7 Energy: The Transition from Depletable to Renewable Resources

If it ain't broke, don't fix it!

—Old Maine proverb

Introduction

Energy is one of our most critical resources; without it, life would cease. We derive energy from the food we eat. Through photosynthesis, the plants we consume—both directly and indirectly when we eat meat—depend on energy from the sun. The materials we use to build our houses and produce the goods we consume are extracted from the earth's crust, and then transformed into finished products with expenditures of energy.

Currently, many industrialized countries depend on oil and natural gas for the majority of their energy needs. According to the International Energy Agency (IEA), these resources together supply 59 percent of all primary energy consumed worldwide. (Adding coal, another fossil fuel resource, increases the share to 86 percent of the total.) Fossil fuels are depletable, nonrecyclable sources of energy. Crude oil proven reserves peaked during the 1970s and natural gas peaked in the 1980s in the United States and Europe, and since that time, the amount extracted has exceeded additions to reserves.

Kenneth Deffeyes (2001) and Campbell and Laherrere (1998) estimate that *global* oil production will peak early in the twenty-first century. As Example 7.1 points out, however, due to the methodology used, these predictions of the timing of the peak are controversial.

Even if we cannot precisely determine when the fuels on which we currently depend so heavily will run out, we still need to think about the process of transition to new energy sources. According to depletable resource models, oil and natural gas would be used until the marginal cost of further use exceeded the marginal cost of substitute resources—either more abundant depletable resources such as coal, or renewable sources such as solar energy.[1] In an efficient market path, the transition to these alternative sources would be smooth and harmonious. Have the allocations of the last several decades been efficient or not? Is the market mechanism flawed in

[1]When used for other purposes, oil can be recyclable. Waste lubricating oil is now routinely recycled.

EXAMPLE 7.1

Hubbert's Peak

When can we expect to run out of oil? It's a simple question with a complex answer. In 1956 geophysicist M. King Hubbert, then working at the Shell research lab in Houston, predicted that U.S. oil production would reach its peak in the early 1970s. Though Hubbert's analysis failed to win much acceptance from experts either in the oil industry or among academics, his prediction came true in the early 1970s. With some modifications, this methodology has since been used to predict the timing of a downturn in global annual oil production as well as when we might run out of oil.

These forecasts and the methods that underlie them are controversial, in part because they ignore such obvious economic factors as prices. The Hubbert model assumes that the annual rate of production follows a bell-shaped curve, regardless of what is happening in oil markets; oil prices don't matter. It seems reasonable to believe, however, that by affecting the incentive to explore new sources and to bring them into production, prices should affect the shape of the production curve.

How much difference would incorporating prices make? Pesaran and Samiei (1995) find, as expected, that modifying the model to include price effects causes the estimated ultimate resource recovery to be larger than implied by the basic Hubbert model. Moreover, a study by Kaufman and Cleveland (2001) finds that forecasting with a Hubbert-type model is fraught with peril.

> *. . . production in the lower 48 states stabilizes in the late 1970's and early 1980's, which contradicts the steady decline forecast by the Hubbert model. Our results indicate that Hubbert was able to predict the peak in US production accurately because real oil prices, average real cost of production, and [government decisions] co-evolved in a way that traced what appears to be a symmetric bell-shaped curve for production over time. A different evolutionary path for any of these variables could have produced a pattern of production that is significantly different from a bell-shaped curve and production may not have peaked in 1970. In effect, Hubbert got lucky. [p. 46]*

Does this mean we are not running out of oil? No. It simply means we have to be cautious when interpreting forecasts of the timing of the transition to other sources of energy. In 2005, the Administrator of the U.S. Energy Information Agency (EIA) presented a compendium of 36 studies of global oil production and all but one forecasted a production peak. The EIA's own estimates of the timing range from 2031 to 2068 (Caruso, 2005). The issue, it seems, is no longer whether oil production will peak, but when.

Sources: M. Pesaran and H. Samiei, "Forecasting Ultimate Resource Recovery." INTERNATIONAL JOURNAL OF FORECASTING, Vol. 11, No. 4 (1995), pp. 543–555; R. Kaufman and C. Cleveland, "Oil Production in the Lower 48 States: Economic, Geological, and Institutional Determinants." ENERGY JOURNAL, Vol. 22, No. 1 (2001), pp. 27–49; and G. Caruso, "When Will World Oil Production Peak?" A presentation at the 10th Annual Asia Oil and Gas Conference in Kuala Lumpur, Malaysia, June 13, 2005.

its allocation of depletable, nonrecyclable resources? If so, is it a fatal flaw? If not, what caused the inefficient allocations? Is the problem correctable?

In this chapter we shall examine some of the major issues associated with the allocation of energy resources over time and explore how economic analysis can clarify our understanding of both the sources of the problems and their solutions.

Natural Gas: Price Controls

In the United States, during the winter of 1974 and early 1975, serious shortages of natural gas developed. Customers who had contracted for and were willing to pay for natural gas were unable to get as much as they wanted. The shortage (or curtailments, as the Federal Energy Regulatory Commission (FERC) calls them) amounted to two trillion cubic feet of natural gas in 1974–1975, which represented roughly 10 percent of the marketed production in 1975. In an efficient allocation, shortages of that magnitude would never have materialized. What happened?

The source of the problem can be traced directly to government controls over natural gas prices. This story begins, oddly enough, with the rise of the automobile, which traditionally has not used natural gas as a fuel. The increasing importance of the automobile for transportation created a rising demand for gasoline, which in turn stimulated a search for new sources of crude oil. This exploration activity uncovered large quantities of natural gas (known as associated gas), in addition to large quantities of crude oil, which was the object of the search.

As natural gas was discovered, it replaced manufactured gas—and some coal—in the geographic areas where it was found. Then, as a geographically dispersed demand developed for this increasingly available gas, a long-distance system of gas pipelines was constructed. In the period following World War II, natural gas became an important source of energy for the United States.

The regulation of natural gas began in 1938 with the passage of the Natural Gas Act. This act transformed the Federal Power Commission (FPC), which subsequently become FERC, into a federal regulatory agency charged with maintaining "just" prices. In 1954 a Supreme Court decision in *Phillips Petroleum Co. v. Wisconsin* forced the FPC to extend their price control regulations to the producer. Previously they had limited their regulation to pipeline companies.

Because the process of setting price ceilings proved cumbersome, the hastily conceived initial "interim" ceilings remained in effect for almost a decade before the Commission was able to impose more carefully considered ceilings. What was the effect of this regulation?

By returning to our models in the previous section, we can see the havoc this would raise. The ceiling would prevent prices from reaching their normal levels. Since price increases are the source of the incentive to conserve, the lower prices would cause more of the resource to be used in earlier years. Consumption levels in those years would be higher under price controls than without them.

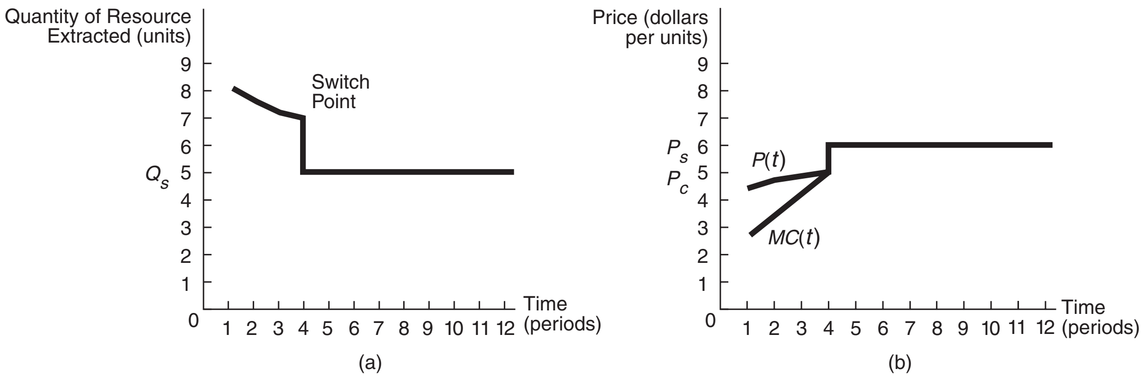
Effects on the supply side are also significant. Producers would produce the resource only when they could do so profitably. Once the marginal cost rose to meet the price ceiling, no more would be produced, in spite of the large demand for the resource at that price. Thus, as long as price controls were permanent, less of the resource would be produced with controls than without. Furthermore, more of what would be produced would be used in the earlier years.

The combined impact of these demand-and-supply effects would be to distort the allocation significantly (see Figures 7.1a and 7.1b). While a number of aspects differentiate this allocation from an efficient one, several are of particular importance: (1) more of the resource is left in the ground, (2) the rate of consumption is too high, (3) the time of transition is earlier, and (4) the transition is abrupt, with prices suddenly jumping to new, higher levels. All are detrimental. The first effect means we would not be using all of the natural gas available at prices consumers were willing to pay. Because price controls would cause prices to be lower than efficient, the resource would be depleted too fast. These two effects would cause an earlier and abrupt transition to the substitute possibly before the technologies to use it were adequately developed.

The discontinuous jump to a new technology, which results from price controls, can place quite a burden on consumers. Attracted by artificially low prices, consumers would invest in equipment to use natural gas, only to discover—after the transition—that natural gas was no longer available.

One interesting characteristic of price ceilings is that they affect behavior even before they are binding.[2] This effect is clearly illustrated in Figures 7.1a and 7.1b in the earlier years. Even though the price in the first year is lower than the price ceiling, it is not equal to the efficient price. (Can you see why? Think what price controls do to the marginal user cost faced by producers.) The price ceiling causes a reallocation of resources toward the present, which, in turn, affects prices in the earlier years.

FIGURE 7.1 (a) Increasing Marginal Extraction Cost with Substitute Resource in the Presence of Price Controls: Quantity Profile (b) Increasing Marginal Extraction Cost with Substitute Resource in the Presence of Price Controls: Price Profile



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[2]For a complete analysis of this point, see Lee (1978).

Price controls may cause other problems as well. Up to this point, we have discussed permanent controls. Not all price controls are permanent; they can change unpredictably at the whim of the political process. The fact that prices could suddenly rise when the ceiling is lifted also creates unfortunate incentives. If producers expect a large price increase in the near future, they have an incentive to stop production and wait for the higher prices. This could cause severe problems for consumers.

For legal reasons, the price controls on natural gas were placed solely on gas shipped across state lines. Gas consumed within the states where it was produced could be priced at what the market would bear. As a result, gas produced and sold within the state received a higher price than that sold in other states. Consequently, the share of gas in the interstate market fell over time as producers found it more profitable to commit reserve additions to the *intrastate*, rather than the *interstate*, market. During 1964–1969, about 33 percent of the average annual reserve additions were committed to the interstate market. By 1970–1974, this commitment had fallen to a little less than 5 percent.

The practical effect of forcing lower prices for gas destined for the interstate market was to cause the shortages to be concentrated in states served by pipeline and dependent on the interstate shipment of gas. As a result, the ensuing damage was greater than it would have been if all consuming areas had shared somewhat more equitably in the shortfall. Governmental control of prices not only precipitated the damage, it intensified it!

It seems fair to conclude that, by sapping the economic system of its ability to respond to changing conditions, price controls on natural gas created a significant amount of turmoil. If this kind of political control is likely to recur with some regularity, perhaps the overshoot and collapse scenario might have some validity. In this case, however, it would be caused by government interference rather than any pure market behavior. If so, the proverb that opens this chapter becomes particularly relevant!

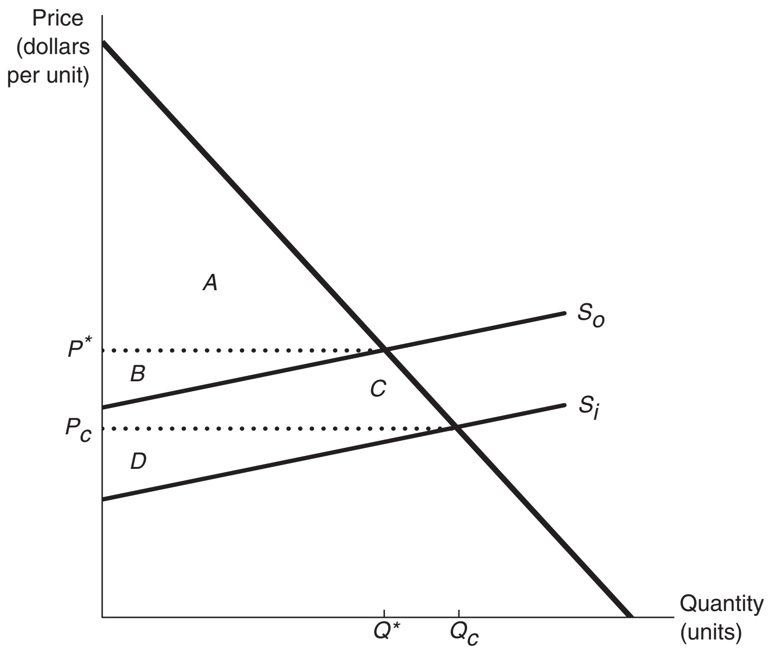
Why did Congress embark on such a counterproductive policy? The answer is found in rent-seeking behavior that can be explained through the use of our consumer and producer surplus model. Let's examine the political incentives in a simple model.

Consider Figure 7.2. An efficient market allocation would result in Q^* supplied at price P^*. The net benefits received by the country would be represented by areas A and B. Of these net benefits, area A would be received by consumers as consumer surplus and B would be received by producers as a producer surplus.

Suppose now that a price ceiling were established. From the above discussion we know that this ceiling would reduce the marginal user cost because higher future prices would no longer be possible. In Figure 7.2, this has the effect for current producers of lowering the perceived supply curve, due to the lower marginal user cost. As a result of this shift in the perceived supply curve, current production would expand to Q_c and price would fall to P_c. Current consumers would unambiguously be better off, since consumer surplus would be area $A + B + C$ instead of area A. They would have gained a net benefit equal to $B + C$.

It may appear that producers could also gain if $D > B$, but that is not correct because this diagram does not take into account the effects on other time periods.

FIGURE 7.2 The Effect of Price Controls



Since producers would be overproducing, they would be giving up the scarcity rent they could have gotten without price controls. Area *D* measures current profits only without considering scarcity rent. When the loss in scarcity rent is considered, producers unambiguously lose net benefits.

Future consumers are also unambiguously worse off. In the terms of Figure 7.2, which represents the allocation in a given year, as the resource was depleted, the supply curve for each subsequent year would shift up, thereby reflecting the higher marginal extraction costs for the remaining endowment of the resource. When the marginal extraction cost ultimately reached the level of the price control, the amount supplied would drop to zero. Extracting more would make no sense to suppliers because their cost would exceed the controlled price. Since the demand would not be zero at that price, a shortage would develop. Although consumers would be willing to pay higher prices and suppliers would be happy to supply more of the resource at those higher prices (if they were not prevented from doing so by the price control), the price ceiling would keep those resources in the ground.

Congress may view scarcity rent as a possible source of revenue to transfer from producers to consumers. As we have seen, however, scarcity rent is an opportunity cost that serves a distinct purpose—the protection of future consumers. When a government attempts to reduce this scarcity rent through price controls, the result is an overallocation to current consumers and an underallocation to future consumers. Thus, what appears to be a transfer from producers to consumers is, in large part, also a transfer from future consumers to present consumers. Since current consumers mean current votes and future consumers may not know whom to blame by the time shortages appear, price controls are politically attractive. Unfortunately, they are also inefficient; the losses to future consumers and producers are greater than the gains to current consumers. Because controls distort the allocation toward the present, they are also unfair. Thus, markets in the presence of price controls are indeed myopic, but the problem lies with the controls, not the market.

Over the long run, price controls end up harming consumers rather than helping them. Scarcity rent plays an important role in the allocation process, and attempts to eliminate it can create more problems than solutions. After long debating the price control issue, Congress passed the Natural Gas Policy Act on November 9, 1978. This act initiated the eventual phased decontrol of natural gas prices. By January 1993, no sources of natural gas were subject to price controls.

Oil: The Cartel Problem

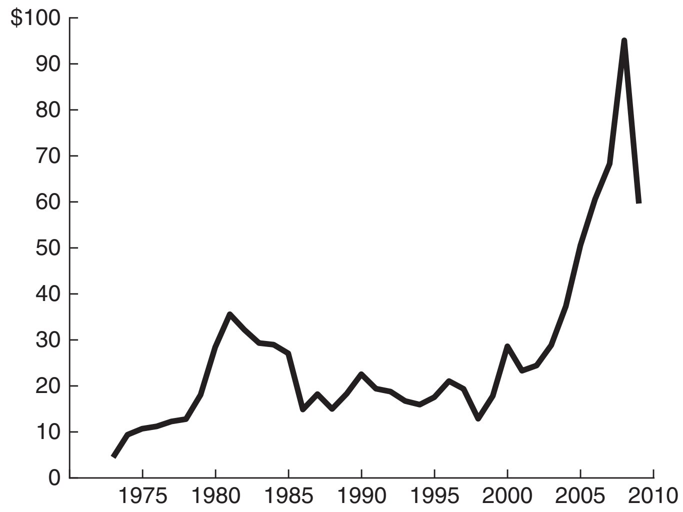
Since we have considered similar effects on natural gas, we note merely that historically price controls have been responsible for much mischief in the oil market as well. A second source of misallocation in the oil market, however, deserves further consideration. Most of the world's oil is produced by a cartel called the Organization of Petroleum Exporting Countries (OPEC). The members of this organization collude to exercise power over oil production and prices. As established in Chapter 2, seller power over resources due to a lack of effective competition leads to an inefficient allocation. When sellers have market power, they can restrict supply and thus force prices higher than otherwise. (Figure 7.3 shows oil prices over time.)

Though these conclusions were previously derived for nondepletable resources, they are valid for depletable resources as well. A monopolist can extract more scarcity rent from a depletable resource base than competitive suppliers simply by restricting supply. The monopolistic transition results in a slower rate of production and higher prices.[3] The monopolistic transition to a substitute, therefore, occurs later than a competitive transition. It also reduces the net present value society receives from these resources.

The cartelization of the oil suppliers has apparently been very effective (Smith, 2005). Why? Are the conditions that make it profitable unique to oil, or could oil cartelization be the harbinger of a wave of natural resource cartels? To answer these questions, we must isolate those factors that make oil cartelization possible. Although many factors are involved, four stand out: (1) the price elasticity of demand for OPEC oil in both the long run and the short run; (2) the income elasticity of demand for oil; (3) the supply responsiveness of the oil producers who are not OPEC members; and (4) the compatibility of interests among members of OPEC.

[3]The conclusion that a monopoly would extract a resource more slowly than a competitive mining industry is not perfectly general. It is possible to construct demand curves such that the extraction of the monopolist is greater than or equal to that of a competitive industry. As a practical matter, these conditions seem unlikely. That a monopoly would restrict output, while not inevitable, is the most likely outcome.

FIGURE 7.3 Real Crude Oil Price (1973–2009)



Sources: Monthly Energy Review (MER), U.S. Energy Information Administration (EIA) (http://www.eia.doe.gov/mer/prices.html); Consumer Price Index (CPI), Bureau of Labor Statistics (http://www.bls.gov/cpi/data.htm).

Note: Prices are in 2009 dollars.

Price Elasticity of Oil Demand

The elasticity of demand is an important ingredient because it determines how responsive demand is to price. When demand elasticities are between 0 and –1 (i.e., when the percent quantity response is smaller than the percent price response), price increases lead to increased revenue. Exactly how much revenue would increase when prices increase depends on the magnitude of the elasticity. Generally, the smaller the absolute value of the price elasticity of demand (the closer it is to 0.0), the larger the gains to be derived from forming a cartel.

The price elasticity of demand for oil depends on the opportunities for conservation, as well as on the availability of substitutes. As storm windows cut heat losses, the same temperature can be maintained with less heating oil. Smaller, more fuel-efficient automobiles reduce the amount of gasoline needed to travel a given distance. The larger the set of these opportunities and the smaller the cash outlays required to exploit them, the more price-elastic the demand. This suggests that demand will be more price-elastic in the long run (when sufficient time has passed to allow adjustments) than in the short run.

The availability of substitutes is also important because it limits the degree to which prices can be raised by a producer cartel. Abundant quantities of substitutes available at prices not far above competitive oil prices can set an upper limit on the cartel price. Unless OPEC controls those sources as well—and it doesn't—any attempts to raise prices above those limits would cause the consuming nations to simply switch to these alternative sources; OPEC would have priced itself out of the market.

As described in more detail in a subsequent section of this chapter, alternative sources clearly exist, although they are expensive and the time of transition is long.

Income Elasticity of Oil Demand

The income elasticity of oil demand is important because it indicates how sensitive oil demand is to growth in the world economy. As income grows, oil demand should grow. This continual increase in demand fortifies the ability of OPEC to raise its prices.

The income elasticity of demand is also important because it registers how sensitive demand is to the business cycle. The higher the income elasticity of demand, the more sensitive demand is to periods of rapid economic growth or to recessions. This sensitivity was a major source of the 1983 weakening of the cartel and the significant fall in oil prices starting in late 2008. A recession caused a large reduction in the demand for oil, putting new pressure on the cartel to absorb this demand reduction. Conversely, whenever the global economy recovers, the cartel benefits disproportionately.

Non-OPEC Suppliers

Another key factor in the ability of producer nations to exercise power over a natural resource market is their ability to prevent new suppliers, not part of the cartel, from entering the market and undercutting the price. Currently OPEC produces about 45 percent of the world's oil. If the remaining producers were able, in the face of higher prices, to expand their supply dramatically, they would increase the amount of oil supplied and cause the prices to fall, which would decrease OPEC's market share. If this response were large enough, the allocation of oil would approach the competitive allocation.

Recognizing this impact, the cartel must take the nonmembers into account when setting prices. Salant (1976) proposed an interesting model of monopoly pricing in the presence of a fringe of small nonmember producers that serves as a basis for exploring this issue. His model includes a number of suppliers. Some form a cartel. Others, a smaller number, form a "competitive fringe." The cartel is assumed to set the price of oil to maximize its collective profits by restricting its production, taking the competitive fringe production into account. The competitive fringe cannot directly set the price, but, since it is free to choose the level of production that maximizes its own profits, its output does affect the cartel's pricing strategy.

What conclusions does this model yield? The model concludes that a resource cartel would set different prices in the presence of a competitive fringe than in its absence. With a competitive fringe, it would set the initial price somewhat lower than the pure monopoly price and allow price to rise more rapidly. This strategy maximizes cartel profits by forcing the competitive fringe to produce more in the earlier periods (in response to higher demand) and eventually to exhaust their supplies. Once the competitive fringe has depleted its reserves, the cartel would raise the price and thereafter prices would increase much more slowly.

Thus, the optimal strategy, from the point of view of the cartel, is to hold back on its own sales during the initial period, letting the other suppliers exhaust their supplies. Sales and profits of the competitive fringe, in this optimal cartel strategy, decline over time, while sales and profits of the cartel increase over time as prices rise and the cartel captures a larger share of the market.

One fascinating implication of this model is that the formation of the cartel raises the present value of competitive fringe profits by an even greater percentage than the present value of cartel profits. Those without the power gain more in percentage terms than those with the power!

Though this may seem counterintuitive, it is actually easily explained. The cartel, in order to keep the price up, must cut back on its own production level. The competitive fringe, however, is under no such constraint and is free to take advantage of the high prices caused by the cartel's withheld production without cutting back its own production. Thus, the profits of the competitive fringe are higher in the earlier period, which, in present value terms, are discounted less. All the cartel can do is wait until the competitive suppliers become less of a force in the market. The implication of this model is that the competitive fringe is a collective force in the oil market, even if it controls as little as one-third of the production.

The impact of this competitive fringe on OPEC behavior was dramatically illustrated by events in the 1985–1986 period. In 1979, OPEC accounted for approximately 50 percent of world oil production, while in 1986 this had fallen to approximately 30 percent. Taking account of the fact that total world oil production was down during this period over 10 percent for all producers, the pressures on the cartel mounted and prices ultimately fell. The real cost of crude oil imports in the United States fell from $34.95 per barrel in 1981 to $11.41 in 1986. OPEC simply was not able to hold the line on prices because the necessary reductions in production were too large for the cartel members to sustain.

In the summer of 2008, the price of crude oil soared above $138 per barrel. The price increase was due to strong worldwide demand coupled with restricted supply from Iraq because of the war. However, these high prices also underscored the major oil companies' difficulty finding new sources outside of OPEC countries. High oil prices in the 1970s drove Western multinational oil companies away from low-cost Middle Eastern oil to high-cost new oil in places such as the North Sea and Alaska. Most of these oil companies are now running out of big non-OPEC opportunities, which diminishes their ability to moderate price.

Compatibility of Member Interests

The final factor we shall consider in determining the potential for cartelization of natural resource markets is the internal cohesion of the cartel. With only one seller, the objective of that seller can be pursued without worrying about alienating others who could undermine the profitability of the enterprise. In a cartel composed of many sellers, that freedom is no longer as wide ranging. The incentives of each member and the incentives of the group as a whole may diverge.

Cartel members have a strong incentive to cheat. A cheater, if undetected by the other members, could surreptitiously lower its price and steal part of the market from the others. Formally, the price elasticity of demand facing an individual member is substantially higher than that for the group as a whole, because some of the increase in individual sales at a lower price represents sales reductions for other members. When producers face markets characterized by a high price elasticity, lower prices maximize profits. Thus, successful cartelization presupposes a means for detecting cheating and enforcing the collusive agreement.

In addition to cheating, however, cartel stability is also threatened by the degree to which members fail to agree on pricing and output decisions. Oil provides an excellent example of how these dissensions can arise. Since the 1974 rise of OPEC as a world power, Saudi Arabia has frequently exercised a moderating influence on the pricing decisions of OPEC. Why?

One highly significant reason is the size of Saudi Arabia's oil reserves (see Table 7.1). Saudi Arabia's reserves are larger than those of any other member. Hence, Saudi Arabia has an incentive to preserve the value of those resources. Setting prices too high would undercut the future demand for its oil. As previously stated, the demand for oil in the long run is more price-elastic than in the short run. Countries with smaller reserves, such as Nigeria, know that in the long run their reserves will be gone and therefore these countries are more concerned about the near future. Since alternative sources of supply are not much of a threat in the near future because of long development times, countries with small reserves want to extract as much rent as possible now.

TABLE 7.1 The World's Largest Oil Reserves

Country	Reserves (in billions of barrels)
Saudi Arabia	266.7
Canada[1]	178.1
Iran	136.2
Iraq	115.0
Kuwait	104.0
Venezuela	99.0
United Arab Emirates	97.8
Russia	60.0
Libya	43.7
Nigeria	36.2
Kazakhstan	30.0
United States	21.3

[1] PennWell Corporation, *Oil & Gas Journal*, Vol. 106, No. 48 (December 22, 2008), except United States. Oil includes crude oil and condensate. Data for the United States are from the Energy Information Administration, *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves, 2007 Annual Report*, DOE/EIA-0216(2007) (February 2009). *Oil & Gas Journal*'s oil reserve estimate for Canada includes 5.392 billion barrels of conventional crude oil and condensate reserves and 172.7 billion barrels of oil sands reserves.

Source: http://www.eia.doe.gov/emeu/international/oilreserves.html compiled from PennWell Corporation, *Oil & Gas Journal*, Vol. 106, No. 48 (December 22, 2008).

The size of Saudi Arabia's production not only provides an incentive to preserve the stability of the oil market over the longer run, it also gives it the potential to make its influence felt. Its capacity to produce is so large that it can unilaterally affect world prices as long as it has excess capacity to use in pursuit of this goal.

This examination of the preconditions for successful cartelization reveals that creating a successful cartel is not an easy path to pursue for producers. It is therefore not surprising that OPEC has had its share of trouble exercising control over price in the oil market. When possible, however, cartelization can be very profitable. When the resource is a strategic raw material on which consuming nations have become dependent, cartelization can be very costly to those consuming nations.

Strategic-material cartelization also confers on its members political, as well as economic, power. Economic power can become political power when the revenue is used to purchase weapons or the capacity to produce weapons. The producer nations can also use an embargo of the material as a lever to cajole reluctant adversaries into foreign policy concessions. When the material is of strategic importance, the potential for embargoes casts a pall over the normally clear and convincing case for free trade of raw materials among nations.

Fossil Fuels: National Security and Climate Considerations

The Climate Dimension

All fossil fuels contain carbon. When these fuels are burned, unless the resulting carbon is captured, it is released into the atmosphere as carbon dioxide. As explained in more detail in Chapter 16, carbon dioxide is a greenhouse gas, which means that it is a contributor to what is known popularly as global warming, or more accurately (since the changes are more complex than simply universal warming) as climate change.

Climate considerations affect energy policy in two ways: (1) the level of energy consumption matters (as long as carbon-emitting sources are part of the mix) and (2) the mix of energy sources matters (since some emit more carbon than others). As can be seen from Table 7.2, among the fossil fuels, coal contains the most carbon per unit of energy produced and natural gas contains the least.

From an economic point of view, the problem with how the market makes energy choices is that in the absence of explicit regulation, emissions of carbon generally involve an externality to the energy user. Therefore, we would expect that market choices, which are based upon the relative private costs of using these fuels, would involve an inefficient bias toward fuels containing carbon, thereby jeopardizing the timing and smooth transition toward fuels that pose less of a climate change threat. In Chapter 16, we shall cover a host of policies that can be used to internalize those costs, but in the absence of those policies it might be necessary to subsidize renewable sources of energy that have little or no carbon.

TABLE 7.2 Carbon Content of Fuels

Fuel Type	Metric Tons of Carbon (per billion BTUs)
Coal	25.61
Coal (Electricity Generation)	25.71
Natural Gas	14.47
Residual Fuel Oil	21.49
Oil (Electricity Generation)	19.95
Liquefied Petroleum Gas	17.02
Distillate Fuel Oil	19.95

Source: Energy Information Administration.

The National Security Dimension

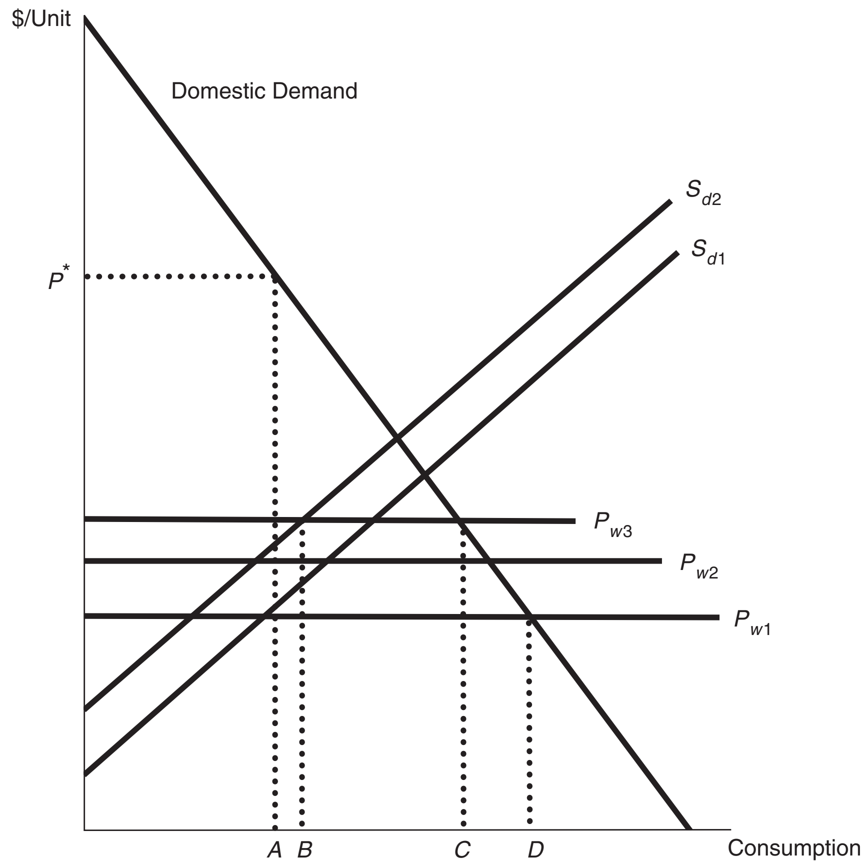
Vulnerable strategic imports also have an added cost that is not reflected in the marketplace. National security is a classic public good. No individual importer correctly represents our collective national security interests in making a decision on how much to import. Hence, leaving the determination of the appropriate balance between imports and domestic production to the market generally results in an excessive dependence on imports due to both climate change and national security considerations (see Figure 7.4).

In order to understand the interaction of these factors five supply curves are relevant. Domestic supply is reflected by two options. The first, S_{d1}, is the long-run domestic supply curve without considering the climate change damages resulting from burning more oil, while the second, S_{d2}, is the domestic supply curve that includes these per-unit damages. Their upward slopes reflect increasing availability of domestic oil at higher prices, given sufficient time to develop those resources. Imported foreign oil is reflected by three supply curves: P_{w1} reflects the observed world price, P_{w2} includes a "vulnerability premium" in addition to the world price, and P_{w3} adds in the per-unit climate change damages due to consuming more imported oil. The vulnerability premium reflects the additional national security costs caused by imports. All three curves are drawn horizontally to the axis to reflect the assumption that any importing country's action on imports is unlikely to affect the world price for oil.

As shown in Figure 7.4, in the absence of any correction for national security and climate change considerations, the market would generally demand and receive *D* units of oil. Of this total amount, *A* would be domestically produced and *D*-*A* would be imported. (Why?)

In an efficient allocation, incorporating the national security and climate change considerations, only *C* units would be consumed. Of these, *B* would be domestically produced and *C*-*B* would be imported. Note that because national security and climate change are externalities, the market in general tends to consume too much oil and vulnerable imports exceed their efficient level.

FIGURE 7.4 The National Security Problem



What would happen during an embargo? Be careful! At first glance, you would guess that we would consume where domestic supply equals domestic demand, but that is not right. Remember that S_{d1} is the domestic supply curve, *given enough time to develop the resources*. If an embargo hits, developing additional resources cannot happen immediately (multiple year time lags are common). Therefore, in the short run, the supply curve becomes perfectly inelastic (vertical) at *A*. The price will rise to P^* to equate supply and demand. As the graph indicates, the loss in consumer surplus during an embargo can be very large indeed.

How can importing nations react to this inefficiency? As Debate 7.1 shows, several strategies are available.

The importing country might be able to become self-sufficient, but should it? If the situation is adequately represented by Figure 7.4, then the answer is clearly no. The net benefit from self-sufficiency (the allocation where domestic supply S_{d1} crosses the demand curve) is clearly lower than the net benefit from the efficient allocation (*C*).

DEBATE 7.1

How Should the United States Deal with the Vulnerability of Its Imported Oil?

Currently the United States imports most of its oil and its dependence on OPEC is growing. Since oil is such a strategic material, how can that vulnerability be addressed? The 2004 U. S. presidential campaign outlined two very different approaches.

President George W. Bush articulated a strategy of increasing domestic production, not only of oil, but also of natural gas and coal. His vision included opening up a portion of the Arctic National Wildlife Refuge for oil drilling. Tax incentives and subsidies would be used to promote domestic production.

Senator John Kerry, on the other hand, sought to promote a much larger role for energy efficiency and energy conservation. Pointing out that expanded domestic production could exacerbate environmental problems (including climate change), he supported such strategies as mandating standards for fuel economy in automobiles and energy efficiency standards in appliances. He was strongly opposed to drilling in the Arctic National Wildlife Refuge.

Over the long run, both candidates favored a transition to a greater reliance on hydrogen as an alternative fuel. Although hydrogen is a clean-burning fuel, its creation can have important environmental impacts; some hydrogen-producing processes (such as those based on coal) pollute much more than others (such as when the hydrogen is created using solar power).

Using economic analysis, figure out what the effects of the Bush and Kerry strategies would be on (1) oil prices in the short run and the long run, (2) emissions affecting climate change, and (3) U.S. imports in the short run and the long run. If you were in charge of OPEC, which strategy would you like to see chosen by Americans? Why?

Why, you might ask, is self-sufficiency so inefficient when embargoes obviously impose so much damage and self-sufficiency could grant immunity from this damage? Why would we want any imports at all when national security is at stake?

The simple answer is that the vulnerability premium is lower than the cost of becoming self-sufficient, but that response merely begs the question, "why is the vulnerability premium lower?" It is lower for three primary reasons: (1) embargoes are not certain events—they may never occur; (2) domestic steps can be taken to reduce vulnerability of the remaining imports; and (3) accelerating domestic production would incur a user cost by lowering the domestic amounts available to future users.

The expected damage caused by one or more embargoes depends on the likelihood of occurrence, as well as the intensity and duration. This means that the P_{w2} curve will be lower for imports having a lower likelihood of being embargoed. Imports from countries less hostile to our interests are more secure and the vulnerability premium on those imports is smaller.[4]

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[4]It is this fact that explains the tremendous U.S. interest in Mexican oil, in spite of the fact that, historically, it has not been cheaper.

For any remaining vulnerable imports, we can adopt certain contingency programs to reduce the damage an embargo would cause. The most obvious measure is to develop a domestic stockpile of oil to be used during an embargo. The United States has taken this route. The stockpile, called the *strategic petroleum reserve*, was originally designed to contain one billion barrels of oil (see Example 7.2). A one billion barrel stockpile would replace three million barrels a day for slightly less than one year or a larger number of barrels per day for a shorter period of time. This reserve would serve as an alternative domestic source of supply, which, unlike other oil resources, could be rapidly deployed on short notice. It is, in short, a form of insurance. If this protection can be purchased cheaply, implying a lower P_{w2}, imports become more attractive.

To understand the third and final reason that paying the vulnerability premium would be less costly than self-sufficiency, we must consider vulnerability in a dynamic, rather than static, framework. Because oil is a depletable resource, a user cost is associated with its efficient use. To reorient the extraction of that resource toward the present, as a self-sufficiency strategy would do, reduces future net benefits. Thus, the self-sufficiency strategy tends to be myopic in that it solves the short-term vulnerability problem by creating a more serious one in the future. Paying the vulnerability premium creates a more efficient balance between the present and future, as well as between current imports and domestic production.

We have established the fact that government can reduce our vulnerability to imports, which tends to keep the risk premium as low as possible. Certainly for oil, however, even after the stockpile has been established, the risk premium is not zero; P_{w1} *and* P_{w2} will not coincide. Consequently, the government must also concern itself with achieving both the efficient level of consumption and the efficient share of that consumption borne by imports. Let's examine some of the policy choices.

As noted in Debate 7.1, energy conservation is one popular approach to the problem. One way to accomplish additional conservation is by means of a tax on fossil fuel consumption. Graphically, this approach would be reflected as a shift inward of the after-tax demand curve. Such a tax would reduce energy consumption and emissions of greenhouse gases (an efficient result) but would not achieve the efficient share of imports (an inefficient result). An energy tax falls on *all* energy consumption, whereas the security problem involves only imports. While energy conservation may increase the net benefit, it cannot ever be the sole policy instrument used or an efficient allocation will not be attained.

Another possible strategy employs the subsidization of domestic supply. Diagrammatically, this would be portrayed in Figure 7.4 as a shift of the domestic supply curve to the right. Notice that the effect would be to reduce the share of imports in total consumption (an efficient result) but reduce neither consumption nor climate change emissions (an inefficient result). This strategy also tends to drain domestic reserves faster, which makes the nation more vulnerable in the long run (another inefficient result).

While subsidies of domestic fossil fuels can reduce imports, they will tend to intensify the climate change problem and increase long-run vulnerability. In 2010, the International Energy Agency released *The World Energy Outlook 2010*, a report

EXAMPLE 7.2

Strategic Petroleum Reserve

The U.S. strategic petroleum reserve (SPR) is the world's largest supply of emergency crude oil. The federally owned oil stocks are stored in huge underground salt caverns along the coastline of the Gulf of Mexico.

Decisions to withdraw crude oil from the SPR are made by the President under the authority of the Energy Policy and Conservation Act. In the event of an "energy emergency," SPR oil would be distributed by competitive sale. In practice what constitutes an energy emergency goes well beyond embargoes. The SPR has been used only three times and no drawdown involved protecting against an embargo.

- During Operation Desert Storm in 1991 sales of 17.3 million barrels were used to stabilize the oil market in the face of supply disruptions arising from the war.
- After Hurricane Katrina caused massive damage to the oil production facilities, terminals, pipelines, and refineries along the Gulf regions of Mississippi and Louisiana in 2005, sales of 11 million barrels were used to offset the domestic shortfall.
- A series of emergency exchanges conducted after Hurricane Gustav, followed shortly thereafter by Hurricane Ike, reduced the level by 5.4 million barrels.

The Strategic Petroleum Reserve has never reached the original one billion barrel target, but the Energy Policy Act of 2005 directed the Secretary of Energy to bring the reserve to its authorized one billion barrel capacity. Acquiring the oil to build up the reserve is financed by the Royalty-in-Kind program. Under the Royalty-in-Kind program, producers who operate leases on the federally owned Outer Continental Shelf are required to provide from 12.5 to 16.7 percent of the oil they produce to the U.S. government. This oil is either added directly to the stockpile or sold to provide the necessary revenue to purchase oil to add to the stockpile.

Source: U.S. Department of Energy Strategic Petroleum Reserve Web site: http://www.fe.doe.gov/programs/reserves/index.html and http://www.spr.doe.gov/dir/dir.html (accessed November 1, 2010).

urging nations to eliminate fossil fuel subsidies to curb energy demand and cut the carbon dioxide (CO_2) emissions that cause climate change. They estimated that eliminating fossil fuel subsidies would reduce CO_2 emissions 5.8 percent by 2020. Fossil fuel subsidies were estimated at $312 billion in 2009, compared with $57 billion for renewable energy.

A third approach would tailor the response more closely to the national security problem. One could use either a tariff on imports equal to the vertical distance between P_{w1} *and* P_{w2} or a quota on imports equal to $C–B$. With either of these approaches, the price to consumers would rise to P_1, total consumption would fall to C, and imports would be $C–B$. This achieves the appropriate balance between imports and domestic production (an efficient result), but it does not internalize the climate change cost from using domestic production (an inefficient result).

The use of tariffs or quotas also has some redistributive consequences. Suppose a tariff were imposed on imports equal to the difference between P_{w1} and P_{w2}. The rectangle represented by that price differential times the quantity of imports would then represent tariff revenue collected by the government.

If a quota system were used instead of a tariff and the import quotas were simply given to importers, that revenue would go to the importers rather than the government. This explains why importers prefer quotas to a tariff system.

The effect of either system on domestic producer surplus should also be noticed. Producers of domestic oil would be better off with a tariff or quota on imported oil than without it. Each raises the cost or reduces the availability of the foreign substitute, which results in higher domestic prices. The higher domestic prices induce producers to produce more, but they also result in higher profits on the oil that would have been produced anyway, echoing the premise that public policies may not only restore efficiency but also tend to redistribute wealth.

The Other Depletable Sources: Unconventional Oil and Gas, Coal, and Nuclear Energy

While the industrialized world currently depends on conventional sources of oil and gas for most of our energy, over the long run, in terms of both climate change and national security issues, the obvious solution involves a transition to domestic renewable sources of energy that do not emit greenhouse gases. What role does that leave for the other depletable resources, namely unconventional oil and gas, coal, and uranium?

Although some observers believe the transition to renewable sources will proceed so rapidly that using these fuels will be unnecessary, many others believe that depletable transition fuels will probably play a significant role. Although other contenders do exist, the fuels receiving the most attention (and controversy) as transition fuels are unconventional sources of oil and gas, coal, and uranium. Coal, in particular, is abundantly available, both globally and domestically, and its use frees nations with coal from dependencies on foreign countries.

Unconventional Oil and Gas Sources

The term *unconventional oil and gas* refers to sources that are typically more difficult and expensive to extract than conventional sources. One unconventional source of both oil and natural gas is shale. The flow rate from shale is sufficiently low that oil or gas production in commercial quantities requires that the rock be fractured in order to extract the gas. While gas has been produced for years from shales with natural fractures, the shale gas boom in recent years has been due to a process known as "hydraulic fracturing" (or popularly as "fracking"). To overcome the problem of impermeability, wells

EXAMPLE 7.3

Fuel from Shale: The Bakken Formation

According to the U.S. Geological Service, one of the larger domestic discoveries in recent years of unconventional oil and associated gas can be found in the Bakken Formation in Montana and North Dakota. Parts of the formation extend into the Canadian Provinces of Saskatchewan and Manitoba.

A U.S. Geological Survey assessment, released April 10, 2008, shows some 3–4.3 billion barrels of "technically recoverable" oil in this Formation. (Technically, recoverable oil resources are defined as those producible using currently available technology and industry practices.) This estimate represented a 25-fold increase in the estimated amount of recovered oil compared to the agency's 1995 estimate.

Whereas traditional oil fields produce from rocks with relatively high porosity and permeability, so oil flows out fairly easily, the Bakken Formation consists of low-porosity and -permeability rock, mostly shale, from which oil flows only with difficulty. To overcome this problem, wells are drilled horizontally, at depth, into the Bakken and fracking is used to increase the permeability.

One of the barriers to extracting these resources involves their environmental impact. The U.S. EPA and Congress have noted that serious concerns have arisen from citizens and their representatives about hydraulic fracturing's potential impact on drinking water, human health, and the environment. Concluding that these issues deserve further study, EPA's Office of Research and Development (ORD) will be conducting a scientific study, expected to be completed in 2012, to investigate the possible relationships between hydraulic fracturing and drinking water. Once that study is completed, the future role for the Bakken Formation will likely become clearer.

Sources: 3 to 4.3 Billion Barrels of Technically Recoverable Oil Assessed in North Dakota and Montana's Bakken Formation—25 Times More Than 1995 Estimate—at http://www.usgs.gov/newsroom/article.asp?ID=1911; Hydraulic Fracturing at http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/index.cfm

are drilled horizontally, at depth, and then water and other materials (like sand) are pumped into the well at high pressure to create open fractures, which increase the permeability in these tight rocks. The oil can then flow more easily out of these fractures and tight pores. As Example 7.3 demonstrates, while some of these resources are quite large, they may also pose some difficult environmental and human health challenges.

While many other unconventional oil resources may still be economically out of reach at the present time, two unconventional oil sources are currently being tapped—extra-heavy oil from Venezuela's Orinoco oil belt and bitumen, a tar-like hydrocarbon that is abundant in Canada's tar sands. The Canadian source is particularly important from the U.S. national security perspective, coming as it does, from a friendly neighbor to the North.

The main concern about these sources is also their environmental impact. It not only takes much more energy to extract these unconventional resources (making the net energy gain smaller), but, in the case of Canadian tar sands, large amounts of water are also necessary either to separate bitumen from the sand and other solids, or to produce steam, depending on the oil-recovery method. Emissions of air pollutants, including CO_2, are usually even greater for unconventional sources than they are for conventional sources.

Coal

Coal's main drawback is its contribution to air pollution. High sulfur coal is potentially a large source of sulfur dioxide emissions, one of the chief culprits in the acid-rain problem. It is also a major source of particulate emissions and mercury as well as carbon dioxide, one of the greenhouse gases.

Coal is heavily used in electricity generation and the rate of increase in coal use for this purpose is especially high in China. With respect to climate change, the biggest issue for coal is whether it could be used without adding considerably to greenhouse gas emissions. As the fossil fuel with the highest carbon emissions per unit of energy supplied, that is a tall order.

Capturing CO_2 emissions from coal-fired plants before they are released into the environment and sequestering the CO_2 in underground geologic formations is now technologically feasible. Energy companies have extensive experience in injecting captured carbon dioxide into oil fields as one means to increase the pressure and, hence, increase the recovery rate from those fields. Whether this practice can be extended to saline aquifers and other geologic formations without leakage at reasonable cost is the subject of considerable current research.

Implementing these carbon capture and storage systems require modifications to existing power plant technologies, modifications that are quite expensive. In the absence of any policy controls on carbon emissions, the cost of these sequestration approaches would rule them out simply because the economic damages imposed by failing to control the gases are externalities. The existence of suitable technologies is not sufficient if the underlying economic forces prevent them from being adopted.

Uranium

Another potential transition fuel, uranium, used in nuclear electrical-generation stations, has its own limitations—abundance and safety. With respect to abundance, technology plays an important part. Resource availability is a problem with uranium as long as we depend on conventional reactors. However, if countries move to a new generation of breeder reactors, which can use a wider range of fuel, availability would cease to be an important issue. In the United States, for example, on a heat-equivalent basis, domestic uranium resources are 4.2 times as great as domestic oil and gas resources if they are used in conventional reactors. With breeder reactors, the U.S. uranium base is 252 times the size of its oil and gas base.

With respect to safety, two sources of concern stand out: (1) nuclear accidents, and (2) the storage of radioactive waste. Is the market able to make efficient decisions about the role of nuclear power in the energy mix? In both cases, the answer is no, given the current decision-making environment. Let's consider these issues one by one.

The production of electricity by nuclear reactors involves radioactive elements. If these elements escape into the atmosphere and come in contact with humans in sufficient concentrations, they can induce birth defects, cancer, or death. Although some radioactive elements may also escape during the normal operation of a plant, the greatest risk of nuclear power is posed by the threat of nuclear accidents.

As the accident in Fukushima, Japan in 2011 made clear, nuclear accidents could inject large doses of radioactivity into the environment. The most dangerous of these possibilities is the core meltdown. Unlike other types of electrical generation, nuclear processes continue to generate heat long after the reactor is turned off. This means that the nuclear fuel must be continuously cooled, or the heat levels will escalate beyond the design capacity of the reactor shield. If, in this case, the reactor vessel fractures, clouds of radioactive gases and particulates would be released into the atmosphere.

For some time, conventional wisdom had held that nuclear accidents involving a core meltdown were a remote possibility. On April 25, 1986, however, a serious core meltdown occurred at the Chernobyl nuclear plant in the Ukraine. Although safety standards are generally conceded to be much higher in other industrialized countries than in the countries of the former Soviet Union, the Fukushima accident demonstrated that even higher standards are no guarantee of accident-free operation.

An additional concern relates to storing nuclear wastes. The waste-storage issue relates to both ends of the nuclear fuel cycle—the disposal of uranium tailings from the mining process and spent fuel from the reactors—although the latter receives most of the publicity. Uranium tailings contain several elements, the most prominent being thorium-230, which decays with a half-life of 78,000 years to a radioactive, chemically inert gas, radon-222. Once formed, this gas has a very short half-life (38 days).

The spent fuel from nuclear reactors contains a variety of radioactive elements with quite different half-lives. In the first few centuries, the dominant contributors to radioactivity are fission products, principally strontium-90 and cesium-137. After approximately 1,000 years, most of these elements will have decayed, leaving the transuranic elements, which have substantially longer half-lives. These remaining elements would remain a risk for up to 240,000 years. Thus, decisions made today affect not only the level of risk borne by the current generation—in the form of nuclear accidents—but also the level of risk borne by a host of succeeding generations (due to the longevity of radioactive risk from the disposal of spent fuel).

Nuclear power has also been beset by economic challenges. New nuclear power plant construction became much more expensive, in part due to the increasing regulatory requirements designed to provide a safer system. Its economic advantage over coal dissipated and the demand for new nuclear plants declined. For example, in 1973, in the United States, 219 nuclear power plants were either planned or in operation. By the end of 1998, that number had fallen to 104, the difference being due primarily to cancellations. More recently, after a period with no new applications, high oil prices, government subsidies, and concern over greenhouse gases had caused some resurgence of interest in nuclear power prior to the Fukushima accident.

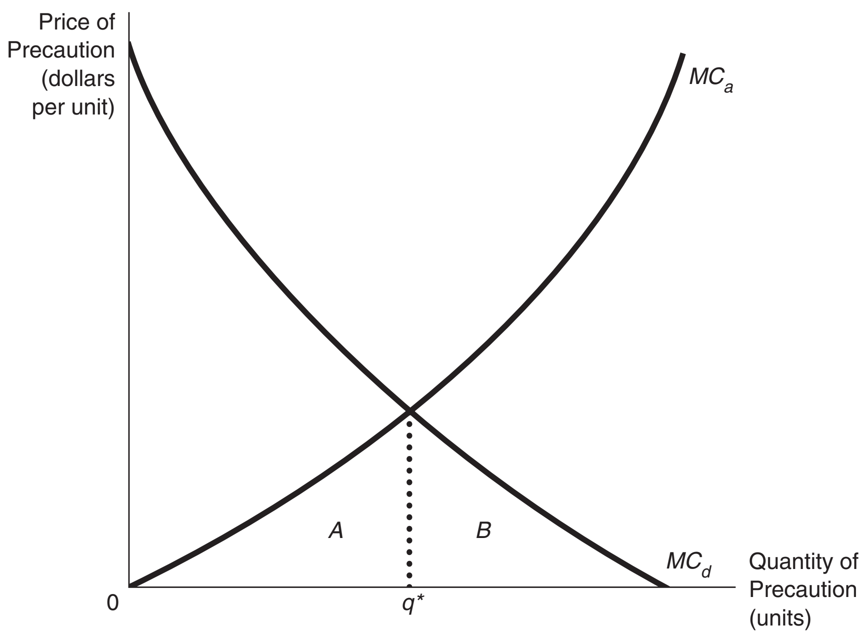
Not all nations have made the same choice with respect to the nuclear option. Japan, along with France, for example, has used standardized plant design and regulatory stability to lower electricity generating costs for nuclear power to the point that they are lower than for coal. Attracted by these lower costs, both countries have relied heavily on nuclear power.

With respect to waste, France chose a closed fuel cycle at the very beginning of its nuclear program, involving reprocessing used fuel so as to recover uranium and plutonium for reuse and to reduce the volume of high-level wastes for disposal. Recycling allows 30 percent more energy to be extracted from the original uranium and leads to a great reduction in the amount of wastes for disposal. What role that nuclear power will play in the future energy plans of these two countries after Fukushima remains to be seen.

Can we expect the market to make the correct choice with respect to nuclear power? We might expect the answer for the problem of nuclear accidents to be no, because this seems to be such a clear case of externalities. Third parties, those living near the reactor, would receive the brunt of the damage from a nuclear accident. Would the utility have an incentive to choose the efficient level of precaution?

If the utility had to compensate fully for all the damages caused, then the answer would be yes. To see why, consider Figure 7.5. Curve MC_a is the marginal cost of damage avoidance. The more precaution that is taken, the higher is the marginal cost. Curve MC_d is the marginal cost of expected damage, suggesting that as more precautionary measures are taken, the additional reduction in damages obtained from those measures declines.

FIGURE 7.5 The Efficient Level of Precaution



The efficient level of precaution is the one minimizing the sum of the costs of precaution and the expected costs of the unabated damage. In Figure 7.5, that point is q^*, and the total cost to society from that choice is the sum of area *A* and area *B*.

Will a private utility choose q^*? Presumably it would, if the curves it actually faces are MC_a and MC_d. The utility would be responsible for the costs of precautionary behavior, so it would face MC_a. How about MC_d? We might guess that the utility would face MC_d because people incurring damages could, through the judicial system, sue for damages. In the United States, that guess is not correct for two reasons: (1) the role of the government in sharing the risk, and (2) the role of insurance.

When the government first allowed private industry to use atomic power to generate electricity, there were no takers. No utility could afford the damages if an accident occurred. No insurance company would underwrite the risk. Then in 1957, with the passage of the Price-Anderson Act, the government underwrote the liability. That act provided for a liability ceiling of $560 million (once that amount had been paid, no more claims would be honored), of which the government would bear $500 million. The industry would pick up the remaining $60 million. The act was originally designed to expire in 10 years, at which time the industry would assume full responsibility for the liability.

The act didn't expire, although over time a steady diminution of the government's share of the liability has occurred. Currently the liability ceiling still exists, albeit at a higher level; the amount of private insurance has increased; and a system has been set up to assess all utilities a retrospective premium in the event of an accident.

The effect of the Price-Anderson Act is to shift inward the private marginal damage curve that any utility faces. Both the liability ceiling and the portion of the liability borne by government reduce the potential compensation the utility would have to pay. As the industry assumes an increasing portion of the liability burden and the individual utility assumes less, the risk sharing embodied in the retrospective premium system (the means by which it assumes that burden) breaks the link between precautionary behavior by the individual utility and the compensation it might have to pay. Under this system, increased safety by the utility does not reduce its retrospective premiums.

The cost to all utilities, whether they have accidents or not, is the premium paid both before and after any accident. These premiums do not reflect the amount of precautionary measures taken by an individual plant; therefore, individual utilities have little incentive to provide an efficient amount of safety. In recognition of the utilities' lower-than-efficient concern for safety, the U.S. government has established the Nuclear Regulatory Commission to oversee the safety of nuclear reactors, among its other responsibilities.

To further complicate the problem, the private sector is not the only source of excessive nuclear waste. The U.S. Department of Energy, for example, presides over a nuclear weapons complex containing 15 major facilities and a dozen or so smaller ones.

Both the operating safety and the nuclear waste storage issue can be viewed as a problem of determining appropriate compensation. Those who gain from nuclear power should be forced to compensate those who lose. If they can't, in the absence of externalities, the net benefits from adopting nuclear power are not positive.

If nuclear power is efficient, by definition the gains to the gainers will exceed the losses to the losers. Nonetheless, it is important that this compensation actually be paid because without compensation, the losers can block the efficient allocation.

A compensation approach is already being taken in those countries still expanding the role of nuclear power. The French government, for example, has announced a policy of reducing electricity rates by roughly 15 percent for those living near nuclear stations. And in Japan during 1980, the Tohoku Electric Power Company paid the equivalent of $4.3 million to residents of Ojika, in northern Japan, to entice them to withdraw their opposition to building a nuclear power plant there. Do you think the effectiveness of this approach would be affected by the Fukushima accident?

To the extent it works, this approach could also help resolve the current political controversy over the location of nuclear waste disposal sites. Under a compensation scheme, those consuming nuclear power would be taxed to compensate those who live in the areas of the disposal site. If the compensation is adequate to induce them to accept the site, then nuclear power is a viable option and the costs of disposal are ultimately borne by the consumers. Attracted by the potential for compensation, some towns, such as Naurita, Colorado, have historically sought to become disposal sites.

Are future generations adequately represented in this transaction? The quick answer is no, but that answer is not correct. Those living around the sites will experience declines in the market value of land, reflecting the increased risk of living or working there. The payment system is designed to compensate those who experience the reduction, the current generation. Future generations, should they decide to live near a disposal site, would be compensated by lower land values. If the land values were not cheap enough to compensate them for the risk of that location, they would not have to live there. As long as full information on the risks posed is available, those who do bear the cost of locating near the sites do so only if they are willing to accept the risk in return for lower land values.

Electricity

For a number of electric utilities, conservation has assumed an increasing role. To a major extent, conservation has already been stimulated by market forces. High oil and natural gas prices, coupled with the rapidly increasing cost of both nuclear and coal-fired generating stations, have reduced electrical demand significantly. Yet many regulatory authorities are coming to the conclusion that more conservation is needed.

Perhaps the most significant role for conservation is its ability to defer capacity expansion. Each new electrical generating plant tends to cost more than the last, and frequently the cost increase is substantial. When the new plants come on line, rate increases to finance the new plant are necessary. By reducing the demand for electricity, conservation delays the date when the new capacity is needed. Delays in the need to construct new plants translate into delays in rate increases as well.

Governments are reacting to this situation in a number of ways. One is to promote investments in conservation, rather than in new plants, when conservation is the cheaper alternative. Typical programs have established systems of rebates for residential customers to install conservation measures in their homes, provided free home weatherization to qualified low-income home owners, offered owners of multifamily residential buildings incentives for installing solar water heating systems, and provided subsidized energy audits to inform customers about money-saving conservation opportunities. Similar incentives have been provided to the commercial, agricultural, and industrial sectors.

The total amount of electric energy demanded in a given year is not the only concern. How that energy demand is spread out over the year is also a concern. The capacity of the system must be high enough to satisfy the demand even during the periods when the energy demand is highest (called *peak periods*). During other periods, much of the capacity remains underutilized.

Demand during the peak period imposes two rather special costs on utilities. First, the peaking units, those generating facilities fired up only during the peak periods, produce electricity at a much higher marginal cost than do base-load plants, those fired up virtually all the time. Typically, peaking units are cheaper to build than base-load plants, but they have higher operating costs. Second, it is the growth in peak demand that frequently triggers the need for capacity expansion. Slowing the growth in peak demand can delay the need for new, expensive capacity expansion, and a higher proportion of the power needs can be met by the most efficient generating plants.

Utilities respond to this problem by adopting load-management techniques to produce a more balanced use of this capacity over the year. One economic load-management technique is called *peak-load pricing*. Peak-load pricing attempts to impose the full (higher) marginal cost of supplying peak power on those consuming peak power by charging higher prices during the peak period.

While many utilities have now begun to use simple versions of this approach, some are experimenting with innovative ways of implementing rather refined versions of this system. One system, for example, transmits electricity prices every five minutes over regular power lines. In a customer's household, the lines attached to one or more appliances can be controlled by switches that turn the power off any time the prevailing price exceeds a limit established by the customer. Other less sophisticated pricing systems simply inform consumers, in advance, of the prices that will prevail in predetermined peak periods.

Studies by economists indicate that even the rudimentary versions of peak-load pricing work. The greatest shifts are typically registered by the largest residential customers and those with several electrical appliances.

Also affecting energy choices is the movement to deregulate electricity production. Historically, electricity was generated by regulated monopolies. In return for accepting both government control of prices and an obligation to service all customers, utilities were given the exclusive rights to service-specific geographic areas.

In the 1990s, it was recognized that while electricity distribution has elements of a natural monopoly, generation does not. Therefore, several states and a number of national governments have deregulated the generation of electricity, while keeping the distribution under the exclusive control of a monopoly. In the United States, electricity deregulation officially began in 1992 when Congress allowed independent energy companies to sell power on the wholesale electricity market.

Forcing generators to compete for customers, it was believed, would produce lower electricity bills for customers. Experience reveals that lower prices have not always been the result (see Example 7.4).

Electricity deregulation has also raised some environmental concerns. Since electricity costs typically do not include all the costs of environmental damage, the sources offering the lowest prices could well be highly polluting sources. In this case, environmentally benign generation sources would not face a level playing field; polluting sources would have an inefficient advantage.

One policy approach for dealing with these concerns involves renewable energy credits (RECs). Renewable energy sources, such as wind or solar, are frequently characterized by relatively large capital costs, relatively low variable costs (since the fuel is costless), and low pollution emissions. Energy markets may ignore the advantages of low pollution emissions (since pollution imposes an external cost) and are likely to be characterized by short-term energy sales and price volatility (to the detriment of investors, who usually prefer investments with low capital costs and short payback periods). Under these circumstances, investments in capital-intensive, renewable energy technologies are unlikely to be sufficient to achieve an efficient outcome.

Renewable energy credits are designed to facilitate the transition to renewable power by overcoming these obstacles. A generator of electricity from a renewable source (such as wind or photovoltaics) can produce two saleable commodities. The first is the electricity itself, which can be sold to the grid, while the second is the renewable energy credit that turns the environmental attributes (such as the fact that it was created by a qualifying renewable source) into a legally recognized form of property that can be sold separately. Generally renewable generators create one REC for every 1,000 kilowatt-hours (or, equivalently, 1 megawatt-hour) of electricity placed on the grid.

The demand for these credits comes from diverse sources, but the most prominent are: (1) voluntary markets, involving consumers or institutions that altruistically choose to support green electricity and (2) compliance markets, involving electricity generators that need to comply with a renewable energy standard.

Some states with restructured electricity markets authorize voluntary markets in which households or institutions can directly buy green power, if offered (typically at a higher price) by their generator, or by purchasing RECs if their current provider does not offer green power. This allows consumers or institutions to lower their own carbon footprint since the REC they purchase and retire represents a specific amount of avoided greenhouse gas emissions. Educational institutions, for example, are incorporating the purchase of RECs into their strategies for achieving the goal of carbon neutrality adopted after signing onto the American College & University Presidents' Climate Commitment. As of August 2010, some 30 REC retail products were available to consumers and institutions.

The compliance market, apparently the larger of the two, has arisen because some states have imposed renewable portfolio standards (RPS) on electricity generators. Requiring a certain percent of electricity in the jurisdiction be generated from qualified renewable power sources, these standards can either be met by actually generating the electricity from qualified sources or purchasing a sufficient number of RECs from generators that have produced a higher percent

EXAMPLE 7.4

Electricity Deregulation in California: What Happened?

In 1995, the state legislature of California reacted to electricity rates that were 50 percent higher than the U.S. average by unanimously passing a bill to deregulate electricity generation within the state. The bill had three important features: (1) all utilities would have to divest themselves of their generation assets; (2) retail prices of electricity would be capped until the assets were divested; and (3) the utilities were forced to buy power in a huge open-auction market for electricity, known as a spot market, where supply and demand were matched every day and hour.

The system was seriously strained by a series of events that restricted supplies and raised prices. Although the fact that demand had been growing rapidly, no new generating facility had been built over a decade and much of the existing capacity was shut down for maintenance. An unusually dry summer reduced generating capacity at hydroelectric dams and electricity generators in Oregon and Washington, traditional sources of imported electricity. In addition, prices rose for the existing supplies of natural gas, a fuel that supplied almost one-third of the state's electricity.

This combination of events gave rise to higher wholesale prices, as would be expected, but the price cap prevented them from being passed on to consumers. Since prices could not equilibrate the retail market, blackouts (involving a complete loss of electricity to certain areas at certain times) resulted. To make matters worse, the evidence suggests that wholesale suppliers were able to take advantage of the short-term inflexibility of supply and demand to withhold some power from the market, thereby raising prices more and creating some monopoly profits. And on April 6, 2001, Pacific Gas and Electric, a utility that served a bit more than one-third of all Californians, declared bankruptcy.

Why had a rather simple quest for lower prices resulted in such a tragic outcome? Are the deregulation plans in other states headed for a similarly dismal future? Time will tell, of course, but that outcome seems unlikely. A reduction of supplies could affect other areas, though the magnitude of the confluence of events in California seems unusually harsh. Furthermore, the design of the California deregulation plan was clearly flawed. The price cap, coupled with the total dependence on the spot market, created a circumstance in which the market not only could not respond to the shortage but in some ways made it worse. Since neither of those features is an essential ingredient of a deregulation plan, other areas can choose more prudent designs.

Sources: Severin Borenstein, Jim Bushnell, and Frank Wolak. "Measuring Market Inefficiencies in California's Restructured Wholesale Electricity Market," A paper presented at the American Association meetings in Atlanta, January 2001; P. L. Joskow. "California's Electricity Market Meltdown," *Economies et Sociétés* Vol. 35, No. 1–2 (January–February 2001): pp. 281–296.

from those sources than the mandate. By providing this form of flexibility in how the mandate is met, RECs lower the compliance cost, not only in the short run (by allowing the RECs to flow to the areas of highest need), but also in the long run (by making renewable source generation more profitable in areas not under a renewable energy mandate than it would otherwise be).

Although by 2010 some 38 states and the District of Columbia had a renewable energy standard and a majority of those have REC programs, RECs are no panacea. Experience in several U.S. states shows that a poorly designed system does little to increase renewable generation (Rader, 2000). On the other hand, appropriately designed systems can provide a significant boost to renewable energy (see Example 7.5). The details matter.

Another innovation in the electric power industry has also given rise to a new market trading a new commodity.[5] Known as the forward capacity market, this approach uses market forces to facilitate the planning of future electric capacity investment.

The Independent System Operator for New England (ISO-NE) is the organization responsible for ensuring the constant availability of electricity, currently and for future generations, in the New England area. ISO-NE meets this obligation in three ways: by ensuring the day-to-day reliable operation of New England's bulk power generation and transmission system, by overseeing and administering the region's wholesale electricity markets, and by engaging in comprehensive, regional planning processes.

EXAMPLE 7.5

Tradable Energy Credits: The Texas Experience

Texas has rapidly emerged as one of the leading wind power markets in the United States, in no small part due to a well-designed and carefully implemented renewable portfolio standard (RPS coupled with renewable energy credits. While the RPS specifies targets and deadlines for producing specific proportions of electricity from renewable resources (wind, in this case), the credits lower compliance cost by increasing the options available to any party required to comply.

The early results have been impressive. Initial RPS targets in Texas were easily exceeded by the end of 2001, with 915 megawatts of wind capacity installed in that year alone. The response has been sufficiently strong that it has become evident that the RPS capacity targets for the next few years would be met early. RPS compliance costs are reportedly very low, in part due to a complementary production tax credit (a subsidy to the producer), the especially favorable wind conditions in Texas, and an RPS target that was ambitious enough to allow economies of scale to be exploited. The fact that the cost of administering the program is also low, due to an efficient Web-based reporting and accounting system, also helps.

Finally, and significantly, retail suppliers have been willing to enter into long-term contracts with renewable generators, reducing exposure of both producers and consumers to potential volatility of prices and sales. Long-term contracts ensure developers a stable revenue stream and, as a result, access to low-cost financing, while offering customers a reliable, steady supply of electricity.

Sources: O. Langniss and R. Wiser. "The Renewables Portfolio Standard in Texas: An Early Assessment," *Energy Policy* Vol. 31 (2003): pp. 527–535; N. Rader. "The Hazards of Implementing Renewable Portfolio Standards," *Energy and Environment,* Vol. 11, No. 4 (2000): pp. 391–405; L. Nielsen and T. Jeppesen. "Tradable Green Certificates in Selected European Countries—Overview and Assessment," *Energy Policy* Vol. 31 (2003): pp. 3–14; and The Texas Renewable Credit website http://www.texasrenewables.com/

[5]For details on this market, see http://www.iso-ne.com/markets/othrmkts_data/fcm/index.html.

The objective of the Forward Capacity Market (FCM), run by ISO-NE, is to assure that sufficient peak generating capacity for reliable system operation for a future year will be available. Since ISO-NE does not itself generate electricity, to assure this future capacity, they solicit bids in a competitive auction not only for additional generating capacity, but also for legally enforceable additional reductions in peak demand from energy efficiency, which reduces the need for more capacity. This system allows strategies for reducing peak demand to complete on a level playing field with strategies to expand capacity.

Another quite different approach to promoting the use of renewable resources in the generation of electric power is known as a *feed-in tariff*. Used in Germany, this approach focuses on establishing a stable price guarantee rather than a subsidy or a government mandate (see Example 7.6).

EXAMPLE 7.6

Feed-in Tariffs

Promoting the use of renewable resources in the generation of electricity is both important and difficult. Germany provides a very useful example of a country that seems to be especially adept at overcoming these barriers. According to one benchmark, at the end of 2007, renewable energies were supplying more than 14 percent of the electricity used in Germany, exceeding the original 2010 goal of 12.5 percent.

What prompted this increase? The German feed-in tariff determines the prices received by anyone who installs qualified renewable capacity producing electricity for the grid. In general, a fixed incentive payment per kilowatt-hour is guaranteed for that installation. The level of this payment (determined in advance by the rules of the program) is based upon the costs of supplying the power and is set at a sufficiently high level so as to assure installers that they will receive a reasonable rate of return on their investment. While this incentive payment is guaranteed for 20 years for each installed facility, each year the level of that guaranteed 20-year payment is reduced (typically in the neighborhood of 1–2 percent per year) for new facilities to reflect expected technological improvements and economies of scale.

This approach has a number of interesting characteristics:

- It seems to work.
- No subsidy from the government is involved; the costs are borne by the consumers of the electricity.
- The relative cost of the electricity from feed-in tariff sources is typically higher in the earlier years than for conventional sources, but lower in subsequent years (as fossil fuels become more expensive). In Germany the year in which electricity becomes cheaper due to the feed-in tariff is estimated to be 2025.
- This approach actually offers two different incentives: (1) it provides a price high enough to promote the desired investment and (2) it guarantees the stability of that price rather than forcing investors to face the market uncertainties associated with fluctuating fossil fuel prices or subsidies that come and go.

Source: Jeffrey H. Michel. (2007). "The Case for Renewable Feed-In Tariffs." Online Journal of the EUEC, Volume 1, Paper 1, available at http://www.euec.com/journal/Journal.htm

Energy Efficiency

As the world grapples with creating the right energy portfolio for the future, energy efficiency policy is playing an increasingly prominent role. In recent years the amount of both private and public money being dedicated to promoting energy efficiency has increased a great deal.

The role for energy efficiency in the broader mix of energy polices depends, of course, on how large the opportunity is. Estimating the remaining potential is not a precise science, but the conclusion that significant opportunities remain seems inescapable.

The existence of these opportunities can be thought of as a necessary, but not sufficient condition for government intervention. Depending upon the level of energy prices and the discount rate, the economic return on these investments may be too low to justify intervention. Additionally, policy intervention could, in principle, be so administratively costly as to outweigh any gains that would result.

The strongest case for government intervention flows from the existence of externalities. Markets are not likely to internalize these external costs on their own. The natural security and climate change externalities mentioned above, as well as other external co-benefits such as pollution-induced community health effects, certainly imply that the market undervalues investments in energy efficiency.

The analysis provided by economic research in this area, however, makes it clear that the case for policy intervention extends well beyond externalities. Internalizing externalities is a very important, but incomplete, policy response.

Consider just a few of the other foundations for policy intervention. Inadequately informed consumers can impede rational choice, as can a limited availability of capital (preventing paying more up front for the more energy-efficient choice even when the resulting energy savings would justify the additional expense in present value terms). Perverse incentives can also play a role as in the case of one who lives in a room (think dorm) or apartment where the amount of energy used is not billed directly, resulting in a marginal cost of additional energy use that is zero.

A rather large suite of policy options has been implemented to counteract these other sources of deficient levels of investment in energy efficiency. Some illustrations include the following:

- Certification programs such as Energy Star for appliances or LEED (Leadership in Energy and Environmental Design) standards for buildings attempt to provide credible information for consumers to make informed choices on energy efficiency options.
- Minimum efficiency standards (e.g., for appliances) prohibit the manufacture, sale, or importation of clearly inefficient appliances.
- An increased flow of public funds into the market for energy efficiency has led to an increase in the use of targeted investment subsidies. The most common historic source of funding in the electricity sector involved the use of a small mandatory per kilowatt-hour charge (typically called a "system benefit charge" or "public benefit charge") attached to the distribution service bill. The newest source of funding comes from the revenue accrued

from the sale of carbon allowances in several state or regional carbon cap-and-trade programs (described in detail in Chapter 14). The services funded by these sources include supplementing private funds for diverse projects such as weatherization of residences for low-income customers to more efficient lighting for commercial and industrial enterprises.

The evidence suggests that none of these policies either by themselves or in concert are completely efficient, but that they have collectively represented a move toward a more efficient use of energy. Not only does the evidence seem to suggest that they have been effective in reducing wasteful energy demand, but also that the programs have been quite cost-effective, with program costs well below the cost of the alternative, namely generating the energy to satisfy that demand.

Transitioning to Renewables

Ultimately our energy needs will have to be fulfilled from renewable energy sources, either because the depletable energy sources have been exhausted or, as is more likely, the environmental costs of using the depletable sources have become so high that renewable sources will be cheaper.

One compelling case for the transition is made by the mounting evidence that the global climate is being jeopardized by current and prospective energy consumption patterns. (A detailed analysis of this problem is presented in Chapter 16.) To the extent that rapidly developing countries, such as China and India, were to follow the energy-intensive, fossil fuel–based path to development pioneered by the industrialized nations, the amount of CO_2 released into the air would be unprecedented. A transition away from fossil fuels to other energy forms in both the industrialized and developing nations would be an important component in any strategy to reduce CO_2 emissions. Can our institutions manage that transition in a timely and effective manner?

Renewable energy comes in many different forms. It is unlikely that any one source will provide the long-run solution, in part because both the timing (peak demands) and form (gases, liquids, or electricity) of energy matter. Different sources will have different comparative advantages so, ultimately, a mix of sources will be necessary. Consider some of the options. The extent to which these sources will penetrate the market will depend upon their relative cost and consumer acceptance.

Hydroelectric Power

Hydroelectric power, which is generated when turbines convert the kinetic energy from a flowing body of water into electricity, passed that economic test a long time ago and is already an important source of power. This source of power is clean from an emissions point of view and domestic hydropower can help with national security concerns as well. On the other hand, hydroelectric dams can be a significant impediment to fish migrations and water quality. The impounded water can flood ecosystems and displace villages, and the buildup of silt behind the dams not only can lower the life of the facility, but also can alter the upstream and downstream ecosystems.

According to the U.S. Department of Energy (DOE),[6] hydropower in the United States rose from 15 percent of electricity generation in 1907 to 40 percent in 1940, but fell to only 10 percent by 2003. DOE estimates that some 80,000 MW of hydro power are currently operating in the United States and their resource assessment identified 5,677 sites in the United States with an undeveloped capacity of about 30,000 MW.

While hydroelectric power has been cost-effective for some time, other renewable resources have not been. Some, like wind, have become cost-effective, while the cost-effectiveness of others awaits further technological developments or additional increases in the costs of fossil fuels. This would occur, for example, by the imposition of a carbon tax or cap-and-trade policy to internalize the climate-change externality.

Wind

Wind power is beginning to penetrate the market on a rather large scale. New designs for turbines that convert wind energy to electricity have reduced the cost and increased the reliability of wind-generated electricity to the point that it now can compete with conventional sources in favorable sites even when environmental costs have not been internalized. (Favorable sites are those with sufficiently steady, strong winds.) Although many unexploited favorable sites still exist around the world, the share of wind power in the total energy mix will ultimately be limited as availability of unexploited sites diminishes.

Wind also has environmental effects that have triggered strong local controversies (see Debate 7.2).

Photovoltaics

Technological change can lower the relative cost of renewable resources. Perhaps the best example of how research can lower costs is provided by the experience with photovoltaics. Photovoltaics involve the direct conversion of solar energy to electricity (as opposed to indirect conversions, such as when solar-heated steam is used to drive a turbine). Anticipating a huge potential market, private industry has been very interested in photovoltaics and has poured a lot of research dollars into improving its commercial viability. The research has paid off. In 1976, the average market price for photovoltaic modules was $30. By 2002 this price had already fallen to $3.75.[7] Rural electrification projects using photovoltaics are slowly spreading into developing countries. Their attractiveness is especially high in regions that have not already established a traditional grid system of large generators and distribution lines. Photovoltaic systems allow these countries to provide electricity to remote regions while avoiding the very high capital cost associated with expanding traditional grid systems into those areas.

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[6]U.S. Department of Energy Web site: http://www1.eere.energy.gov/windandhydro/hydro_history.html

7U.S. Department of Energy Renewable Energy Annual (REA): http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/rea_sum.html

DEBATE 7.2

Dueling Externalities: Should the United States Promote Wind Power?

On the surface the answer seems like a no-brainer, since wind power is a renewable energy source that emits no greenhouse gases, unlike all the fossil fuels it would be likely to replace. Yet some highly visible, committed environmentalists, including Robert F. Kennedy, Jr., have strongly opposed wind projects. Why has this become such a public contentious issue?

Opposition to wind power within the environmental community arises for a variety of reasons. Some point out that the turbines can be noisy for those who live, camp, or hike nearby. Others note that these very large turbines can be quite destructive to bats and birds, particularly if they are constructed in migratory pathways. And a number of opponents object to the way the view would be altered by a large collection of turbines on otherwise-pristine mountaintops or off the coast.

Both the benefits from wind power (reduced impact on the climate) and the costs (effects on aesthetics, birds and noise) are typically externalities. This implies that the developers and consumers of wind power will neither reap all of the environmental benefits from reduced impact on the climate, nor will they typically bear the environmental costs. Making matters even more difficult some of the environmental costs will be concentrated on a relatively few people (those living nearby, for example), while the benefits will be conferred on all global inhabitants, many of whom will bear absolutely no costs whatsoever. The concentrated costs may be an effective motivator to attend the hearings, which are likely to be held near the proposed site, but the diffuse benefits will likely not be.

Since the presence of externalities typically undermines the ability of a market to produce an efficient outcome, it is not surprising that the permitting process for new wind power facilities is highly regulated. Regulatory processes generally encourage public participation by holding hearings. With environmental externalities lying on both sides of the equation and with many of the environmental costs concentrated on a relatively small number of people, it is neither surprising that the hearings have become so contentious, nor that the opposition to wind power is so well represented.

Source: Robert F. Kennedy Jr. "An Ill Wind Off Cape Cod." THE NEW YORK TIMES, Op-Ed, December 16, 2005; and Felicity Barringer, "Debate over Wind Power Creates Environmental Rift." THE NEW YORK TIMES, June 6, 2006.

Active and Passive Solar Energy

The sun's energy can also be used for heating in either an active or passive mode. The difference between the two is that while the passive mode uses no external energy sources, the active mode may use nonsolar energy to power pumps or fans. Solar energy can be used to provide space heating or to provide hot water.

Since the input energy comes from the sun's rays, it is costless; but the system to collect those rays, to transform them into useful heat, and to distribute the heat requires a capital investment. When storage or backup systems are required, they add to the cost.

Ocean Tidal Power[8]

One energy source that relies on the natural cycles of the earth is tidal power. It capitalizes on the fact that coastal areas experience two high and two low tides in a period of time somewhat longer than 24 hours. The energy in the water as it rushes in or out of an inlet or cove is transformed into electricity by a conversion device, commonly a turbine. According to the U.S. Department of Energy, for the tidal differences to be harnessed into electricity, the difference between high and low tides must be at least 5 meters, or more than 16 feet. Only about 40 sites on the earth have tidal ranges of this magnitude. Although no tidal power plants currently are operating in the United States, conditions are good for tidal power generation in both the Pacific Northwest and the Atlantic Northeast regions of the country.

Tidal power plants are not without their environmental impacts. Some designs can impede sea life migration, and silt buildups behind such facilities can impact local ecosystems.

Like many other renewable sources, the input energy is free, but construction costs are high. As a result, the U.S. Department of Energy estimates that the cost per kilowatt-hour of tidal power is currently not competitive with conventional fossil fuel power, but internalizing all the external costs of fossil fuel power could affect that outlook.

Liquid Biofuels

Liquid biofuels, which are made from plant material, are currently receiving a lot of attention in policy circles because potentially they can reduce greenhouse gases and imports of oil simultaneously. These include two alcohols—ethanol and methanol—and biodiesel, an oxygenated fuel produced from a range of biomass-derived feedstocks, including oilseeds, waste vegetable oils, cooking oil, and even animal fats. How cost-effective are they? Hill et al. (2006) examine this issue in detail and provide some useful insights:

- Ethanol yields 25 percent more energy than the energy invested in its production, whereas biodiesel yields 93 percent more.
- Compared with ethanol, biodiesel releases just 1 percent, 8.3 percent, and 13 percent of the agricultural nitrogen, phosphorus, and pesticide pollutants, respectively, per net energy gain.
- Relative to the fossil fuels they displace, greenhouse gas emissions are reduced 12 percent by the production and combustion of ethanol and 41 percent by biodiesel. The advantages of biodiesel over ethanol come from lower agricultural inputs and more efficient conversion of feedstocks to fuel.

How about economic impacts? The authors also point out that neither of these biofuels can replace much petroleum without impacting food supplies and costs,

[8]The information in this section was derived from http://www.eere.energy.gov/consumer/renewable_energy/ocean/index.cfm/mytopic=50008

and those impacts could be serious. We pay more attention to this choice between using crops for food or fuel in Chapter 11.

The bottom line is that both the type of fuel produced and the type of biomass used to produce it matter. Biodiesel has significant energy and environmental benefits over ethanol. Furthermore, biofuels produced from low-input biomass grown on agriculturally marginal land or from waste biomass would, they believe, provide much greater supplies and stronger environmental benefits than food-based biofuels. This analysis certainly raises serious questions about the wisdom of the current U.S. approach that relies heavily on subsidizing ethanol from corn.

Geothermal Energy

A rather different source, geothermal energy is derived from the earth's heat. In some places, geothermal reservoirs of steam or hot water occur where hot magma comes close enough to the surface to heat groundwater to quite high temperatures. When the temperature of the geothermal water reaches 220 degrees Fahrenheit or higher, geothermal energy can be used to generate electricity.

In other places, geothermal can be used even if the water temperatures are much more moderate. When the temperature of a geothermal source is around 50 degrees Fahrenheit and higher, it can be used in combination with heat pumps to provide space heating in the winter and cooling (air-conditioning) in the summer. (Heat pumps are electric devices that use compression and decompression of gas to heat and/or cool a house. Geothermal heat pumps are similar to ordinary heat pumps, but they use the geothermal water resource instead of outside air as the input source for the pump.)

Geothermal systems generally have a higher initial (capital) cost than alternative heating and cooling systems. Based on the estimated yearly energy and maintenance cost savings, the payback period (the number of years it takes for an investor to recover the capital cost from annual cost savings) for a geothermal heat pump system can vary from two to ten years.

Hydrogen

One fuel that is currently receiving intense interest for the long run is hydrogen. (Iceland, for example, has announced its intention to become a hydrogen-fueled economy.) Although hydrogen is the most plentiful element in the universe, it is normally combined with other elements. Water, for example, combines two atoms of hydrogen with one atom of oxygen (H_2O). Hydrogen is also found in "hydrocarbons" that make up many of the fossil fuels, such as gasoline, natural gas, methanol, and propane.

Hydrogen can be made by separating it from hydrocarbons, using heat. Currently, most hydrogen is made this way from natural gas. Alternatively, it can be produced by separating the hydrogen and oxygen atoms in water. If an electric current (produced by photovoltaics, for example) is conducted through a reservoir of water, the liquid splits into its constituent elements. NASA has used liquid hydrogen since the 1970s to propel the space shuttle and other rockets into orbit.

In addition to being directly combustible, hydrogen can be used in fuel cells. Fuel cells offer a promising technology for use as a source of heat and electricity for buildings, and as an electrical power source for electric vehicles. Hydrogen fuel cells powered the NASA space shuttle's electrical systems, producing a clean by-product—pure water—which the crew drank.

Several barriers must be dealt with if the hydrogen-based economy is to become a reality. The technologies that use hydrogen as a fuel are currently very expensive, and the infrastructure needed to get the hydrogen to users is undeveloped.

It is unlikely that hydrogen will be fully competitive with more conventional fuels in the absence of a specific role for government. One potentially substantial cost savings from using hydrogen, the reduction in air pollution damage, is an externality. Since consumers are likely to ignore, or at least weigh less, external costs in their choice of fuels, in the absence of corrective government policy (such as a tax on more polluting fuels), demand will be biased away from hydrogen, and potential suppliers will be discouraged from entering the market.

Consumer acceptance is an important ingredient in the transition to any alternative source of energy. New systems are usually less reliable and more expensive than old systems. Once they become heavily used, reliability normally increases and cost declines; experience is a good teacher. Since the early consumers, the pioneers, experience both lower reliability and higher costs, procrastination can be an optimal individual strategy. Waiting until all the bugs have been worked out and costs come down reduces uncertainty. If every consumer procrastinates about switching, however, the industry will not be able to operate at a sufficient scale and will not be able to gain enough experience to produce the reliability and lower cost that will ensure a large, stable market. How can this initial consumer reluctance be overcome?

One strategy involves using tax dollars to subsidize purchases by the pioneers. Once the market is sufficiently large that it can begin to take advantage of economies of scale and eliminate the initial sources of unreliability, the subsidies could be eliminated. The available empirical evidence based upon the impact of earlier policies (Durham et al., 1988; Fry, 1986) suggests that the tax credit approach did increase the degree of market penetration of solar equipment in the United States.

In the United States, substantial tax credits authorized at both the federal and state levels have been influential in inducing independent producers to accept the financial and engineering risks associated with developing wind power. Although the initial federal tax credits expired in 1985, a 1.5¢/Kwh production incentive for producers of electricity generated from wind power was reinstated in 1992. Since that time the subsidy has elapsed and been reinstated irregularly.

In contrast to the "on-again, off-again" nature of the U.S. subsidies, European nations have been steadily increasing the economic incentives for encouraging wind power, with the result that Europe is now dominating the production of wind power. An alternative approach would involve removing inefficient subsidies or internalizing the externalities for competing fuels in order to create a level playing field for sustainable energy sources. In the absence of those steps, decisions that depend on private, not social, costs will inefficiently favor polluting sources.

Removing subsidies has a certain political appeal. Removal can lower government expenditures (or raise tax revenue in the case of eliminating tax breaks), welcome news during periods of tight budgets. The fact that removal could improve efficiency does not, however, mean that this step is easily taken. The producers of favored energy sources clearly benefit from those subsidies and would fight their removal.

Summary

We have seen that the relationship between government and the market is not always harmonious and efficient. In the past, price controls have tended to reduce energy conservation, to discourage exploration and supply, to cause biases in the substitution among fuel types that penalize future consumers, and to create the potential for abrupt, discontinuous transitions to renewable sources. This important example makes a clear case for less, not more, regulation.

This conclusion is not universally valid, however. Other dimensions of the energy problem, such as climate change and national security issues, suggest the need for some government role. Insecure foreign sources require policies such as tariffs and strategic reserves to reduce vulnerability and to balance the true costs of imported and domestic sources. In addition, government must ensure that the costs of energy fully reflect not only the potentially large environmental costs, including climate change, but also the national security costs associated with our dependence on foreign sources of energy. Government action must also assure that inefficient subsidies do not undermine the transition to sustainable energy resources.

Economic analysis reveals that no single strategy is sufficient to solve the national security and climate change problems simultaneously. Subsidizing domestic supply, for example, would reduce the share of imports in total consumption (an efficient result), but it would reduce neither consumption nor climate change emissions (inefficient results). The expansion of domestic production also tends to drain domestic reserves faster, which makes the nation more vulnerable in the long run (another inefficient result). On the other hand, energy conservation (promoted by a tax on energy, for example) would reduce energy consumption and emissions of greenhouse gases (efficient outcomes) but would not achieve the efficient share of imports (an inefficient result) since an energy tax falls on all energy consumption, whereas the national security problem involves only imports.

Given the inefficient biases against public safety in the Price-Anderson Act, government should also continue to oversee nuclear reactor safety and should ensure that communities accepting nuclear waste disposal sites are fully compensated. Given the environmental difficulties with all three of the depletable transition fuels (unconventional oil, coal, and uranium), energy efficiency, energy conservation, and electric load-management techniques are now playing (and will continue to play) a larger role.

The menu of energy options as the economy transitions to renewable sources offers a large number of choices, including photovoltaics, active and passive solar energy, wind, ocean tidal power, biomass fuels, geothermal energy, and hydrogen. It is far from clear what the ultimate mix will turn out to be, but it is very clear that government policy is a necessary ingredient in any smooth transition to a sustainable-energy future. Since many of the most important costs of energy use are externalities, an efficient transition to these renewable sources will not occur unless the playing field is leveled. The potential for an efficient and sustainable allocation of energy resources by our economic and political institutions clearly exists, even if historically it has not always occurred.

Discussion Questions

1. Should benefit–cost analysis play the dominant role in deciding the proportion of electric energy to be supplied by nuclear power? Why or why not?
2. Economist Abba Lerner proposed a tariff on oil imports equal to 100 percent of the import price. This tariff is designed to reduce dependence on foreign sources as well as to discourage OPEC from raising prices (since, due to the tariff, the delivered price would rise twice as much as the OPEC increase, causing a large subsequent reduction in consumption). Should this proposal become public policy? Why or why not?
3. Does the fact that the strategic petroleum reserve has never been used to offset shortfalls caused by an embargo mean that the money spent in creating the reserve has been wasted? Why or why not?

Self-Test Exercises

1. During a worldwide recession in 1983, the oil cartel began to lower prices. Why would a recession make the cartel more vulnerable to price cutting? How would the reduced demand be shared between the competitive fringe and the cartel members in the absence of this price cutting?
2. Assume the demand and marginal cost conditions given in the second self-test exercise in Chapter 2. In addition, assume that the government imposes a price control at P = \$80/3. (a) Find the consumer and producer surplus associated with the resulting allocation. (b) Compare this price control allocation to the monopoly allocation in part (c) of that self-test exercise .
3. Not long ago, a conflict between a paper company and a coalition of environmental groups arose over the potential use of a Maine river for hydroelectric power generation. As one aspect of its case for developing the dam, the paper company argued that without hydroelectric power the energy cost of operating five particular paper machines would be so high that they

would have to be shut down. Environmental groups countered that the energy cost was estimated to be too high by the paper company because it was assigning all of the high-cost (oil-fired) power to these particular machines. That was seen as inappropriate because all machines were connected to the same electrical grid and therefore drew power from all sources, not merely the high-cost sources. They suggested, therefore, that the appropriate cost to assign to the machines was the much lower average cost. Revenue from these machines was expected to be sufficient to cover this average cost. Who was right?

4. In the section of this chapter dealing with load management by the utilities, it was mentioned that peaking plants are typically cheap to build (compared to base-load plants), but that they have relatively high operating costs. Explain why it makes sense for utilities to use this lower-capital, high-operating-cost type of plant for peaking and the high-capital, lower-operating-cost type of plant for base load.
5. If OPEC raised the price of oil high enough, would that be sufficient to promote an efficient energy mix?
6. Label the following as True, False, or Uncertain and explain your choice. (Uncertain means that it can be either true or false depending upon the circumstances.)
   a. All members of a resource cartel share a common objective—increase prices as much and as soon as possible.
   b. By holding prices lower than they would otherwise be, placing a price control on a depletable resource increases both the speed with which the resource is extracted over time and the cumulative amount ultimately extracted.
   c. A price control actually has no influence on the extraction path of a depletable resource until such time as the market price actually reaches the level of the price control.
   d. Forcing companies that drill offshore for oil to compensate victims of any oil spill from one of its facilities would be an efficient requirement.
7. Explain why the existence of a renewable energy credit market would lower the compliance costs for utilities forced to meet a renewable portfolio standard.
8. Using Figure 7.4, show how the level of oil imports and the price level would be affected if the country represented in that figure acted to internalize national security issues, but ignored climate change impacts.

Further Reading

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