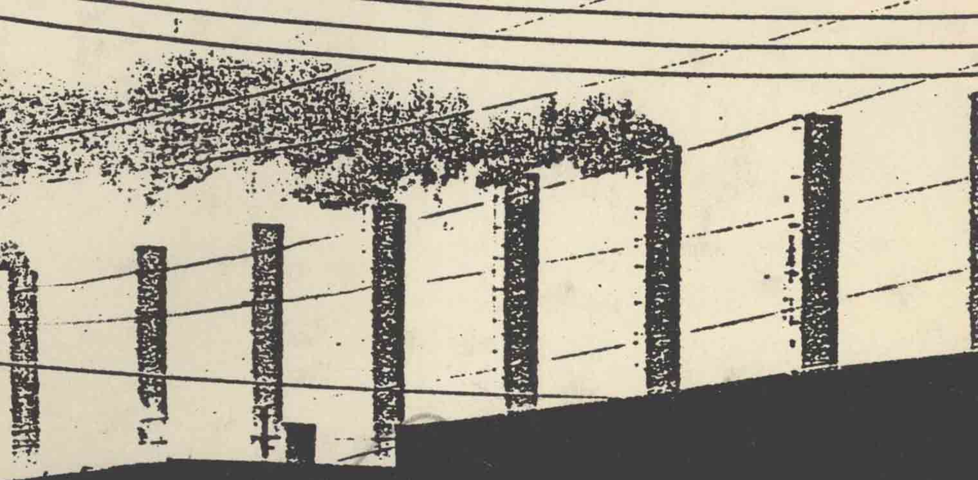

# THE EFFICIENT USE OF ENERGY RESOURCES

William D. Nordhaus

A Cowles Foundation Monograph

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To

JEFF, MONICA, and BECKA

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To those about to embark, I can only say I hope you enjoy the voyage as much as I did.

# INTRODUCTION

Another book on energy requires apology more than introduction. My basic apology is twofold: questions concerning energy and exhaustible resources are of fundamental importance to our economy and society, and many of them remain unanswered.

*The Basic Themes*

The fundamental economic question about energy resources is: How fast should we consume our low-cost resources? (Of course, in a mixed market economy such as the United States there are no simple and direct levers to control the rate of consumption of our resources, and we must use policy instruments like interest rates, taxes, price controls or subsidies, and environmental constraints.) From a technological point of view, we face three different kinds of resources. First, there are inexpensive but limited oil and gas resources—ideal from an economic and environmental point of view. Second, there are abundant, but less attractive, resources that may be used when the low-cost resources run thin—coal, high-cost oil and gas, high-grade uranium in the current generation of nuclear power reactors. This second group generally suffers from the shortcoming that it is expensive and often environmentally risky or dirty.

A third group is the superabundant resources that would provide virtually limitless energy for centuries to come—these are fusion, fission, solar, and unknown. These share two features—they are unproven for large-scale use, and they are relatively expensive. Beyond that, some are thought to be clean (solar energy), while some are thought to be environmentally very risky (some nuclear breeder reactors); some are virtually proven (the liquid metal fast breeder reactor), while others have not passed the test of technical feasibility (fusion); some are soft, some hard, and so forth.

This book asks a number of questions about the time pattern of use of these various resources:

1. What does economic theory have to contribute to the question of efficient use of energy resources? Quite a bit, as is shown in chapter 1. Efficient use of energy resources entails using cheap before expensive resources. A deeper set of results concerns the efficient pricing of resources. Each resource will, in a competitive market, have a "royalty" attached to it. The royalty will be zero for resources that are not scarce, positive for those that are. For all resources, the royalty will be rising at the market interest rate.

By working backward from exhaustion, we can determine what an efficient price for oil or other resources would be. The basic result can easily be seen where there are no extraction costs—roughly accurate for Mideast oil today. In this case, at the point when substitution of the next resource (higher-cost oil, coal, whatever) occurs, the price of Mideast oil and its substitute must be equal. For concreteness, call that year 2020. In 2020, then, the royalty on Mideast oil must equal the cost of the substitute. Since, in an efficient market, the royalty must rise at the interest rate, the royalty today must be the discounted value of the royalty in 2020. If the discount rate is 6 percent, and the substitute costs \$20.00, then in 1975 the royalty on Mideast oil, *and its efficiency price*, must equal $\$20.00/(1.06)^{45} = \$1.45$.

2. How can we apply these simple economic theories to the real world? Clearly, casual examples like those presented in the last paragraph are insufficient to indicate what an efficient price would be in the real world. Chapters 2 through 4 describe the construction and components of a model designed to determine the efficient path for using energy resources.

The model has two different components. The first, discussed in chapter 2, describes the "demand" side of the energy market. It reports the results of a detailed econometric model of energy demand and then shows how these results can be used in the energy model. The second component is the technology, described in chapter 3, which presents estimates of the extent of energy resources, as well as the costs of extraction and conversion. Alternative models of cost of extraction are briefly described. Finally, chapter 4 lists the detailed equations used in the linear programming energy model.

One major spillover from the model construction is the estimates of energy demand functions in chapter 2. These rely on a combination of techniques for estimating the price-responsiveness of energy demanded in the United States and Europe. The basic result is that energy demand is shown to be moderately elastic with respect to price, with elasticities in the range of −0.5 to −1.0 depending on the sector, country, and specification.

3. The most important investigation, in my mind, relates to the estimate of the efficiency price of oil, given in chapter 5. Relying on the model, and the (clearly unrealistic) assumption that the energy market is competitive, we estimate that the efficient price of oil (for 1975 in 1975 prices) is $3.00 per barrel. This compares with a price of approximately $11.00 per barrel in 1978 (again in 1975 prices). The reason why the calculated efficiency price is so surprisingly low is basically the reason given in question 1 above—the cost of the next substitute resource is relatively modest, and the time at which substitution occurs is distant. Extensive sensitivity analysis in chapter 5 gives a range of $2.03 to $3.71 per barrel—still well below the present market price.

4. Given the enormous discrepancy between actual and calculated efficiency price, does this suggest that the Organization of Petroleum Exporting Countries (OPEC) is responsible for the difference? Chapter 1 investigates briefly the theory of monopoly in resource markets. Under limited but plausible assumptions it is shown that the monopoly price will be set at approximately the substitute price. In the example in (1)

above, then, if a monopolist had control of the oil market, he would set the price at slightly below the substitute (say, $19.00), rather than at the competitive price of $1.45.

Is OPEC responsible for the current oil price? It is a tempting hypothesis to attribute the rise of the world oil price from 1972 to 1974 to the effective monopolization of the world oil market by OPEC. This temptation is reinforced by the result in chapter 5 that the market price in the late 1960s and early 1970s was virtually equal to the calculated efficiency price. In chapter 6, we look more carefully at the empirical support for this hypothesis, both in the current study and in other studies. Most studies make a motivational hypothesis that OPEC is interested in maximizing its discounted profits (the "wealth maximizing monopolist"). The basic result of this and other economic studies indicates that the wealth-maximizing price for OPEC oil today lies at the bottom end of the $10.00 to $20.00 per barrel range (in 1975 prices). These studies confirm that the price rise of 1973–74 can be traced basically to the virtual monopolization of the international oil market. Although a large degree of short-run monopoly power exists, and given the undeniable presence of irrational elements in oil pricing, the evidence strongly suggests that any further substantial rise in the oil price would take prices well above the long-run monopoly price.

5. How likely is it that the future will see a repetition of the dramatic price rises of 1973–74? Chapter 6 describes the trajectory of wealth-maximizing oil prices for this model as well as for other studies. Although there are enormous uncertainties, these studies indicate that on economic grounds the 1973–74 increase attained the long-run monopoly price. Taking the median of the studies presented there, the real price of oil that would maximize the wealth of OPEC would rise about 2 percent per annum over the period 1975 to 2005.

6. What is the chance that global environmental effects will appear as a result of unrestrained market forces? There is widespread evidence that the combustion of fossil fuels—leading to buildup of atmospheric carbon dioxide—will be the first man-made environmental problem of global signi-

ficance. Chapter 8 outlines the essence of the proble... investigates possible control strategies. The conclusion is that we are probably heading for major climatic changes over the next 200 years if market forces are unchecked. Global temperatures would rise in the order of 5 degrees centigrade, with much more dramatic increases in the polar regions. Further consequences—on agriculture or the level of the oceans—would clearly follow.

Chapter 8 describes several control strategies, of which the most efficient one is a "carbon tax" on the combustion of fossil fuels. It is shown that (depending on the desired level of control) these can reduce the seriousness of the effects with modest but manageable economic costs.

*Looking Backward*

This study represents work done over the period 1970 to 1976. It was virtually complete when I was asked to become a member of President Carter's Council of Economic Advisers. As a result, a few loose ends will appear, for chapters 3, 6, and 7 were written on the fly. Basically, however, the work represents a view of the world shortly after the oil crisis.

Looking backward, it seems useful to ask what seems right and what seems wrong. I view the results described here as primarily *methodological*, as indicating a technique by which economic and engineering tools can be used to analyze trends in markets and the contributions of new technologies. Since the original version was written in 1973, this class of technique has gained wide currency among energy modelers.

On the basic *empirical* results of this study, concerning the *efficiency price* of energy resources, nothing has arisen to change my view substantially. Undiscovered oil is being discovered and is turning into proven reserves at a good clip; demand for oil is growing at about what the energy demand functions would predict; no major new findings or analytical problems have been uncovered.

There are, however, three features of energy markets which pose very great uncertainties and may modify the empirical results, especially in the short run. These features are the cost of new technologies, the determinants of OPEC pricing, and the regulation of the economy. When recent evidence of these three features is combined, it appears likely that, especially in the short run, the cost and price trajectories outlined below are understated.

The *costs of new or unproven technologies* must perforce be laden with uncertainty. Until considerable experience is developed with technology, there is no way of predicting the cost of future technologies except with a large margin of error. Studies of cost overruns—essentially errors of cost estimates—in large construction projects and in military aircraft development indicate that the ultimate costs routinely vary by a factor of two from first estimates. At the same time, it is just as routine to note that after development and when engineers begin to move down the "learning curve," very rapid improvement in costs generally follows introduction.

Given these inherent uncertainties, I have particular concern that the cost of the first generation of new technologies —particularly synthetic fuels such as shale oil and gasified and liquefied coal—may have been substantially underestimated. The most recent studies of synthetic fuels indicate that costs are from 25 to 60 percent higher than the figures used in the present study. Assuming the most recent estimates are accurate and that no learning occurs after introduction, this would lead to higher costs, higher prices, and lower energy demands.

A second area in which there continue to be considerable uncertainties concerns *OPEC pricing* of oil and gas. In chapter 6 it is shown that there is substantial uncertainty about the wealth-maximizing price in the short run—the main uncertainty deriving from the uncertainty about the short-run price-elasticity of the demand for oil. In the long run, however, the different studies cluster fairly closely. There are no major new developments that would change these estimates; the most recent studies show no change from those given in chapter 6.

Many observers question the validity of such studies, however, because the models generally ignore the role of noneconomic factors in decisions about production and pricing. One problem is that the concept of maximizing net wealth is clearly too narrow an objective for many governments. Other important objectives are to preserve the "black gold" for future generations (to diversify the portfolios away from paper wealth) and to use the oil weapon for political ends. Some countries (Saudi Arabia, Kuwait, United Arab Emirates) are probably simply glutted with cash. There appear to be irrational elements in decision-making, in that discount rates placed on oil are different from rates placed on other goods.

Another set of concerns is the dynamics of cartel behavior. Countries whose reserves have but a short lifetime may put strong pressure, including military threats, to restrain production on countries with large reserves. There are, of course, pressures in the opposite direction. Many oil-producing countries are poor, and they will have a strong inclination to expand production as rapidly as possible as long as they are but a small fraction of the world market. These countries also generally have very high discount rates, which will tend to incline them to bring reserves to market quickly. All these and other factors make the use of the monopoly models suspect, indicating that the quantitative results are of limited validity.

A final area where the fundamental structure of the model can be questioned concerns the effect of *regulatory and environmental* policy. The fundamental assumption that runs through the analysis is that regulatory and environmental policies do not significantly impede market forces. Thus it is assumed that there is no further tightening of the environmental screws beyond levels of 1975. Further, it is assumed that (outside of OPEC) prices reflect costs of production and that there are no non-market impediments to developments or introduction of new technologies.

Each of these assumptions is probably too optimistic. The regulatory problems are perhaps best illustrated for environmental policy. Environmental policy in the energy sector in the United States presents flaws which lead to serious economic inefficiencies. The flaws stem from two basic areas. First, the technique of regulation for environmental spillovers relies on a series of detailed, specific technological requirements for individual firms and utilities as to how they should produce energy. As a result, we spread around our environmental dollars extremely inefficiently. A well-documented example is the $40-billion regulation proposed by the U.S. Environmental Protection Agency in 1978 to reduce sulfur emissions from coal-fired plants. This regulation mandates techniques be used to remove sulfur after mining in preference to using low sulfur coal. It does so on a nationwide basis. As a result, sulfur removal is inefficient—the nation pays more than needed for sulfur removal. More troubling is the possibility that overall health effects will be *worse* under the original, full-control proposal than under a well-designed standard. These and other inefficiencies are troubling because they may lead to costs that are two or three times what is efficient and to the stifling of new technologies.

The assumption of insignificant nonmarket impediments to energy production is also unrealistically optimistic. In the United States government regulation determines a significant fraction of price, allocation, and technical decisions. New technologies are largely funded by government. More troubling, however, is the increasing tendency to eliminate or slow development of energy technologies—like nuclear or coal—due to a "zero-risk" philosophy.

To a considerable extent, such inefficient and irrational policies make technological change and substitution uncertain or extremely expensive. If they become prevalent, there is little hope that we can make a gradual and inexpensive transition from oil and gas to alternative fuels.

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