation of a renewable resource.

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Biographical Sketch

Jason F. Shogren is the Stroock Distinguished Professor of Natural Resource Conservation and Management, and is a professor of economics at the University of Wyoming. His research focuses on the behavioral underpinnings of private choice and public policy, especially for environmental and natural resources. Before returning to his alma mater, he taught at Iowa State and Yale. In 1997, Shogren served as the senior economist for environmental and natural resource policy on the Council of Economic Advisers in the White House. Currently, he serves on the Environmental Economics Science Advisory Board for the US Environmental Protection Agency, and the Intergovernmental Panel on Climate Change. Wyoming Governor Geringer recently appointed him to the State's Environmental Quality Council. Shogren is also on the advisory committee for *Enlibra*, the Western Governors Association's new doctrine for environmental management. He was an associate editor of the *Journal of Environmental Economics and Management*, and the *American Journal of Agricultural Economics*. Recent publications include *Environmental Economics* (Oxford University Press), *Private Property and the Endangered Species Act* (University of Texas Press); *Endangered Species Protection in the United States* (Cambridge University Press); and papers on risk, conflict, cooperation, valuation, environmental policy, and experimental economics. The American Association of Agricultural Economics selected his essay with J. Tschirhart on the Endangered Species Act as the Best Article in *Choices* for 1999.