Chapter 12
Environmental Problems in Economics

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Abstract Economics is a specialized field in social science that studies the fundamental problems of how best to allocate limited resources between economic agents to achieve optimal results. Typically, the mainstream economics subjects offered by a university economics faculty are macroeconomics and microeconomics. However, because of recent academic developments, students can now also read environmental economics and resource economics as part of the mainstream methodology. Section 12.1 examines the relationship between the environment and economics using the figures of Herman E. Daly, who originated ecological economics. Here, the focus is on those points not considered in so-called mainstream economics. Then, Sect. 12.2 provides a chronological discussion of the optimal usage of exhaustible resources as the introductory theme to resource economics. Here, "Hotelling's Rule," which is introduced as a propositional statement, indicates that the price necessarily needs to increase as the quantity of a resource decreases. Lastly, Sect. 12.3 investigates whether Hotelling's Rule is evident in data on the quantity of resources and prices. This section also discusses economics issues that arise from the analysis of environmental problems.

Keywords Environmental economics • Resource economics • Exhaustible resource • Hotelling's Rule

12.1 Economics and Environment

12.1.1 What Is Economics?

Economics is a specialized field in social science that studies the fundamental issues of how best to allocate limited resources between economic agents to achieve optimal results. Limited resources are, by their very nature, scarce, and in our daily lives, we often think of ways to use them efficiently, even if we do not know much about economics. For example, "how can I spend the 24 hours in my day?" "what

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should I buy with my monthly allowance?" or "how can I allocate the tasks in my job when I have only two subordinates?"

The term "resource" includes natural resources, such as energy resources and mineral resources, but also includes abstract resources, such as goods (assets, services), money (funds), people (labor), and time.

In economics, the results of allocating these resources are measured in terms of a benefit or a net benefit, which is the amount remaining after subtracting the costs incurred. Benefits and costs are measured in monetary units, such as the yen or dollar. When the net benefit is maximized after allocating our resources, this is viewed as a favorable allocation in economics terms.

We can also use utility and profit to measure the resource allocation results, depending on the subject of the analysis. Utility measures the amount of satisfaction gained from using the goods and is a concept peculiar to economics. Profit is a measure of the amount gained from selling goods after we have subtracted our costs of producing the goods.

University economics faculties all offer subjects such as macroeconomics and microeconomics, and students read economics based on these ideas. Then, they read the applied fields of international economics (goods), financial theory (money), labor economics (people, time), environmental economics, and resource economics and study how economics can explain real-world problems.

12.1.2 The Relationship Between the Environment and Economics

There are other fields such as political economic science, economic history, history of economic thought, and theory of comparative economic systems that are not based on mathematical principles. Others focus on actual conditions and systems rather than mathematical principles. Many universities also offer Marxian economics, which they present as the principles of economics.

Researchers in such fields refer to the typical framework of macroeconomics and microeconomics as mainstream economics, or neoclassical economics, pointing out weaknesses in mainstream economics theory and sometimes presenting alternative ideas. This movement ultimately went beyond the academic society of economics, creating a unique field of arts and science, integrated into ecological economics. Ecological economics combines material balance, the law of increasing entropy in thermodynamics, and ecological systems.

Herman E. Daly, who originated ecological economics, indicated several points that mainstream economics misses, as shown in Figs. 12.1 and 12.2. First, our economy is included in the ecological system (environment). The economy takes in materials and energy from the ecological system, sometimes recycles them, and finally returns materials and energy, which have become useless. In addition, the

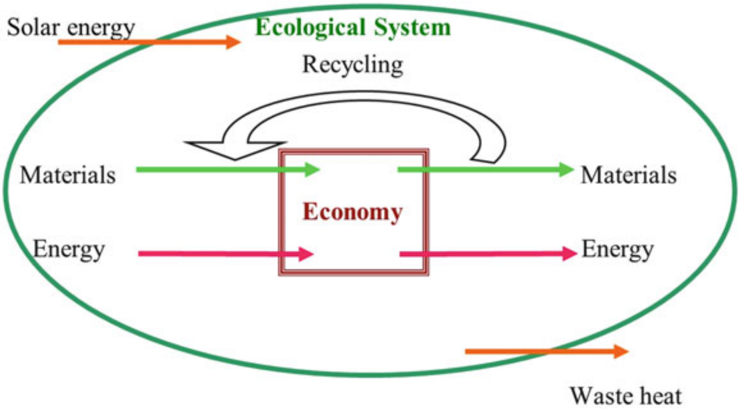

Fig. 12.1 Relationship between the environment and the economy (1): empty world (Source: Daly (2005) and Stiglitz and Walsh (2012))

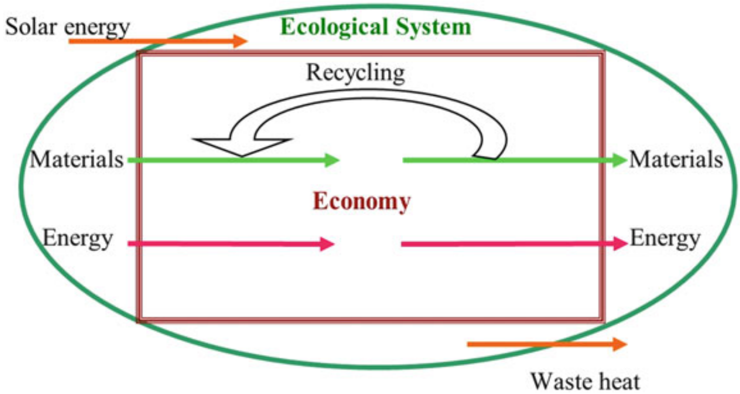

Fig. 12.2 Relationship between the environment and the economy (2): full world (Source: Herman E. Daly (translated by Isao Nitta, Shinobu Kuramoto and Masayuki Omori), "Beyond Growth: The Economics of Sustainable Development", Misuzu Shobo P. 69 (2005))

ecological system takes in solar energy from outside the system and emits waste heat.

The difference between Figs. 12.1 and 12.2 is the scale of the economy included in the ecological system. Figure 12.1 shows the economy in an empty world, as compared to the ecological system. Figure 12.2 shows the economy in a full world, almost bursting the ecological system.

The "optimal scale" of economy is the desirable maximum scale of the economy in relation to the environment. Surprisingly, mainstream economics cannot determine this optimal scale, because its definition of an economy does not include the natural environment.

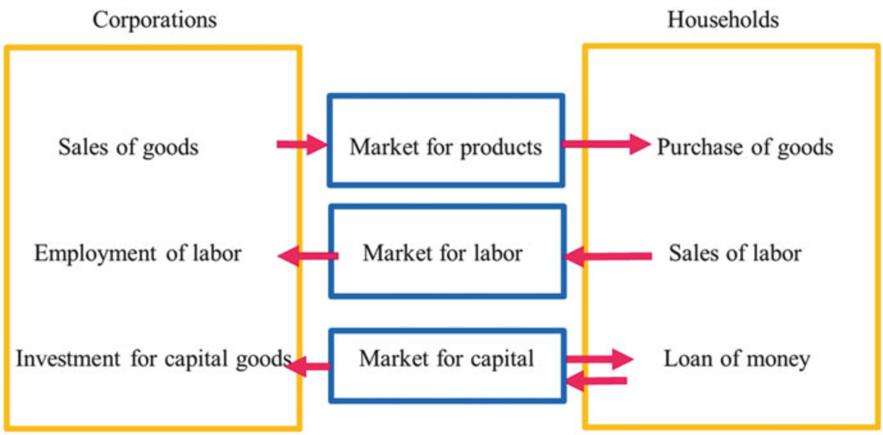

Fig. 12.3 Economic agents and the market as presented in economics textbooks (Source: Joseph E. Stiglitz and Carl E. Walsh (translated by Shiro Yabushita, et al.) (2012) Economics 4th ed. Toyo Keizai Inc. p. 22)

Note that the concept of an equilibrium national income (or equilibrium output) is taught at an early stage in macroeconomics. This refers to the scale of the national income in which the demand for goods and services is matched by their supply in the overall economy. However, this concept does not consider whether the economy is optimal in terms of the environment.

Figure 12.3 shows the flow and market of goods, people, and money as typically presented in (mainstream) economics textbooks, according to Joseph E. Stiglitz et al. The diagram shows two economic agents, which can be corporations or households. If governments and foreign countries are included as economic agents, the flow becomes more complicated.

The "Market for Products" in Fig. 12.3 do not explain how the goods appear, where the goods go after being used, or, if the economy is an independent system, whether the materials/energy to be used already exist and nothing is discarded after use. In other words, it is a system of perfect recycling. Needless to say, this is not a realistic economy.

A resource constraint is often assumed in mainstream economics. This means that the total amount of labor and capital stock in an economy is set. The concept of a resource constraint is also used for other "resources," such as limited natural resources or a limited amount of space that can be used for landfills.

12.1.3 Weaknesses of Mainstream Economics

Keeping in mind the connection between the environment and the economy, as indicated by Daly, we can identify three "weaknesses" in the framework of mainstream economics.

Question (1): How do the goods appear? Answer (1): The goods are produced by the combination of labor and capital. If we denote labor as L, capital as K, and production as Y, we have the production function $Y = f(L, K)$. Additional question (1): Should we not also include the input of natural resources and energy?

Question (2): Where do the goods go after being used? Answer (2): This question is not considered because economics deals with stages of production and consumption only. Even if waste is generated, it disappears at no cost. Additional question (2): Should economics not also include the problems of waste treatment and recycling?

Question (3): Is unlimited economic development possible? Answer (3): Unless there is some restriction to restrict growth, quantitative growth is possible. Additional question (3): Based on Figs. 12.1 and 12.2, how does an economy expand beyond the capacity of the environment?

The additional questions raised here are not typically considered by students of macroeconomics or microeconomics. They only become aware of these points when studying environmental economics or resource economics, which complement mainstream economics, or when studying an applied field in economics.

Note that the single term "environmental economics" can include mainstream economics, as well as subjects not based on mathematical principles. This point is peculiar to social science. Different methods are used to analyze one phenomenon.

An introductory problem in resource economics, introduced in this chapter, is how to apply economics to solving the problem of resource exhaustion. A further criticism of mainstream economics is its assumption that economic agents necessarily behave rationally (Söderbaum 2010). However, an introductory argument using mathematical principles is based on scientific methods and has significant merit.

Note that the textbooks on ecological economics by Herman E. Daly et al. provide a detailed explanation of mainstream economics, while also describing the importance of understanding (Figs. 12.1 and 12.2) (Daly and Farley 2004).

12.2 Optimal Use of Exhaustible Resources

12.2.1 An Increase in the Price of Resources

Figure 12.4 shows the change in the optimal price of an exhaustible resource derived from the theory of economics. Exhaustible resources are those that decrease in quantity as they are used, for example, fossil fuels such as coal and oil.

Here, t, on the horizontal axis, represents the period (e.g., a year), and the price of the resource in period t (or after t years) is p_t, as shown on the vertical axis. Furthermore, suppose the price p_0 at the initial point is 1. The price of the resource

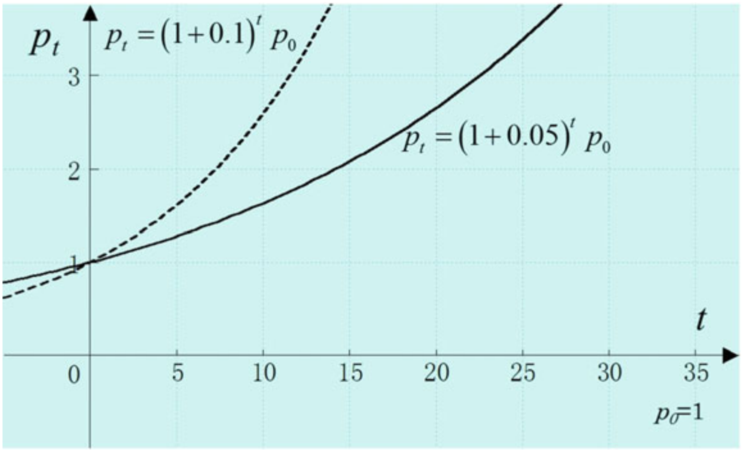

Fig. 12.4 Changes in the optimal price of exhaustible resources (Source: Author. t denotes the period (year), p_t denotes the price of the resource in period t, and p_0 is the price of the resource at the initial point)

is represented by the exponential function $p_t = (1 + r)^t p_0 = (1 + r)^t$, which passes through the vertical axis at 1. Here, r indicates the interest rate.

Two curves are shown in Fig. 12.4. The solid line is the price of the resource when the interest rate is 5 % ($r = 0.05$), and the dotted line is the price when the interest rate is 10 % ($r = 0.1$). A higher interest rate means the rate of the change in price increases more steeply.

Unlike a renewable resource, such as fishery resources and forest resources, an exhaustible resource cannot increase in quantity. Therefore, the amount available at the initial point reduces with use.

When the market mechanism of the economy functions properly, the price of a good is determined by the point at which supply and demand become equal. However, the amount that can be supplied from an exhaustible resource decreases over time. In other words, resources become scarce. As a result, the price of the resource will gradually increase over time. As the resource nears the point of exhaustion, the market price is expected to reach a very high level.

12.2.2 *Hotelling's Rule*

As mentioned earlier, the concept of a resource includes goods, money, labor, and time within mainstream economics. In contrast, resource economics focuses on how materials and energy are input from the environment into the economy and how to use these resources, including recycling, as well as prices and economic results. Natural resources have certain characteristics. First, the optimal use of an exhaustible resource is explained.

Before the field of resource economics existed, Harold Hotelling, an economist, spoke of the optimal use of an exhaustible resource over time (Hotelling 1931). His conclusion later came to be known as “Hotelling’s Rule” and is the first propositional statement that students of resource economics learn.

There are numerous ways to use Hotelling’s Rule. Suppose there is a form of economy where a resource of amount X is used up in the current year ($t = 0$) and next year ($t = 1$). This is the simplest form. The amounts of the resource used in each year are x_0, x_1, respectively. Since the resource will be used up after 2 years, we assume that $X = x_0 + x_1$.

Next, the utility (degree of satisfaction) gained by economic agents by using resource x is assumed to be $u(x)$. As x increases, u increases accordingly. However, the degree of increase will decline gradually, which is shown in differential calculus as $u^{'}(x) > 0, u^{''}(x) < 0$. Here, u' is called the marginal utility.

Note that the term marginal is used to mean “additional” in the context of economics. It does not mean “limit.”

We use another method in economics, called discounting, when we add values at different times. When an interest rate (or discount) is assumed as $r > 0$, the sum of the utility gained in this year and the next is $u(x_0) + u(x_1)/(1 + r)$.

As an aside, consider the following example. Suppose you deposit 100 yen at a bank this year. Interest is added on this principal in the next year. Suppose the interest rate is at 5 %. Then, the deposit at the beginning of the next year is $(1 + 0.05) \times 100$ yen = 105 yen. We refer to this calculation of interest as compound interest.

Discounting is the reverse of the interest calculation. Therefore, using the same interest rate, the value of 100 yen next year, but assessed this year, is 100 yen $\div$ $(1 + 0.05) \approx 95.2$ yen.

Now let’s return to utility function, $u(x_0) + u(x_1)/(1 + r)$, which we call the “discounted present utility” of an economic agent in the current year. If we rewrite the formula for resource exhaustion as $x_1 = X - x_0$, then substitute the RHS into the utility function, we have $u(x_0) + u(X - x_0)/(1 + r)$. We now have the discounted present utility expressed as a function of x_0 only.

In economics, the operative variable is deemed to be zero after differentiation or partial differentiation in order to maximize the objective function. We can maximize the discounted present value by differentiating x_0 to be zero, giving us $u^{'}(x_1) = (1 + r)u^{'}(x_0)$.

Furthermore, the prices of the resource this year and next year are assumed to be p_0, p_1, respectively. The economic agents use resources where the price is equal to the marginal utility u' to maximize their utility each year.

Therefore, we have $p_1 = (1 + r)p_0$. This formula shows that the price of the resource next year is equal to the price of the resource this year multiplied by (1 + interest rate). This is the simplest form of Hotelling’s Rule, namely, when there are only two periods.

The connection between the prices of the resource in the two periods is easily extended to T years (Conrad 1999). Note that the result is shown here, but not the calculation. The price of the exhaustible resource in t years is equal to the initial price p_0 multiplied by (1 + interest rate) t times. In other words, $p_t = (1+r)^t p_0$. The two curves in Fig. 12.4 show the case where p_0 is 1.

12.2.3 Examples

So far, we have discussed abstract theory. Here, we show examples of how to calculate the use and price of resources when they are used up in 2 years, assuming a specific utility function.

First, the utility gained by the economic agents from using the resource is assumed as $u(x) = x^\alpha$. We also assume that $0 < \alpha < 1$. Differentiating once and twice with respect to x gives $u'(x) = \alpha x^{\alpha-1} > 0, u''(x) = \alpha(\alpha-1)x^{\alpha-2} < 0$, respectively, for the range of α, satisfying the condition of the utility function.

When the resources are used up in 2 years, the discounted present utility of economic agents in the current year is $x_0^\alpha + x_1^\alpha/(1+r)$. Then, recall that $x_1 = X - x_0$. Substituting this into the discounted utility function gives the objective function $x_0^\alpha + (X - x_0)^\alpha/(1+r)$.

This objective function is a function of x_0. We find the solution to $x_0 = \frac{(1+r)^{1/(1-\alpha)}}{1+(1+r)^{1/(1-\alpha)}}X$ by differentiating it to be zero and adjusting. Next, the value is assigned to $x_1 = X - x_0$ to give us $x_1 = \frac{1}{1+(1+r)^{1/(1-\alpha)}}X$.

Here, we assume the following values, $\alpha = 0.5$, $r = 0.05$, $X = 10$, and then calculate the answer using a scientific electronic calculator or computer software. The amount of each resource used and their prices in each year are $x_0 = 5.244$, $x_1 = 4.756$, $p_0 = 0.218$, $p_1 = 0.229$, respectively. Here, p_1 divided by p_0 is 1.05, which tells us that the prices increase by (1 + interest rate).

Now, we can extend this calculation to T years. Again, we only show the result of the calculation, based on the following prices: $p_T = (1+r)p_{T-1} = (1+r)^2 p_{T-2} = \cdots = (1+r)^{T-1} p_1 = (1+r)^T p_0$. In other words, we can find out the price after T years by multiplying the price of the resource at the initial point by (1 + interest rate) T times.

Figure 12.5 shows the remaining amount of a resource $\left(= 10 - \sum_{t=0}^{i} x_t \right)$ and its price as the resource is used up over six periods (i.e., 5 years). Again, we assume $\alpha = 0.5$, $r = 0.05$, $X = 10$. Note that the curve representing the prices becomes clearer as the period on the horizontal axis becomes longer.

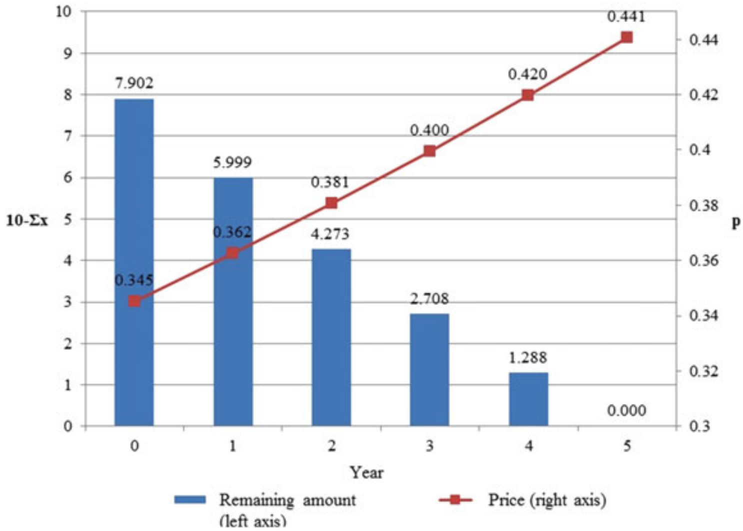

Fig. 12.5 Example of remaining resources and the prices in six periods (Source: Author. Resources at the initial point is 10; interest rate is 5 %)

12.3 The Task of Economics

12.3.1 From Actual Data

Hotelling's Rule was introduced in the previous section as a rational conclusion of economics. When an exhaustible resource is used for a prolonged period, its price will increase at an interest rate as the amount of the resource decreases. The change in the price of an exhaustible resource does not necessarily follow an ascending curve in reality (see Fig. 12.6).

Figure 12.6 shows the confirmed amount of oil reserves and the real prices of imported oil in the United States. The graph is based on data publicly disclosed by the US Energy Information Administration, Department of Energy, on their website. The Consumer Price Index of March 2014 is used to calculate the real price, with the price in 1970 taken as 100. The data of oil reserves are available until 2011, but the price data are available until 2013.

The figure shows that over the 40 years since the beginning of the 1970s, the price of oil has not increased as the supply has decreased.

The price of oil is an important economic index and has an impact on the prices of all kinds of goods. However, this price does not only depend on the available amount of oil reserves. Other factors, such as the existence of alternative energy sources, technology, and the discovery of new oil reserves, also play a role (Krautkraemer 2009).

In resource economics, methods to determine the optimal use of resources have been researched since the 1970s, when the limits of resources and the environment

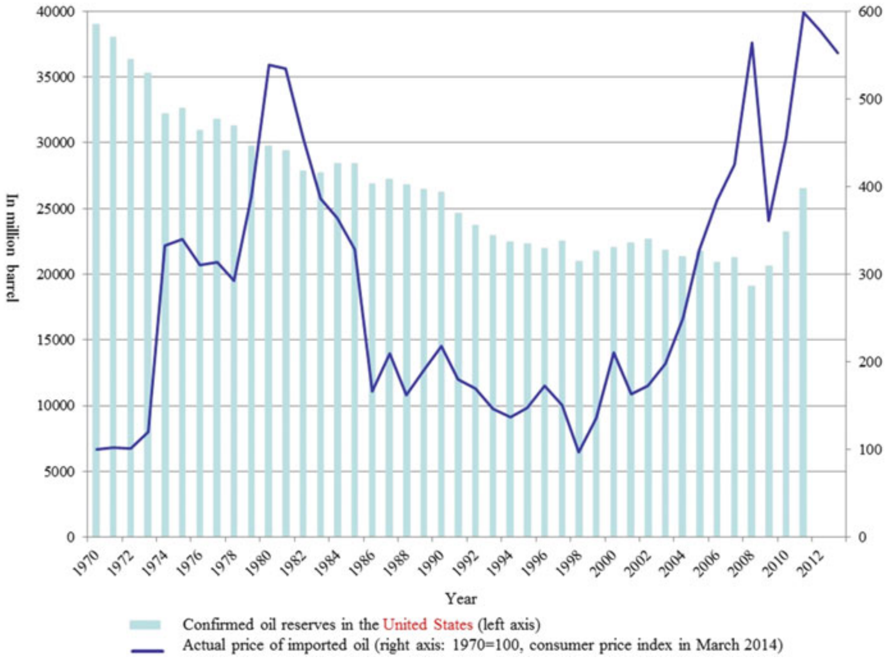

Fig. 12.6 Confirmed oil reserve and prices in the United States (Source: Author: based on publicly disclosed data of the U.S. Energy Information Administration, Department of Energy http://www.eia.gov/)

began attracting attention as a result of the oil crisis at the time. Here, the dynamic optimization model became popular owing to its ease of use.

An effect known as "back-stop technology" was analyzed at much the same time. This required a higher supply cost than oil, but had the same function. Here, the same function as oil can be supplied indefinitely at the same cost if the price becomes equal to the cost (Nordhaus 1973).

However, it is difficult to estimate when such technology appears in an economy. On the other hand, a critical situation that requires alternative technology means economics can be useful when formulating environmental policies.

Japan has begun to emphasize renewable energy, such as solar power and wind power, and is beginning to move away from its dependence on nuclear energy. This shift was triggered by the Great East Japan Earthquake of March 2011 and the subsequent nuclear disaster. However, these alternative sources of energy will take time to replace nuclear power as back-stop technologies.

Are current policies of encouraging renewable energy, such as the feed-in tariff, valid in the long term? These options are expensive to implement. Furthermore, are they going to be better for the environment? Are there any side effects?

The difficulty of predicting answers to these questions means we need to use some trial and error when using these economic models to formulate environmental policies.

12.3.2 Conclusion

In this chapter, we first explained the research fields covered by economics, and noted that mainstream economics does not typically incorporate the natural environment. Next, we examined the optimal use of exhaustible resources as part of resource economics and explained various environment problems from an economics viewpoint using models and examples. In addition, we learnt that economic theories reach conclusions that are easy to understand, but fail to fully explain the real movements of oil stocks and prices.

A sound understanding of real-world situations and environmental problems is required before we can solve these problems using economics. Then, to accurately express the structure of a problem, we require a mathematical model, the results of which should be considered when formulating policies.

While this sounds reasonable, there are many factors to be taken into account and balanced. Most (mainstream) economics based on mathematical principles require that agents make rational decisions. Models that deviate from this assumption tend not be accepted. Moreover, descriptions not based on mathematical principles are considered to be lacking in logic and, consequently, are often ignored.

However, once a precedent is accepted, the range of acceptance of economics widens. A recent example is the field of behavioral economics, which has become most popular (Makabe 2010). However, whether behavioral economics can replace mainstream economics remains to be seen.

In contrast, environmental economics and resource economics still have little influence in economics and in the general community. This chapter briefly introduced resource economics, but readers are encouraged to explore the methods explained here further.

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