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Market Failure and the Structure of Externalities

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Policy interest in renewable energy technologies has been gathering momentum for the past several decades, and increased incentives and funding for renewable energy are often described as the panacea for a variety of issues ranging from environmental quality to national security to green job creation. Sizable policies and programs have been implemented worldwide to encourage a transition from fossil-based electricity generation to renewable electricity generation, and in particular to fledgling green technologies such as wind, solar, and biofuels.

The United States has a long history of policy activity in promoting renewables, including state-level programs, such as the California Solar Initiative, which provides rebates for solar photovoltaic purchases, as well as federal programs, such as tax incentives for wind. Even in the recent stimulus package, the American Recovery and Reinvestment Act of 2009, $6 billion was allocated for renewable energy and electric transmission technology loan guarantees (U.S. Congress 2009). (See Chapter 11 for further discussion of the U.S. experience.) Moreover, such policies are not restricted to the developed world. For example, China promulgated a National Renewable Energy Law in 2005 that provides tax and other incentives for renewable energy and has succeeded in creating a burgeoning wind industry (Cherni and Kentish 2007).

Advocates of strong policy incentives for renewable energy in the United States use a variety of arguments to justify policy action, such as ending the "addiction" to foreign oil, addressing global climate change, or creating new technologies to increase U.S. competitiveness. However, articulation of these goals leaves open the question of whether renewable energy policy is a sensible means to reach these goals, or even whether particular renewable energy policy helps meet these goals. Furthermore, many different policy instruments are possible, so one must evaluate what makes a particular policy preferable over others.

Economic theory can provide guidance and more rigorous motivation for renewable energy policy, relying on analysis of the ways privately optimal choices deviate from economically efficient choices. These deviations are described as market failures and, in some cases, behavioral failures.[1] Economic theory indicates that policy measures to mitigate these deviations can improve net social welfare, as long as the cost of implementing the policy is less than the gains if the deviations can be successfully mitigated.

Under this perspective, policy analysis involves identifying market failures and choosing appropriate policy instruments for each. While an almost unlimited number of different possible policy instruments can be envisioned, an analysis of relevant market failures allows us to identify which instruments are most likely to improve economic efficiency. This endeavor is complicated by the complexity of some market failures, which may vary intertemporally or geographically.

This chapter explores these issues in the context of renewable energy, with a particular focus on renewable energy used for electricity generation. It first sets the stage with a brief background on the fundamental issues inherent in renewable energy. Next, it elaborates on the concepts of competitive markets and resource use, and how the deviations found in reality from the assumptions of perfect markets may result in market failures. This leads naturally to articulating the classes of possible deviations from perfect markets. A discussion follows of the use of policy instruments to help mitigate or correct for these market failures, with a particular focus on how the structure of the failure influences the appropriate policy approach.

Fundamental Issues in Renewable Energy

Renewable energy, including wind, solar, hydro, geothermal, wave, and tidal, offers the possibility of a large, continuous supply of energy in perpetuity. Analysis of the natural energy flows in the world shows that they provide usable energy many orders of magnitude greater than the entire human use of energy (Hermann 2006). For example, the amount of sunlight reaching the earth is more than 10,000 times greater than the total human direct use of energy, and the amount of energy embodied in wind is at least 4 times greater (Archer and Jacobson 2005; Da Rosa 2005; EIA 2008). In principle, renewable energy offers the possibility of a virtually unlimited supply of energy forever.

In contrast, most of the energy sources we rely on heavily today, such as oil, natural gas, coal, and uranium, are depletable resources that are present on the earth as finite stocks. As such, eventually these stocks will be extracted to the point that they will not be economical to use, because of either the availability of a substitute energy source or scarcity of the resource. The greater the rate of use relative to the size of the resource stock, the shorter the time until this ultimate depletion can be expected.

These simple facts about the nature of depletable and renewable resources point to a seemingly obvious conclusion: the United States and the rest of the world will eventually have to make a transition to alternative or renewable sources of energy. However, the knowledge that the world will ultimately transition back to renewable resources is *not* sufficient reason for policies to promote those resources. Such transitions will happen regardless of policy, simply as a result of market incentives.

The fundamental question is whether markets will lead the United States and the rest of the world to make these transitions at the appropriate speed and to the appropriate renewable resource conversions, when viewed from a social perspective. If not, then the question becomes, why not? And if markets will not motivate transitions at the appropriate speed or to the appropriate renewable supplies, the question becomes whether policy interventions can address these market failures so as to make the transitions closer to the socially optimal.

The question of why not may seem clear to those who follow the policy debates. Environmental and national security concerns are foremost on the list of rationales for speeding up the transition from depletable fossil fuels to renewable energy. Recently there have also been claims that promoting new renewable technologies could allow the United States, or any country, to become more competitive on world markets or could create jobs.

But much national debate often combines these rationales and fails to differentiate among the various policy options, renewable technologies, and time patterns of impacts. The rest of the chapter explores these issues in greater detail in order to disentangle and clarify the arguments for renewable energy policy.

Resource Use and Deviations from Perfectly Functioning Markets

Welfare economic theory provides a framework for evaluating policies to speed the transition to renewable energy. A well-established result from welfare economic theory is that absent market or behavioral failures, the unfettered market outcome is economically efficient.[2] Market failures can be defined as deviations from perfect markets due to some element of the functioning of the market structure, whereas behavioral failures are systematic departures of human choice from the choice that would be theoretically optimal.[3]

A key result for analysis of renewable energy is that if the underlying assumptions hold, then the decentralized market decisions would lead to an economically efficient use of both depletable and renewable resources at any given time. Moreover, the socially optimal rate of transition from depletable energy supplies to renewable energy can be achieved as a result of decentralized market decisions, under the standard assumptions that rational expectations of future prices guide the decisions of both consumers and firms (Heal 1993).

Although markets are not perfect, the concept of perfectly competitive markets provides a benchmark for evaluation of actual markets. Identification of market imperfections allows us to evaluate how actual markets deviate from the ideal competitive markets and thus from the economically efficient markets. Hence with economic efficiency as a policy goal, we can motivate policy action based on deviations from perfectly competitive markets—as long as the cost of implementing the policy is less than the benefits from correcting the deviation.[4]

For renewable energy, market failures are more relevant than behavioral failures, as most energy investment decisions are made by firms rather than individuals, so some of the key decisionmaking biases pointed out in the behavioral economics literature are likely to play less of a role. However, behavioral failures may influence consumer choice for distributed generation renewable energy (e.g., residential solar photovoltaic investments) and energy efficiency decisions.[5] These could imply an underuse of distributed generation renewable energy—or an overuse of all energy sources (including renewables) if energy efficiency is underprovided.

Both market failures and behavioral failures can be distinguished from market barriers, which can be defined as any disincentives to the use or adoption of a good (Jaffe et al. 2004). Market barriers include market failures and behavioral failures, but they also may include a variety of other disincentives. For example, high technology costs for renewable energy technologies can be described as a market barrier but may not be a market failure or behavioral failure. Importantly, only market barriers that are also market or behavioral failures provide a rationale based on economic efficiency for market interventions.

Similarly, pecuniary externalities may occur in the renewable energy setting and also do not lead to economic inefficiency. A pecuniary externality is a cost or benefit imposed by one party on another party that operates through the changing of prices, rather than real resource effects. For instance, if food prices increase because of increased demand for biofuels, this could reduce the welfare of food purchasers. However, the food growers and processors may be better off. In this sense, pecuniary externalities may lead to wealth redistribution but do not affect economic efficiency.

Nature of Deviations from Perfectly Functioning Markets

It is a useful to consider deviations from perfectly functioning markets based on whether the market failure is atemporal or intertemporal.

Atemporal deviations are those for which the externality consequences are based primarily on the rate of flow of the externality. For example, an externality associated with air emissions may depend primarily on the rate at which the emissions are released into the atmosphere over a period of hours, days, weeks, or months. Such externalities can be described statically. They may change over time, but the deviation has economic consequences that depend primarily on the amount of emissions released over a short time period (e.g., hours, days, weeks, or months). These may have consequences that are immediate or occur over very long time periods.

Intertemporal deviations are those for which the externality consequences are based primarily on a stock that changes over time depending on the flow of the externality. The flows lead to a change in the stock over a relatively long period of time, typically measured in years, decades, or centuries. The stock can be of a pollutant (e.g., carbon dioxide) or of something economic (e.g., the stock of knowledge or of photovoltaics installed on buildings). If the flow of the externality is larger (smaller) than the natural decline rate of the stock, the stock increases (decreases) over time. Intertemporal externalities can best be described dynamically, for it is the stock (e.g., carbon dioxide), rather than the flow, that leads to the consequences (e.g., global climate change).

For some environmental pollutants (e.g., smog), the natural decline of the stock is rapid—perhaps over the course of hours, days, weeks, or months. For these pollutants, the stock leads to the damages, and the stock is entirely determined by the flow over this short time frame. These can be treated as atemporal deviations, as the dynamic nature of the externality is less important with such a rapid natural decline rate.

For atemporal externalities, the appropriate magnitude of the intervention depends primarily on current conditions. Thus, because conditions can change over time, the appropriate magnitude could increase, decrease, or stay constant over time. For intertemporal externalities, the appropriate magnitude of the intervention depends more on the conditions prevailing over many future years than on current conditions or those at one time. As time passes, the appropriate magnitude of the intervention changes but, more predictably, based on the stock adjustment process. Therefore, the appropriate price or magnitude of the intervention will have a somewhat predictable time pattern.

Atemporal (Flow-Based) Deviations from Economic Efficiency

Atemporal deviations from economic efficiency fall into several categories: labor market supply–demand imbalances, environmental externalities, national security externalities, information market failures, regulatory failures, market power, too-high discount rates for private decisions, imperfect foresight, and economies of scale.

Labor Market Supply–Demand Imbalances

Unemployment represents a situation in which the supply of labor exceeds demand at the prevailing wage structure, perhaps because of legal and institutional frictions slowing the adjustment of the wage structure. In the United States, such unemployment does not occur very often, typically only during recessions. At times of full employment,[6] abstracting from the distortionary impacts of income or labor taxes,[7] the social cost of labor (i.e., the opportunity cost and other costs of that labor to the employee) would be equal to the price of labor (i.e., the wage an employer must pay for additional labor), and hence there is no room to improve economic efficiency through green jobs programs.

With unemployment, however, the price of labor exceeds the social cost of that labor. This difference represents a potential net economic efficiency gain, and thus any activity that employs additional workers may improve economic efficiency. For example, if an additional amount of some economic activity produced no net profit, and therefore would not be privately undertaken, the net social economic gain would be equal to the differential between the price of labor and its social cost.

With unemployment, the opportunity cost (and other cost) of labor to the person being employed could be expected to vary substantially across individuals. Some unemployed persons may use their free time productively to perform work at home or improve skills, so that the opportunity cost of labor might be only slightly below the wage. Others may not be able to make such productive use of their time, so that the opportunity cost might be virtually zero, significantly below the wage. Thus the potential net social gain from additional employment could range from nearly the entire wage to zero.

Little evidence exists to suggest that additional employment in renewable energy can provide larger net social gains than any other industry, including the fossil-fuel industry. Moreover, such gains must be seen as transient possibilities in an economy such as that of the United States, which regularly is near full employment.

Environmental Externalities

Environmental externalities are the underlying motivation for much of the interest in renewable energy. The discussion here focuses on general issues in environmental externalities; specific issues inherent in intertemporal environmental externalities are addressed below in the section titled "Stock-Based Environmental Externalities". Combustion of fossil fuels emits a variety of air pollutants, which are not priced without a policy intervention. Air pollutants from fossil-fuel combustion include nitrogen oxides, sulfur dioxide, particulates, and carbon dioxide. Some of these pollutants present a health hazard, either directly, as in the case of particulates, or indirectly, as in the case of ground-level ozone formed from high levels of nitrogen oxides and other chemicals.

When harmful fossil-fuel emissions are not priced, the unregulated market will overuse fossil fuels and underuse substitutes, such as renewable energy resources. Similarly, if the emissions are not priced, firms will have no incentive to find technologies or processes to reduce the emissions or mitigate the external costs. The evidence for environmental externalities from fossil-fuel emissions is strong, even if estimating the precise magnitude of the externality for any given pollutant may not be trivial.

In some cases, there may also be significant environmental externalities from renewable energy production, such as hydroelectric facilities that produce methane and carbon dioxide emissions from submerged vegetation, or greenhouse gas emissions and nitrogen fertilizer runoff from the production of ethanol biofuels. In many other cases, these environmental externalities are relatively small. Whether renewable energy resources are underused or overused relative to economically efficient levels depends on which of the two environmental externalities is greater: those from fossil fuels or from the renewable energy resources. In most, but by no means all, cases, the externalities from the fossil fuels are greater, implying that the market will underprovide renewable energy.

Unpriced environmental externalities from either fossil fuel or renewable energy use would imply either an overuse of energy in general or an underuse of potential energy efficiency improvements.

National Security Externalities

Oil production around the world is highly geographically concentrated, with the bulk of the oil reserves in the hands of national oil companies in unstable regions or countries of the world, such as the Middle East, Nigeria, Russia, and Venezuela. Oil-importing countries, such as the United States, European nations, and China, have seen large security risks associated with these oil imports. In response, they have laid out substantial diplomatic and military expenditures in these regions, at least partly in order to ensure a steady supply of oil. If increases in oil use lead to additional security risks, these risks represent an externality associated with oil use. Moreover, if the additional security risks are met with increases in diplomatic and military expenditures, then these added expenditures can be used as an approximate monetary measure of the externalities.

However, it appears unlikely that a modest increase or decrease in oil demand will influence these expenditures due to the lumpiness of the expenditures, even though the increases in oil use could lead to additional security risks. Conversely, long-term large changes in oil demand may reduce national security risks and the corresponding military and diplomatic expenditures.

In many countries around the world, such as those in Europe, the use of natural gas may have national security externalities because of similar issues. Quantifying the national security externalities associated with oil or natural gas consumption is more fraught with difficulties than doing so with environmental externalities, yet some analysts have suggested that the magnitude may be substantial (Bohi and Toman 1996). Others are more sanguine and believe that global energy markets can substantially buffer national security risks.

In the U.S. context, natural gas and some renewable energy resources, such as biofuels, are substitutes for oil with few or no energy security externalities and thus would be underused relative to the economically efficient level. Improving the energy efficiency of vehicles and furnaces is also a substitute for oil and would also be underused. Most renewable energy resources produce electricity, so until electric vehicles are a viable large-scale substitute for conventional vehicles fueled by refined oil products, national security externalities apply only indirectly to such renewable energy resources. However, these national security externalities, although indirect, can be important. For example, the production of electricity from renewables could lead to reductions in natural gas used for electricity production. This reduction would lead to more availability of natural gas for other purposes, such as heating, where it could substitute for oil in some locations. For biofuels, national security externalities are of foremost consideration. Moreover, in the European context, renewable energy directly substitutes for natural gas.

Information Market Failures

Information market failures relate most directly to the adoption of distributed generation renewable energy by households, such as solar photovoltaic systems or microgeneration wind turbines. If households have limited information about the effectiveness and benefits of distributed generation renewable energy, an information market failure may occur. In a perfectly functioning market, one would expect profit-maximizing firms to undertake marketing campaigns to inform potential customers. However, for nascent technologies that are just beginning to diffuse into the market, economic theory suggests that additional information can play an important role (Young 2010). Information market failures are closely related to behavioral failures. Reducing information market failures would also be expected to reduce behavioral failures associated with heuristic decisionmaking.

Imperfect foresight by either firms or consumers (or investors in the stock market who influence firms) suggests an inability to predict future conditions accurately, which may lead to an underestimate or overestimate of how energy prices may rise in the future. If firms systematically under- or overestimate future energy prices, then there may be an underinvestment or overinvestment in research and development (R&D) for renewable energy technologies relative to the economically efficient level.

Although it certainly seems plausible that firms have imperfect foresight, it is less plausible to believe that this imperfect foresight will systematically lead to an underestimate of future energy prices, rather than random deviations that are sometimes underestimates and other times overestimates. Even if firms have imperfect foresight, as long as the firms' estimates of future prices are not systematically biased, then on average investment in renewable energy technologies would still follow the economically efficient path. In this situation, errors leading to overinvestment would be balanced by those leading to underinvestment. At present, there is little evidence either for or against the hypothesis that firms systematically underestimate future price increases.

Another information market failure is the classic principal-agent or split-incentive problem, which may influence renewable energy adoption in two ways. First, in many cases for rental properties, landlords make the decision about whether to invest in distributed generation renewable energy, while tenants pay the energy bills (Jaffe and Stavins 1994; Murtishaw and Sathaye 2006). Second, if landlords are not compensated for their investment decisions with higher rents, then they would tend to underinvest in distributed generation renewable energy. This market failure has been most carefully examined in the context of energy efficiency (e.g., see Levinson and Niemann 2004), but the extent to which this market failure is important for renewable energy has not yet been empirically examined.

Finally, there may be a principal-agent problem relating to managerial incentives. In many cases, managers have their compensation tied to the current stock price, rather than the long-term performance of the company (Rappaport 1978). However, investors may have difficulty distinguishing between managerial decisions that boost short-term profits at the expense of long-term profits and those that boost both short- and long-term profits. In the context of renewable energy, the emphasis on short-term performance may lead to underinvestment in R&D for renewable energy technologies, for the benefits of developing such technologies are likely to be received over the long term, while the costs are borne in the short term. Of course, this issue may occur in any industry and is not unique to renewable energy resources.

Regulatory Failures

In some cases, the regulatory structure can create perverse incentives. For example, average cost pricing of electricity implies that consumers often face a price of electricity that does not reflect the marginal cost of providing electricity at any given time. This may influence the adoption of distributed generation renewables, such as residential solar photovoltaic (PV) systems. In many locations, electricity output from a solar PV unit tends to be higher during the day, corresponding to times of high electricity demand. To the extent that the solar PV output is correlated with high wholesale electricity prices, consumers and firms deciding whether to install a new solar PV unit will undervalue solar PV absent tariffs that account for the time variation. Borenstein (2008) quantifies this effect in California, finding that solar is currently undervalued by 0% to 20% under the current regulatory framework, and that this could rise to 30% to 50% if the electricity system were managed with more reliance on price-responsive demand and peaking prices, because solar output would be concentrated at times with even higher value.

Too-High Discount Rates

In some cases, the discount rate for private investment decisions may be higher than the social discount rate for investments with a similar risk profile. For example, the corporate income tax distorts incentives for firms to invest, effectively implying that they require a higher rate of return on investments than they would otherwise. Alternatively, credit limitations may also occasionally lead to a higher rate of return required for investments. These credit limitations may be due to macroeconomic problems, such as the recent liquidity crisis in the United States, or individual limitations on the firm involved in the renewable energy investment. Individual credit limitations may also apply in cases where consumers are interested in installing distributed or off-grid generation.

Discount rates that are too high may lead to two effects. First, if firms investing in renewable energy technologies have distorted discount rates, this could lead to underinvestment in renewable energy resources relative to the economically efficient level. Second, if discount rates are too high for firms extracting depletable resources, such as fossil fuels, then the fuels are extracted too rapidly, leading to prices that are lower than economically efficient. Because the depletable resource would be depleted too rapidly, the transition to renewable energy technologies may then be hastened relative to the efficient transition. However, investment in renewables may be second best, in that it would still be optimal to invest more, conditional on the too-rapid extraction of depletable resources.

This phenomenon is applicable not only to energy-related investments, but also to investments throughout the economy. Thus this issue provides reasons for changing incentives for investment throughout the economy, but it does not provide a particular reason for shifting investments from other parts of the economy to renewable energy, unless evidence suggested that high discount rates are particularly important for renewable energy. However, we are aware of no evidence that could give a sense of the magnitude of this distortion.

Economies of Scale

Economies of scale, particularly increasing returns to scale, refers to a situation where the average cost of producing a unit decreases as the rate of output at any given time increases, resulting from a nonconvexity in the production function for any number of reasons, including fixed costs. This issue may inefficiently result in a zero-output equilibrium only when we have market-scale increasing returns, where the slope of the average cost function is more negative than the slope of the demand function, and the firm cannot overcome the nonconvexity on its own.

Market-scale increasing returns refer to a nonconvex production function at output levels comparable with market demand. Figure 5.1 graphically illustrates the second condition. If the quantity produced is small (e.g., quantity *a*), then no profit-seeking firm would be willing to produce the product, but if production could be increased to some level above the crossing point (e.g., at the quantity *b*), then it would be profitable for the firm to produce: price would exceed average cost.

Usually a firm could overcome the situation in Figure 5.1 on its own simply by selling at a low price. Even if this is a risky endeavor, it is not likely that all firms would ignore this opportunity. However, firms may not be able to take advantage of the opportunity because of capital constraints or a simultaneous coordination problem.

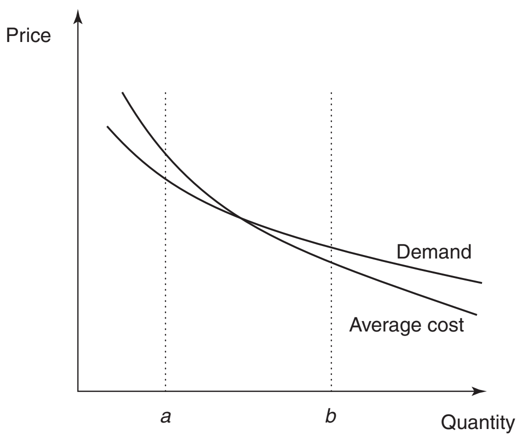

Figure 5.1. Economies of scale: slope of average cost function is more negative than slope of demand function

Capital constraints may be a problem only if the aggregate investment required is extremely large; otherwise, it is likely that some firm could be expected to raise the necessary capital. Capital constraints facing an economy, as occurred in the 2008–2009 recession, could limit such capital investments for an entire economy. Because such events tend to be transient, however, these constraints at most could be expected to delay the investments.

Often economies of scale are accompanied by a "chicken-and-egg" problem, wherein multiple actors must simultaneously invest and ramp up production in order to commercialize a new technology. This may be most relevant in technologies that require a new infrastructure, such as hydrogen-fueled vehicles, which may or may not use renewable energy depending on the hydrogen generation source. Such possibilities require interindustry cooperation and thus may greatly delay investments. Similar chicken-and-egg problems have been overcome in the past, as with personal computers, operating systems, and application software or automobiles, gasoline, service stations, and roads, but these problems greatly complicate investments.

It should be noted that the equilibrium that would occur with market-scale increasing returns would unlikely be a workable competitive equilibrium, but rather a single-firm monopolistic equilibrium. In fact, the situation of market-scale increasing returns is often referred to as a "natural monopoly." This situation raises the possibility of market power.

Market Power

Uncompetitive behavior may influence the adoption of renewable energy technologies in several ways. First, market power in substitutes for renewable energy can influence the provision of renewable energy through two channels. Firms effectively exercising market power in substitutes for renewable energy (e.g., at times the OPEC cartel) would raise the price of energy above the economically efficient level, making investment in renewable energy more profitable and leading to an overinvestment in renewable energy. On the other hand, firms that have market power in substitutes for renewable energy may have an incentive to buy out fledgling renewable energy technologies to reduce competitive pressures—leading to a possible underprovision of renewable energy resources if that purchasing firm "buries" the renewable technology. However, the prospect of being bought by a competitor could provide a strong incentive for a new firm to be created with the explicit intention of selling itself to a larger company. Which effect dominates and whether there is market power in substitutes for renewable energy can be determined only empirically.

Market power may also influence the adoption of renewable energy resources by influencing the rate and direction of technological change. If less competition exists in a market, firms are more likely to be able to fully capture the benefits of their innovations, so incentives to innovate are higher (e.g., see Blundell et al. 1999; and Nickell 1996). Conversely, if more competition exists, firms may have an incentive to try to "escape" competition by investing in innovations that allow them to differentiate their product or find a patentable product. Some evidence suggests that the relationship between competition and innovation may be an inverted U-shaped curve, with a positive relationship at low levels of competition and a negative relationship at higher levels of competition (Aghion et al. 2005; Scherer 1967). This relationship likely holds in all industries, not just the renewable energy industry.

Finally, in some cases, vertically integrated utilities may effectively exercise market power by favoring their own electricity generation facilities over other small generation facilities, including renewable energy facilities. This was a concern for the implementation of renewables when utilities invested mostly in nonrenewable energy, but utilities now typically invest in renewable energy along with conventional generation plants.[8]

Intertemporal (Stock-Based) Deviations

An important intertemporal deviation may occur with the existence of stock-based environmental externalities. A second intertemporal deviation may occur if an imperfect capture of the stock of knowledge is created as a result of current actions, leading to underinvestment or underproduction of those activities that lead to growth of the knowledge stock. These can occur with knowledge generation processes, such as learning by doing or research and development; market diffusion of a new technology; or network externalities. Intuitively, when others can capture some of the benefits from the choice made by a firm or consumer, the uncaptured benefits will be socially valuable but will not be taken into account by the firm or consumer.

Stock-Based Environmental Externalities

As discussed above, some environmental externalities have consequences based on the stock of the pollutant, rather than the flow, and the stock adjusts only slowly over time. For such environmental externalities, the intertemporal nature of the damages from the stock imposes additional structure on the time pattern of deviations.

Particularly relevant to renewable energy supplies are carbon dioxide and other greenhouse gases. For CO_2, every additional metric ton emitted remains in the stock for more than a century. Thus emitting a ton today would have roughly the same cumulative impacts as emitting a ton in 20 years. This implies that, absent changes in the regulatory environment, the magnitude of the deviation for emissions now will be the same as the magnitude of the deviation for emissions 20 years from now. Economic efficiency implies that a society should be almost indifferent between emitting a ton of CO_2 now, 20 years from now, or any year in between .[9] As will be discussed below in the section titled "Policies for Stock-Based Environmental Externalities: Carbon Dioxide", it is this relationship that imposes a structure on the time pattern of efficient policy responses.

Similar issues arise for toxic metals released into the waterways, radioactive nuclear waste, mercury in waterways and oceans, sequestration of carbon dioxide in the deep oceans, and rainforest land degradation.

Imperfect Capture of Future Payoffs from Current Actions

R&D

When firms invest in increasing the stock of knowledge by spending funds on R&D, they may not be able to perfectly capture all of the knowledge gained from their investment. For example, successful R&D (e.g., creating a new class of solar photovoltaic cells) by a particular firm could be expected to result in some of the new knowledge being broadly shared, through trade magazines, reverse engineering by its competitors, or technical knowledge employees bring with them as they change employment among competitive firms. In addition, patent protection for new inventions and innovations has a limited time frame (20 years in the United States), so after the patent lapses, other firms may also benefit directly from the invention or innovation.

Fundamentally, R&D spillovers can be thought of as an issue of imperfect property rights in the stock of knowledge: other firms can share that stock without compensating the original firm that enhanced the knowledge stock. To the extent that those spillover benefits occur, the social rate of return from investment in R&D is greater than the firm's private rate of return from investment in R&D. Indeed, although estimates differ by sector, there appears to be substantial empirical evidence that the social rate of return is several times that of the private rate of return. For example, in the United States, the social rate of return is estimated in the range of 30% to 70% per year, while the private rate of return is 6% to 15% per year (Nordhaus 2002). However, the magnitude of the R&D spillovers depend on the stage in the development of a new technology, with more fundamental research having significantly greater R&D spillovers than later-stage commercialization research (Nordhaus 2009).

Evidence of high social returns to R&D is found not just in the renewable energy sector, but throughout the economy. Thus, to the extent that some R&D in renewable energy technologies comes at the expense of R&D in other sectors with a high social rate of return, the opportunity cost of renewable energy R&D may be quite high (Pizer and Popp 2008). Empirical work suggests that additional R&D investment in renewable energy will at least partly displace R&D in other sectors. Popp (2006) finds that approximately half of the energy R&D spending in the 1970s and 1980s displaced, or crowded out, R&D in other sectors. Part of the rationale for this may be that years of training are required to become a competent research scientist or engineer, and therefore the supply of research scientists and engineers is, at least in the short term, relatively inelastic. In the longer term, crowding out is less likely to be an issue, as universities train more scientists and engineers.

Learning by doing

A similar intertemporal market imperfection due to a knowledge stock spillover may also occur if there is a significant learning-by-doing (LBD) effect that cannot be captured by the firm. LBD has a long history in economics, dating back to Arrow (1962). The basic idea behind LBD is that the cost of producing a good declines with the cumulative production of the good, corresponding to the firm "learning" about how to produce the good better.[10] One interpretation is that with LBD, the cost is dependent on the stock of knowledge, which is proxied by the stock of cumulative past production. In the standard model of LBD, the firm today bears the up-front cost of producing an additional unit and thereby also increasing the knowledge stock, while all firms in the industry benefit from the increased stock of knowledge, leading to reduced costs in the future for all firms—an intertemporal spillover.

Importantly, LBD alone does not necessarily imply a market failure. In some situations, one could imagine that all knowledge leading to cost reductions could be used only by the single firm making the decision. In this special case, there are no spillovers, and the firm would have the incentive to produce optimally, weighing the up-front cost of learning against the benefits of the cost reductions in the future as it would any investment decision.[11]

Outside of this special case, the existence of LBD can represent an externality with the poten-

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tial to be an important market imperfection in renewable energy markets. There is little or no empirical evidence on the degree of spillovers from LBD, but ample evidence exists that the cost of several important renewable energy technologies tends to decline as cumulative production increases (Jamasb 2007). This evidence alone does not prove the existence of a market failure, for other factors may also be able to explain the cost decreases (e.g., R&D or even time-dependent autonomous cost decreases).

The magnitude of a LBD market failure is specific to each technology, and each has to be assessed on a case-by-case basis. Moreover, much like R&D spillovers, LBD spillovers are not unique to renewable energy technologies, but may also be present in any number of fledgling technologies as they diffuse into the market. Hence both R&D and LBD spillovers can be considered broader innovation market failures that lead to underinvestment in or underproduction of certain renewable energy resources.

Network externalities

Network externalities occur when the utility an individual user derives from a product increases with the number of other users of that product. The externality stems from the spillover one user's consumption of the product has on others, so that the magnitude of the externality is a function of the total number of adoptions of the product. Often quoted examples of network externalities include the introduction of the "QWERTY" typewriter keyboard, telephone, and fax machine (David 1985).

An important caveat about network externalities is that the externality may already be internalized. For example, the owner of the network may recognize the network effects and take them into account in his or her decisionmaking (Liebowitz and Margolis 1994). Alternatively, in some cases, the recipients of the network spillover may be able to compensate the provider. For example, for network effects in home computer adoption, the new adopter might take the previous adopter to lunch as thanks for teaching him or her how to use the computer (Goolsbee and Klenow 2002). When the externality is already internalized, network externalities are more appropriately titled "network effects" or "peer effects" and do not lead to market failures (Liebowitz and Margolis 1994).

In the context of renewable energy, network externalities may play a role in the adoption of distributed generation. This may come about if consumers believe that installing renewable energy systems on their homes sends a message to their neighbors that they are environmentally conscious—and that more installations in the neighborhood will increase this "image motivation" or "snob effect." Evidence for this effect has been shown in Sacramento for solar panels (Lessem and Vaughn 2009). Little evidence is available to indicate whether this is truly a network externality or just network effects in distributed generation renewable energy.

Policy Instruments

Each of the failures described above provides motivation for policy to correct the failure, but it is not always a simple task to appropriately match the policy to the failure. Table 5.1 lists some of the more common classes of policy instruments available to address failures relevant to renewable energy. This table is meant to be illustrative, as there exist an almost uncountable variety of different policy instruments.

How do we choose among the policy instruments? Economic theory along with careful analysis can provide guidance. First, both theory and evidence indicate that multiple market failures will likely require multiple interventions, so a sensible policy goal involves matching the most appropriate intervention to the failure (Aldy et al. 2009; Goulder and Schneider 1999). In some cases, several policy instruments can address, or partly address, a given market failure. In these cases, if economic efficiency is the goal, the combination of policy instruments that provides the greatest net benefits should be chosen. In addition, many of the market failures relevant to renewable energy are broader market failures that may apply to a wide range of markets or technologies. Therefore, economic efficiency would

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Table 5.1. Some potential policy instruments

Direct regulation	Command-and-control methods (e.g., requiring firms to generate electricity from renewable energy resources)
Direct government-sponsored R&D	Government funding for scientists and engineers working on improving different renewable energy technologies, support for national laboratories, funding research prizes such as "X prizes"
R&D tax incentives	Subsidies for private renewable energy technology R&D
Instruments to correct market prices: excise taxes, cap-and-trade, subsidies	"Get prices right" by adding to the cost of goods (e.g., through a tax or a permit price) or reducing the cost of goods (e.g., through a subsidy)
Feed-in tariffs	Require electric utilities to purchase electricity from other generators (often small renewable energy generators) at a specified price
Information programs	Education campaigns and required labels
Product standards	Require firms to improve their product characteristics to meet a specified goal (e.g., efficiency of solar PV cell or energy efficiency of lighting)
Marketable marketwide standards: renewable portfolio standards, low-carbon fuel standards, corporate average fuel, economy standards	Require firms (e.g., utilities) to meet a specified standard (e.g., produce a specified amount of electricity from renewables) or purchase permits or certificates from other firms that overcomply with the standard
Transparency rules	Require firms to provide more information about their current conditions to investors
Macroeconomic policy	Fiscal or monetary policies to stabilize the economy and provide liquidity to markets to reduce credit constraints
Corporate taxation reform	Adjusting the corporate income tax to improve corporate incentives
Competition policy/laws	Reduce the exercise of market power through antitrust action
Restructured regulation	Reduce regulatory failures and loopholes in regulations that allow for market power
Intellectual property laws	Laws to encourage innovation by allowing innovators to appropriate the benefits of their work

be further enhanced if the interventions to address these market failures were not focused solely on renewable energy.

Several concerns warrant careful attention in this matching process. First, we care about how effective the intervention will be at actually correcting the market failure. Second, the benefits from the intervention must be weighed against the costs of implementing the policy, including both government administrative costs and individual compliance costs—taking into account the risk of poor policy design or implementation. In addition, careful consideration of any equity or distributional consequences of the intervention is important, both for ethical reasons and for gaining the political support for passage of the policy.

Uncertainty about the magnitude of the market failure and the effectiveness of the interventions is another important concern. In some cases, potential damages from a market failure may be large enough that the most sensible intervention is direct regulation, so that we can be certain the risk is mitigated. For example, if a toxin is deemed to have sufficiently high damages with a high enough probability, it may be sensible for the government to simply ban it. A comprehensive analysis of the costs and benefits of different policy options that explicitly includes uncertainty, in this case could be expected to reveal the need for simply banning the toxin.

Finally, the temporal structure of the market failures may have a profound influence on the temporal structure of optimal intervention. Economic theory suggests that not only should an intervention be matched to the failure, but also the temporal pattern of the intervention should be matched to the temporal pattern of the failure. For example, the optimal correction for failures that decrease in magnitude and eventually vanish over time would be a transient intervention.

Table 5.2 summarizes the matching, with the various market failures listed as rows and policy instruments from Table 5.1 as the columns. For those instruments that appear to be potentially well matched to the market failures, the letters *P* and *T* indicate whether the instrument could be expected to be permanent or transient. Of course, the particular circumstances of each market failure and the potential policy must be assessed. Some potential policies may be useful only under limited circumstances, and the evidence for some market failures in renewable energy is much weaker than others. Moreover, some of the policy options listed may be reasonably well matched with a market failure but may be second best to other policy options.

Policy Instruments for Atemporal (Flow-Based) Deviations

Atemporal deviations lend themselves to policy interventions that vary, perhaps greatly, with changing external conditions. If the underlying market deviation is a continuing problem, then the policy interventions can be expected to have a relatively permanent nature. If the deviation is transient, the appropriate policy intervention would likewise be transient.

Table 5.2. Sources of market failure and some illustrative potential policy instruments

	Direct regulation	Direct government-sponsored R&D	Competitions, such as X prize	R&D tax incentives	Excise taxes	Production subsidies	Feed-in tariffs	Information programs	Product standards	Cap-and-trade	Marketable marketwide standards	Transparency rules	Macroeconomic policy	Corporate taxation reform	Competition policy/laws	Restructured regulation	Intellectual property law
Labor supply/demand imbalances						T							T				
Environmental externalities	P	P	P	P	P	P	P	P	P	P	P	P					
National security externalities	P	P	P	P	P	P	P	P	P	P	P	P					
Information market failures								P	P			P					
Regulatory failures																P	
Too-high discount rates				P									P	P			
Imperfect foresight								P									
Economies of scale						T	T								P		
Market power									P						P	P	
R&D spillovers		P	P	P											P		P
Learning-by-doing						T	T										
Network externalities						T									P		

Note: P indicates permanent change or instrument; *T* indicates transient instrument

Policies for Labor Market Supply–Demand Imbalances

Labor market unemployment in well-functioning developed economies can be expected to be a transient problem, associated with economic recession. Typically, policies are crafted at the national or international level and focus on economywide transient monetary or fiscal policies that are terminated when the economy returns to full employment.[12] However, it is often asserted that subsidizing new renewable technologies is advantageous because it would create jobs.

In theory, in order to align private incentives with socially optimal incentives, the labor cost of providing renewable energy could be subsidized by the difference between the market price of labor and the social cost of that labor. Thus in order to improve economic efficiency, such a labor subsidy must vary sharply over the course of the business cycle; be zero during times of full employment; and differ across employees, depending on the options facing the unemployed person. This set of conditions may make it extremely difficult to implement such a policy.

Moreover, and perhaps most important, unemployment is an economywide phenomenon, so an equally valid argument could be made for subsidizing labor throughout the economy, including in the fossil fuels sector. Thus the "creating jobs" argument does not clearly justify targeting the labor subsidies to the renewable energy industry, unless a particularly large deviation existed between the social cost of the labor and the market price relative to the rest of the economy.

Policies for Environmental Externalities

Table 5.2 lists a wide variety of different policy instruments to address environmental externalities. The most straightforward of these is to simply price the environmental externality, following the theory first developed by Pigou (Baumol 1972). In doing so, firms and consumers will take into account the externality in their decisions of how much to produce and consume. The price could be imposed directly as a pollution tax or pollution fee, with the optimal tax set at the magnitude of the externality. Or a cap-and-trade system could impose a marketwide limit on the emissions, in which case trading of the allowances under a cap-and-trade system would lead to a market-clearing price for the allowances. The cap should be set so that the resulting permit price is equal to the magnitude of the externality.[13] The magnitude of the externality can be estimated based on damage estimates from scientific and economic literature.

In some cases, the risk from particularly severe pollutants (e.g., possibly some criterion air pollutants) may be sufficiently high that the marginal damage associated with the release of the pollutant would always exceed the economic costs of reducing that pollution—implying that direct regulation could be an economically efficient policy. Direct regulation would entail the government setting strict limits on the amount of the severe pollutant emitted or, in some cases, possibly even banning emission of the pollutant entirely.

Environmental externalities from renewable energy can be treated the same way as environmental externalities from fossil-fuel combustion. For most renewables, the environmental externalities are small, so the appropriate tax would be small. A few, such as corn-based ethanol and palm oil biodiesel, may have significant emissions of some pollutants, and the damages from these should be added to the price of the resource.

A second tax or subsidy approach to addressing environmental externalities more closely follows the policies in many countries. Rather than putting a price on both fossil fuel and renewable energy generation corresponding to the magnitude of each externality, the same cost differential could be maintained by subsidizing low-emitting resources and not subsidizing (or taxing) high-emitting resources. However, this approach would have the unintended consequence of making energy use less expensive than its actual social cost, because the external costs would remain unpriced. An additional subsidy on energy efficiency investment can correct for the overuse of energy, removing the primary distortion in energy markets. Unfortunately, this may still lead to a distortion through an overinvestment in the subsidized energy-efficient technologies, because the optimal choice may have involved more energy conservation and less investment in energy-efficient technologies.[14] In addition, such a combination of subsidies may lead to further distortions in factor markets, such as markets for the inputs in the production of energy efficiency equipment. Thus the economic theory suggests that the first-best approach to addressing environmental external damages is through taxes or permits, and the subsidy approach outlined above can be considered a second-best approach to be pursued if the first-best approach is not politically feasible.

Other approaches rely on the idea that if firms must clearly disclose their environmental impacts, they will be motivated to reduce those impacts, and consumers will be motivated to shift their purchases away from damaging products and toward those that are environmentally benign. Information programs designed to publicize the environmentally damaging product or transparency rules designed to document and communicate the environmental damages are prompted by this idea. Enterprise software available from companies such as Hara Software[15] have made it possible to document and broadly communicate carbon dioxide and other environmental impacts in a transparent manner.

Policies for National Security Externalities

Each of the policy instruments available for responding to environmental externalities is also available for responding to national security externalities. Again, the first-best policy intervention works by getting prices right. By pricing the external costs imposed by the consumption of the fuel, firm and consumer decisions will take into account the externality, resulting in an economically efficient outcome. In this case, getting the price right inherently involves taking into account the full external effect, such as the externality that one country's spending an extra dollar on defense causes other countries to spend more on defense. With a correct price on the fuel, firms and consumers will substitute other energy resources that do not lead to national security risks, such as coal or renewable energy, or will find ways of reducing energy use.

Just as for environmental externalities, a second approach would be based on maintaining a price differential between fuels with high and low national security external costs. This approach would face the same issues: overuse of fuel with high external costs and overuse of energy in general. Policies to subsidize energy efficiency would help but may come at the cost of distortions through overinvestment in energy efficiency or overconsumption in some factor markets.

Other policy instruments may also improve economic efficiency by reducing consumption of oil, such as product standards (e.g., for fuel economy), but these approaches inherently lead to additional economic distortions and thus are also not a first-best approach. For example, fuel economy standards lower the effective cost per mile of driving and thus induce more driving, a reaction known as the rebound effect. The additional driving may increase the use of oil, reducing the energy security (and environmental) benefits and at the same time increasing the external costs from accidents and congestion.

Policies for Information Market Failures

Information market failures stem from a variety of sources, and some may be very difficult to address. Those that lead to an underinvestment in distributed generation renewable energy by households may be addressed through information programs to raise awareness. Similarly, consumers typically cannot readily obtain information about their instantaneous use of electricity; they normally receive only a monthly bill for their total electricity use. Programs to provide households with feedback on the price and usage of electricity (e.g., "smart" meters or in-home dashboards to display instantaneous energy use) can help consumers make more informed choices relating to use of energy. Both feedback and information programs may also reduce behavioral failures, possibly providing an additional benefit.

For interventions to address imperfect information, such as imperfect foresight for firms, the intervener—presumably a government agency—would have to possess better information. In situations in which a government agency has superior knowledge, such as of future probable energy prices, an obvious intervention is for the agency to share that information. The Energy Information Administration of the U.S. Department of Energy provides exactly such data and projections accessible to anyone. In fact, given the ability for a government agency to share information broadly,[16] and at low cost, it is very unlikely that imperfect foresight about future energy conditions would provide a strong case for other governmental interventions.

In cases when information is particularly difficult to process or a principal-agent issue exists, consumers may be unable to make informed decisions, suggesting that the government can improve economic efficiency by using its superior information-processing ability to make sensible choices. This reasoning underlies appliance energy efficiency standards and may perhaps pertain to distributed generation renewables in limited cases.

If managerial incentives are misaligned because of the imperfect knowledge of stock market investors, accounting and information rules to promote transparency and a clearer flow of information may be warranted. These accounting and information rules are not specific to renewable energy and may also improve economic efficiency in general.

In addition, if the managers of some firms take a short-term perspective and underinvest in renewable energy, then other firms with a longer-term perspective may invest more to take advantage of the long-term profit opportunities. If other firms with a longer-term perspective do not step in, then there may be motivation for public support for R&D, either through public R&D or subsidies for private R&D. This may not be a very likely outcome, but it could occur in the presence of behavioral failures on the part of stock market investors that lead to a systematic bias toward rewarding short-term performance.

Policies for Regulatory Failures

Policy interventions to reduce regulatory failures involve simply changing the regulatory structure to reduce perverse incentives. For example, to improve on average cost pricing of electricity, real-time pricing (RTP) of electricity at the wholesale level could be expanded to the retail level.[17] However, the benefits of RTP or time-of-use (TOU) pricing would have to be weighed against the technology and implementation costs, however.

Policies for Too-High Discount Rates

If the discount rate is too high because of the corporate income tax, then the failure here is a regulatory failure, and the appropriate response would be a tax reform. One tax reform that would alleviate this issue would be to allow for the expensing of capital investments. Other options include accelerated depreciation for investments, tax credits for research and development, or the elimination of the corporate income tax entirely.[18] These issues are not particular to renewable energy development, however, and a deeper examination of tax reform is beyond the scope of this chapter.

If the discount rates are too high because of credit limitations, then the appropriate government response involves macroeconomic policy actions, primarily by the central bank. Both tax reforms and macroeconomic policy actions are economywide policy actions that may affect renewable energy, but they are unlikely to have a disproportionate effect on the renewable energy sector in particular.

Policies for Imperfect Foresight

If the evidence is sufficiently strong that a systematic bias exists as a result of imperfect foresight, this would imply a variety of government interventions designed to provide information about possible future states of the world in order to improve long-term decisionmaking. Government information programs that involve data collection and possibly forecasting reports may help alleviate the systematic bias by improving firms' ability to predict future conditions. Increasing regulatory consistency by governments implementing clear, predictable long-term renewable energy policies could also help improve long-term decisionmaking by firms.

Policies for Economies of Scale

Although economies of scale are not likely to play a significant role for renewable energy in general, it may play a role in specific areas. One approach to address economies of scale would be a temporary direct subsidy sufficient to induce firms to produce at the higher level. Once a sufficiently high level of production is achieved such that the positive competitive equilibrium can be reached, the subsidy can be removed. As indicated above, because in many cases firms can individually overcome problems of economies of scale, it is unlikely that such approaches are in fact needed.

Policies for Market Power

For market power relating to the possibility of firms buying out competing technologies, possibly including renewable energy technologies, enforcement of antitrust laws is likely to be the most effective intervention. In some cases, vertical disintegration may be warranted to ensure a competitive market. Direct government subsidies for private R&D investment, coupled with limitations on the sale of the subsidized company, are another possible alternative to address market power.

For market power motivating utilities to favor their own generation over that from outside suppliers, a feed-in tariff or equivalent policy may increase economic efficiency if the price is set appropriately. The appropriate price would be the wholesale market price for electricity, adjusted for risk and intermittency. Such a price would prevent utilities from favoring their own generation, but it also would prevent any distortions from a price that does not correspond with the market.[19]

As an alternative to a feed-in tariff, regulators can restructure utilities to ensure that they do not favor their own generation over that from outside suppliers. Alternatively, careful oversight of utilities by public utility commissions can also help address market power.

Policies for Intertemporal (Stock-Based) Deviations

Intertemporal deviations are those in which the external costs are based primarily on a stock that changes over time. Individuals influence these stocks only indirectly, by altering the flows into or out of the stock. But once the flow is determined, those individuals have no further control of the stock. For that reason, policy instruments cannot be directed toward the stock but must be directed toward influencing the flow. For economic efficiency, the strength of the incentives must be guided by the intertemporal nature of the stock externality and can be determined from the discounted net present value of the entire flow of future impacts.

Policies for Stock-Based Environmental Externalities: Carbon Dioxide

Carbon dioxide is perhaps the most important stock-based environmental externality, and therefore the following discussion focuses on this pollutant, but a similar result would hold for any stock-based pollutant.

In any given year, a firm can alter the amount of carbon dioxide it releases into the atmosphere, but once the carbon dioxide is released, the firm has no further control. That additional carbon dioxide remains in the atmosphere, increasing the stock of carbon dioxide for the next century. The economically efficient carbon price in any given year (e.g., 2010) can be determined by taking the damages each subsequent year and discounting them back to the chosen year using the social discount rate. In this sense, the optimal carbon price is still the magnitude of the external cost, just as with atemporal environmental externalities.

The calculated optimal carbon price differs by year (e.g., in 2010 compared with 2020) in three ways. First, and most important, the damages are discounted back further at the earlier date, implying that the carbon price is lower at the earlier time.[20] Second, some damages occur during the time between the two dates. Depending on the damage function, this difference may be small (perhaps as it is between 2010 and 2020) and may not change the increase over time of the optimal carbon price. Third, a natural rate of decline of the stock occurs from dissipation of emissions in the atmosphere. This fact would slightly increase the rate of growth of the optimal carbon price.

The magnitude of the damages from carbon dioxide is controversial, and estimates will improve with increased scientific knowledge. Different time patterns of damages would lead to different time patterns of the carbon price, based on the three points discussed above. For example, if the damages from an additional metric ton of carbon dioxide grow (in real terms) at the social discount rate, then the optimal carbon price will also grow (in real terms) at approximately the social discount rate. Under the unlikely assumption that the incremental damages are constant in real terms into the future, we could find a nearly constant (in real terms) economically efficient carbon price.

Policies for Imperfect Capture of Future Payoffs from Current Actions

R&D

When a market failure occurs as a result of R&D spillovers from imperfect property rights in knowledge generation, several possible government interventions might increase economic efficiency. The government could directly subsidize private R&D to bring the private rate of return from R&D closer to the social rate of return, an example of getting the prices right. Such a subsidy would continue as long as a deviation exists between the private and social rate of return, and perhaps indefinitely. The economically efficient subsidy would be set equal to the present discounted value of the spillovers from R&D. Importantly, R&D spillovers are likely to exist in more than just the renewables sector, so an appropriate policy would also provide the subsidy to private R&D in these other sectors.

The government could also directly fund R&D in sectors where spillovers are particularly high. For example, the U.S. government directly funds research in renewable energy in national laboratories, universities, and some research institutes. Theoretically, public R&D can improve economic efficiency if it is focused on research areas where the social rate of return is sufficiently high relative to the private rate of return. In these cases, little R&D would have been undertaken by firms relative to the economically efficient amount, so public R&D complements private R&D. On the other hand, public R&D can crowd out the private, depending on the nature of the R&D. For example, pure science public R&D would be much less likely to crowd out private R&D than would demonstration projects. The empirical evidence on public R&D is not clear-cut. David et al. (2000) review the empirical evidence on whether public R&D complements or crowds out private R&D and find an ambiguous result, suggesting that the result is situation-dependent and underscoring the importance of the nature of the R&D in the social rate of return of public investment.

Intellectual property law plays a key role in how well firms can capture the rents from their innovative activity. Determining the direction in which to change intellectual property law is not simple. If intellectual property law is tightened (e.g., by increasing the length of time patents hold force), then two opposing effects would exist. Firms could capture more of the benefits of R&D and thus would have a greater incentive to invest in it. But fewer spillover benefits may result from the R&D activity, so the social rate of return from the activity would be lower. Little empirical evidence is available to suggest that either a tightening or loosening of intellectual property law would increase economic efficiency.

LBD

If learning by doing occurs in the production of a new technology (e.g., solar photovoltaic installations), then the act of producing increases the firm's stock of cumulative experience and thus leads to declines in future costs. The stock of cumulative experience grows when insights from previous production by that or another firm allows it to improve its production techniques. The stock also may decline if some of these techniques are forgotten. Theories of LBD often proxy all of these complex dynamics by postulating that the cost of future production for *all* firms at any time will be a function of the cumulative stock of experience from production in the market. But the market failure can be thought of in a more general sense as a spillover from the stock of any single firm's cumulative experience from production to other firms.

Once a firm chooses how much to produce at any given time (i.e., the flow into the stock of experience), it subsequently has no further control over the stock of experience and its impact on future costs. Thus economically efficient policies for LBD must focus on the quantity produced, while taking into account the fact that experience is a stock. The most straightforward policy instrument to address LBD spillovers is a subsidy. The economically efficient per-unit subsidy equals the discounted present value of all future cost reductions resulting from the additional production that cannot be captured by the individual firm.

However, a second element to the economic theory behind LBD also may affect the economically efficient policy: the spillovers from LBD are postulated to decline along with the costs. For example, in the standard formulation, as illustrated in Figure 5.2, the percentage cost decrease depends on the percentage increase in the stock, so every additional unit has a progressively decreasing percentage impact on costs. Consequently, as cost decreases with a greater stock, a given percentage cost decrease leads to a smaller absolute cost decrease. These factors together imply that the LBD externality—and hence the appropriate magnitude of the intervention—will be declining over time. Acting in the opposite direction, if the sales are growing rapidly, the cost reduction is applied to a larger amount of production, reducing the rate of decline of the intervention.

Thus optimal subsidies for LBD will likely be transient and decline over time as LBD runs its course. The speed at which the subsidies are phased out will depend on the particular technology and may require adjustment if different conditions arise than were initially expected. In one example, the optimal solar PV subsidies for California calculated under the baseline assumptions in van Benthem et al. (2008) follow a declining path and are phased out over 15 years.

Network externalities

Network externalities may play a role in the adoption of distributed generation renewable energy. If it can be demonstrated that a network externality truly exists, rather than network effects, then one approach to correct for this externality would be a temporary production subsidy (Goolsbee and Klenow 2002). Once a product has taken over (nearly) the entire market, there would be no room for further spillovers and thus no need for the subsidy policy.

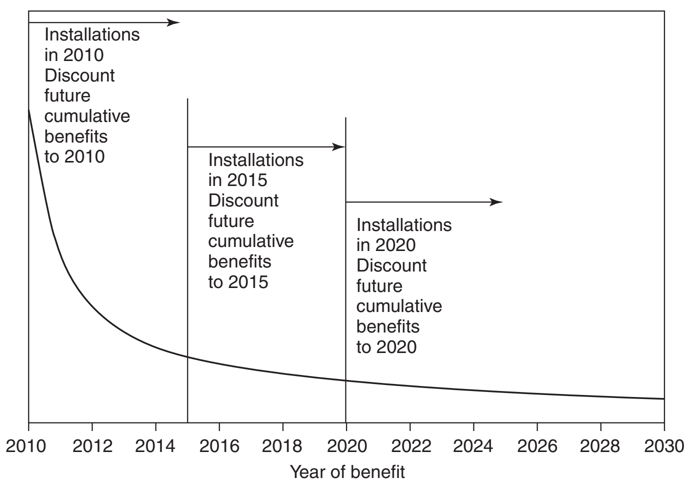

Figure 5.2. Illustrative incremental benefits from additional cumulative installations: LBD

Conclusions

Renewable energy has an immense potential to serve our energy needs, and in the long run, a transition from depletable fossil fuel resources to renewable energy is inevitable. This chapter has delved into reasons why policymakers should be interested in policies to promote renewable energy, pointing to a variety of market failures that may lead to a divergence between the optimal transition to renewables and the observed transition. Economic theory suggests that we can improve economic efficiency by matching the policy instrument to the market failure.

The structure and nature of each market failure have important ramifications for the appropriate policy actions to correct for the market failure and move closer to an optimal transition to renewable energy. The discussion above distinguished between atemporal market failures and intertemporal (i.e., stock-based) market failures. In either case, the economically efficient policy action matches the temporal pattern of the market failure. This implies a temporary policy (e.g., LBD spillovers) in some cases and a permanent policy (e.g., R&D spillovers) in others.

Renewable energy policy is likely to require several different policy instruments to address the various kinds of market failures. When the market failures are closely related, a single policy instrument can address, or partly address, more than one market failure. For instance, provision of information about low-cost or low-effort opportunities to save energy and help preserve the environment may reduce the informational market failure and also influence consumers to partly internalize the environmental externalities (Bennear and Stavins 2007).

For renewable energy, the most important market failures, with the strongest empirical evidence, appear to be environmental externalities, innovation market failures, national security market failures, and regulatory failures. Only a few of the market failures identified in this chapter are unique to renewable energy. Environmental externalities due to fossil-fuel use are the most important of these, but if policy action is already under way to correct for externalities from fossil-fuel emissions, then we must look to other market failures for motivation for renewable energy policy. As these other market failures often apply to other parts of the economy, addressing them may entail policy actions that extend much beyond renewable energy.

Political feasibility is a final consideration with important ramifications for renewable energy policy. In some cases, the first-best policy approach may not be politically feasible. A second-best approach may involve multiple instruments, even in cases when the first-best approach involved only a single instrument. For example, rather than a single tax to internalize environmental externalities, the same price differential can be achieved by combining a smaller tax (or no tax) on fossil fuels with a subsidy for renewable energy. Similarly, a cap-and-trade system may not be politically feasible because of uncertainty about how high the costs of abatement might be, so a more viable option might be to use two instruments in a hybrid cap-and-trade and tax system, commonly known as a cap-and-trade with a safety valve (Jacoby and Ellerman 2004; McKibbin and Wilcoxen 2002; Pizer 2002).

In other cases, the only politically feasible options for addressing the market failures relevant to renewable energy are not the first-choice instruments, but rather second-choice instruments that address the market failures indirectly. Renewable portfolio standards (RPSs) are one of the most prominent examples of a policy instrument that only indirectly addresses the market failures relevant to renewable energy. By setting a requirement on the amount of renewable energy in each utility's electricity generation mix, an RPS adds an implicit subsidy on renewable energy, with the magnitude of the subsidy directly related to the stringency of the cap. If the RPS is carefully set, this implicit subsidy could act just like an appropriately set actual subsidy—leading to the second-best outcome described above. However, finding this appropriate level for an RPS may be exceedingly difficult and subject to intense political disputes.

A sensible set of policies to address the market failures relevant to renewable energy has the potential to greatly improve economic efficiency—and at the same time would have other benefits, such as improving air quality and mitigating the risk of catastrophic global climate change. Much future work remains to better quantify the most relevant market failures and further improve our understanding of how to develop policies to best address these market failures.

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Notes

1. The concept of behavioral failures stems from behavioral economics and is quite new to environmental economics. See Shogren and Taylor (2008) and Gillingham et al. (2009) for recent reviews discussing the concept in the context of environmental economics.
2. Economic theory defines "economically efficient" in technical terms as an allocation of resources where no potential Pareto improvement exists, which refers to a reallocation of resources that benefits at least one individual and imposes no costs on any others. Note that economic efficiency is a distinct concept from the equity or fairness of an allocation of resources.
3. It is still theoretically unclear how to disentangle systematic biases in decisionmaking from inherent preferences, but behavioral welfare analysis is an area of active theoretical development and may eventually shed light on this issue. See, e.g., Bernheim and Rangel (2009).
4. Important equity or fairness concerns may also be involved. This chapter focuses on economic efficiency as a policy goal, while noting that equity considerations, in theory, can often be dealt with through lump-sum transfers of wealth that do not distort incentives or through modifications of the income tax rates. If the policy goal is reducing global inequity, other distributional policies are likely to be more effective than renewable energy policy.
5. It is important to note that unless a behavioral failure is a systematic, rather than random, departure of observed choice from a theoretical optimum, it may be very difficult to formulate policies. If the systematic departure is in a consistent direction, the intervention can work in the opposite direction to correct this deviation. But random deviations would require an intervention contingent on the deviation. For example, poor information about the operating characteristics of distributed photovoltaics could lead some people to install these devices even though they would ultimately come to regret the decision and other people not to install them even though the devices would have turned out to be beneficial. In such circumstances, development and dissemination of information about photovoltaic operating characteristics for alternative locations could improve such decisions. For the most part, however, policy options designed to compensate for random deviations would be difficult to formulate and effectively implement.
6. "Full employment" for a well-functioning developed economy refers here to "at the natural rate of unemployment." Some unemployment will always exist as a result of transitions between jobs and mismatches of available and needed skills.
7. Personal income taxes or labor taxes, such as the U.S. Social Security tax, provide incentives to reduce the supply of labor, so that the marginal social value of labor exceeds the value of that labor to the worker. However, issues of the distortions associated with and the reform of such tax systems go well beyond the scope of this chapter.
8. This remains a concern for the overall economic efficiency of investment, even when it does not distort the mix of renewables versus nonrenewable technologies.
9. "Almost indifferent" because the cumulative impacts of emitting a ton now may be somewhat different from the impacts of emitting a ton in 20 years and because the regulatory environment could change in that period.
10. LBD is closely related to economies of scale, except that learning by doing has a distinctly different intertemporal relationship, where costs decline as a function of cumulative production, and increasing returns to scale implies that average costs decline with production at a given time.

11. If the knowledge leading to cost reductions by one firm could have been used by other firms, but that firm somehow manages to keep all the knowledge private, even if it does not use it (so it is effectively "wasted knowledge"), there would still be a market failure in that some of the potential benefits of the learning would not be captured by anyone.
12. As noted above, this does not deal with the labor market problems associated with income taxes or labor taxes that provide incentives to reduce the supply of labor.
13. A substantial literature addresses the trade-offs between a tax and a cap-and-trade system, particularly relating to policymaking under uncertainty. For a recent review discussing these issues, see Aldy et al. (2009).
14. If behavioral failures have caused an underinvestment in energy efficiency, then there may not be an overinvestment in energy efficiency from the subsidy.
15. Information available at www.hara.com.
16. In some cases, release of information is not possible or is undesirable, such as when it involves weapons programs or other programs closely related to national security.
17. In order to be effective, RTP would have to be complemented with real-time feedback on the electricity price at the current time.
18. Note that reducing taxes in some areas may require increasing taxes in others, so a full analysis should examine the relative distortions from each of the different taxes.
19. For example, in the United States, the Public Utility Regulatory Policies Act (PURPA) of 1978 required electric utilities to buy power from small-scale nonutility producers at the avoided cost rate, which is the cost the utility would incur were it to acquire the electricity from other sources. Choosing the appropriate price turned out to be remarkably problematic.
20. For instance, the 2020 efficient tax would be greater than the 2010 efficient tax by a factor of $(1 + r)^{10}$, where r is the annual social discount rate. At a 5% discount rate, the 2020 carbon tax would be 63% greater than the 2010 carbon tax.

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