ENERGY-EFFICIENT TECHNOLOGIES AND CLIMATE CHANGE POLICIES: ISSUES AND EVIDENCE

Adam B. Jaffe
Richard G. Newell
Robert N. Stavins

Climate Issue Brief No. 19

December 1999

Resources for the Future
1616 P Street, NW
Washington, DC 20036
Telephone 202-328-5000
Fax 202-939-3460
Internet: http://www.rff.org

Climate Issue Briefs are short reports produced as part of RFF’s Climate Economics and Policy Program to provide topical, timely information and analysis to a broad nontechnical audience.

The preparation of these briefs is funded in part by The G. Unger Vetlesen Foundation.

Energy-Efficient Technologies and Climate Change Policies: Issues and Evidence

Adam B. Jaffe, Richard G. Newell, Robert N. Stavins[*]

Introduction

Enhanced energy efficiency occupies a central role in evaluating the efficacy and cost of climate change policies. Ultimately, total greenhouse gas (GHG) emissions are the product of population, economic activity per capita, energy use per unit of economic activity, and the carbon intensity of energy used. Although greenhouse gas emissions can be limited by reducing economic activity, this option obviously has little appeal even to rich countries, let alone poor ones. Much attention has therefore been placed on the role that technological improvements can play in reducing carbon emissions and in lowering the cost of those reductions. In addition, the influence of technological changes on the emission, concentration, and cost of reducing GHGs will tend to overwhelm other factors, especially in the longer term. Understanding the process of technological change is therefore of utmost importance. Nonetheless, the task of measuring, modeling, and ultimately influencing the path of technological development is fraught with complexity and uncertainty—as are the technologies themselves.

The carbon intensity of energy can be reduced by substituting renewable or nuclear sources for fossil fuels (and by substituting lower-carbon natural gas for coal), and through increases in energy efficiency. Recognizing this, recent policy proposals have included tax credits for residential and commercial purchasers of new energy-efficient homes, energy-efficient equipment such as electric and natural gas heat pumps, natural gas water heaters, advanced central air conditioners, and fuel cells, as well as an investment tax credit for industrial combined heat and power systems. Extensions have also been proposed for existing tax credits

---

[*] Adam Jaffe is a professor of economics at Brandeis University; Richard Newell is a fellow at Resources for the Future; and Robert Stavins is the Albert Pratt Professor of Business and Government at the John F. Kennedy School of Government, Harvard University and a university fellow at Resources for the Future.

for fuel-efficient vehicles powered by electricity, fuel cells, and hybrid power. In addition to tax incentives, other proposals include direct spending on research, development, and deployment of energy-efficient products.

Public-private partnerships have also been created or proposed with the aim of developing and deploying energy-efficient technologies for houses (Partnership for Advancing Technology in Housing); appliances (Energy Star Products, Golden Carrot Super Efficient Refrigerator Program); schools (Energy Smart Schools); commercial buildings (Energy Star Buildings, Green Lights); vehicles (Partnership for a New Generation of Vehicles); and industrial processes (Motor Challenge, Climate-Wise). Energy-efficiency standards for many products have been established and in some cases revised since 1988, as shown in Table 1. Many of these policies target technologies that embody a mix of both energy-efficiency improvements as well as decreased carbon intensity (such as credits for natural gas heat pumps).

Although there is little debate over the importance of energy efficiency in limiting GHG emissions, there is intense debate about its cost-effectiveness and about the government policies

Table 1. Effective Dates of Appliance Efficiency Standards, 1988–2001

Technology	**1988**	**1990**	**1992**	**1993**	**1994**	**1995**	**2000**	**2001**
Clothes dryers	X				X			
Clothes washers	X				X			
Dishwashers	X				X			
Refrigerators and freezers		X		X				X
Kitchen ranges and ovens		X						
Room air conditioners		X					X	
Direct heating equipment		X						
Fluorescent lamp ballasts		X						
Water heaters		X						
Pool heaters		X						
Central a.c. and heat pumps			X					
Furnaces—central and small			X					
Furnaces—mobile home		X						
Boilers			X					
Fluorescent lamps—8 ft					X			
Fluorescent lamps—2, 4 ft						X		

Source: Energy Information Administration. 1999. *Analysis of the Climate Change Technology Initiative*. EIA: Washington, DC.

that should be pursued to enhance energy efficiency. At the risk of excessive simplification, we can characterize "technologists" as believing that there are plentiful opportunities for low-cost, or even "negative-cost" improvements in energy efficiency, and that realizing these opportunities will require active intervention in markets for energy-using equipment to help overcome barriers to the use of more efficient technologies. These interventions would guide choices that purchasers would presumably welcome after the fact, although they have difficulty identifying these choices on their own. This view implies that with the appropriate technology and market creation policies, significant GHG reduction can be achieved at very low cost.

Most economists, on the other hand, acknowledge that there are "market barriers" to the penetration of various technologies that enhance energy efficiency, but that only some of these barriers represent real "market failures" that reduce economic efficiency. This view emphasizes that there are tradeoffs between economic efficiency and energy efficiency—it is possible to get more of the latter, but typically only at the cost of less of the former. The economic perspective suggests that GHG reduction is more costly than the technologists argue, and it puts relatively more emphasis on market-based GHG control policies like carbon taxes or tradable carbon permit systems to encourage the least costly means of *carbon efficiency* (not necessarily *energy efficiency*) enhancement available to individual energy users.

In this essay, we first examine what lies behind this dichotomy in perspectives. Ultimately, however, the veracity of different perspectives is an empirical question and reliable empirical evidence on the issues identified above is surprisingly limited. We review the evidence that is available, finding that although energy and technology markets certainly are not perfect (no markets are), the balance of evidence supports the view that there is not as much "free lunch" in energy efficiency as some would suggest. On the other hand, a case can be made for the existence of certain inefficiencies in energy technology markets, thus raising the possibility of some inexpensive GHG control through energy-efficiency enhancement. We conclude with some reflections on the role of appropriate energy efficiency policy in climate change mitigation.

Understanding the "Energy Efficiency Gap"

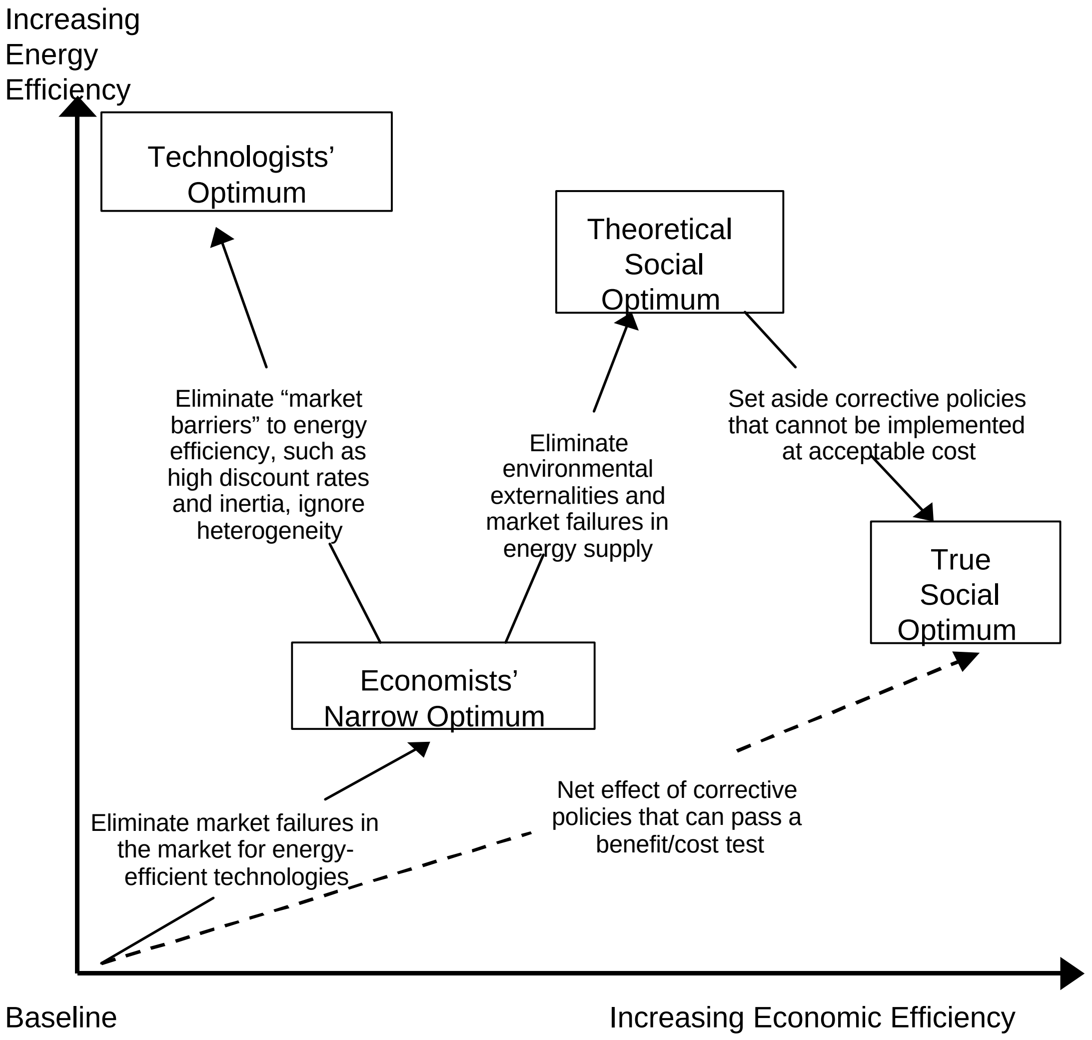
Analysts have pointed out for years that there is an "energy efficiency gap" between the most energy-efficient technologies available at some point in time and those that are actually in use. On this basis, debate has raged about the extent to which there are low-cost or no-cost options for reducing fossil energy use through improved energy efficiency. It turns out that technologists and economists have very different views of this energy efficiency gap and of whether and to what degree it is the result of “market failures” that might be amenable to policy intervention or simply “market barriers” that would be surmountable only at relatively high cost. This debate is illustrated in the *1995 Second Assessment Report of the Intergovernmental Panel on Climate Change*. One part of this report states that energy efficiency improvements on the order of 10 to 30% might be possible at little cost or even with net benefits (ignoring climate benefits), while another part highlights the fact that most economic models indicate a significant cost for stabilizing or cutting OECD emissions below 1990 levels.

The basic dimensions of this debate are the subject of many studies (see the following in Further Readings: Ruderman, Levine, and McMahon; Sutherland; Jaffe and Stavins; Metcalf; and Levine, Koomey, McMahon, and Sanstad). To understand the basic elements of the debate, it is helpful to distinguish first between energy efficiency and economic efficiency, as in Figure 1. The vertical axis measures increased energy efficiency (decreased energy use per unit of economic activity). The horizontal axis measures increased economic efficiency (decreased overall economic cost per unit of economic activity, taking into account energy and other “opportunity costs” of economic goods and services). Different points in the diagram represent the possible energy-using technologies available to the economy as indicated by their energy and economic efficiency.

As a concrete illustration of this distinction, consider two air conditioners that are identical except that one has higher energy efficiency and, as a result, is more costly to manufacture since high-efficiency units require more cooling coils, a larger evaporator, a larger condenser, as well as a research and development effort. Whether it makes sense for an individual consumer to invest in more energy efficiency depends on balancing the value of energy that will be saved against the increased purchase price, which depends on the value of the additional materials and labor that were spent to manufacture the high-efficiency unit. As we discuss below, the value to *society* of saving energy should also include the value of reducing any associated environmental externalities; but again this must be weighed against the costs.

Adoption of more energy-efficient technology is represented in the figure as an upward movement. But not all such movements will also enhance economic efficiency. In some cases it is possible to simultaneously increase energy efficiency and economic efficiency. This will be the case if there are *market failures* that impede the most efficient allocation of society’s energy,

Figure 1. Alternative Notions of the Energy-Efficiency Gap



capital, and knowledge resources in ways that also reduce energy efficiency. These are examples of what economists and others refer to as "win-win" or "no regrets" measures.

In terms of the figure, the economist's notion of a "narrow" optimum is where market failures in the market for energy efficient technologies have been corrected, the result being greater economic efficiency *and* energy efficiency. This optimum is "narrow" in the sense that it focuses solely on energy technology markets and does not consider possible failures in energy supply markets (such as under-priced energy due to subsidies or regulated markets) or, more important, environmental externalities associated with energy use (such as global climate change). When analysts speak of no-cost climate policies based on energy efficiency enhancement, they are often implicitly or explicitly assuming the presence of market failures in energy efficiency. Market failures in the choice of energy efficient technologies could arise from a variety of sources. Some of these are relatively uncontroversial, at least in principle, such as inadequate private sector incentives for research and development and information shortages for purchasers regarding the benefits and costs of adopting technologies. Other potential market failures are more controversial. For example, to what extent is small-scale investment in energy efficiency limited because of financing constraints (a failure of capital markets to efficiently allocate financial resources)? To what extent are there market failures because landlords rather than tenants pay utility bills, and landlords are not adequately rewarded in rental markets for providing energy-efficient dwellings (so-called "principal-agent" problems)? To what extent are businesses not pursuing potentially rewarding energy efficiency investments because managers are not adequately rewarded (and capital markets do not adequately punish such inefficiency)? We discuss some evidence on these questions below.

Eliminating broader market failures takes us to what we call the "theoretical social optimum" in the figure. This represents both increased economic and energy efficiency compared with the economists' narrow optimum. But not all market failures can be eliminated at acceptable costs. In cases where implementation costs outweigh the gains from corrective government intervention, it will be more efficient not to attempt to overcome particular market failures. This takes us from a theoretical social optimum to what we refer to as the "true social optimum" in the figure. Market failures have been eliminated, but only those whose elimination can pass a reasonable benefit-cost test. The result is the highest possible level of economic efficiency, but a level of energy efficiency that is intermediate compared with what would be technologically possible.

In contrast to the economist's perspective, technologists have focused their interest on another notion of an optimum, which typically is based on a very simple "engineering-economic" model. The technologists' optimal energy efficiency is found by minimizing the total purchase and operating costs of an investment, where energy operating costs are discounted at a rate the analyst (not necessarily the purchaser) feels is appropriate.

The problem with this approach is that it does not accurately describe all the factors affecting energy-efficiency investment decisions. First, it typically does not account for changes over time in the savings that purchasers might enjoy from an extra investment in energy efficiency, which depends on trends and uncertainties in the prices of energy and conservation technologies. When making irreversible investments that can be delayed, the presence of this uncertainty can lead to an investment hurdle rate that is larger than the discount rate used by an analyst who ignores this uncertainty. The magnitude of this “option-to-wait” effect depends on project-specific factors, such as the degree of energy price volatility, the degree of uncertainty in the cost of the investment, and how fast the prices of energy and conservation technologies are changing over time. Under conditions characterizing most energy conservation investments, this effect could raise the hurdle rate by up to 10 percentage points. The effect is magnified when energy and technology price uncertainty is increased and when energy prices are rising and technology costs are falling more quickly. On the other hand, if there is no opportunity to wait, this effect can be ignored. For more detail on the relevance of so-called “option values” to energy conservation investments, see Further Readings by Hassett and Metcalf; Metcalf and Rosenthal; and Sanstad, Blumstein, and Stoft.

Second, the magnitude of important variables used in such engineering-economic analysis can vary considerably among purchasers—variables such as the purchaser’s discount rate, the investment lifetime, the price of energy, the purchase price, and other costs. Heterogeneity in these and other factors leads to differences in the expected value that individual purchasers will attach to more energy-efficient or carbon-efficient products. As a result, only purchasers for whom it is especially valuable may purchase a product. For example, it may not make sense for someone who will only rarely use an air conditioner to spend significantly more purchasing an energy-efficient model—they simply may not have adequate opportunity to recoup their investment through energy savings. Analysis based on single estimates for the important factors listed above—unless they are all very conservative—will inevitably lead to an “optimal” level of energy efficiency that is too high for some portion of purchasers. The size of this group, and the magnitude of the resulting inefficiency should they be constrained to choose products that are not right for them, will of course depend on the extent of heterogeneity in the population and the assumptions made by the analyst.

Finally, there is evidence that analysts have substantially *overestimated* the energy savings that higher efficiency levels will bring, partly because projections often are based on highly controlled studies that do not necessarily apply to actual realized savings in a particular situation. For example, studies by Sebold and Fox, Hirst, and others have found that actual savings from utility sponsored programs typically achieve 50 to 80% of predicted savings.

Metcalf and Hassett draw a similar conclusion based on an analysis of residential energy consumption data in which they found that the actual internal rate of return to energy conservation investments in insulation was about 10%, which is substantially below typical engineering estimates that the returns for such investments were 50% or more.

This is not to say that profitable energy-efficiency investments do not exist, but rather that attempts to determine optimal or minimum energy-efficiency levels for particular investments—as is done, for example, during the process of setting minimum energy-efficiency standards—need to account for all costs, not overstate realizable benefits, and use appropriate discount rates.

An important implication of this perspective is that comparisons of an engineering ideal for a particular energy use with average practice for existing technology are inherently misleading, since the former does not incorporate all the real-world factors influencing energy technology decision-making. The overall economic costs of switching to more energy-efficient technology constitute what can be thought of as a *market barrier* to their use, in that individual consumers and producers will not have incentives to use more costly technologies unless policy measures (such as technology standards or carbon taxes) are employed to compel or induce behavioral changes. Unlike market failures, however, market barriers cannot be lowered in a win-win fashion.

Constraining consumers to purchase appliances with a higher level of efficiency based on simplistic analysis will in effect impose extra costs on consumers. The result, as indicated in the figure, is a higher level of energy efficiency, but decreased economic efficiency since consumers are forced to bear costs that they had otherwise avoided. Although it is possible that this may be justified by some larger societal goal to address certain environmental externalities associated with energy consumption, the problem should be approached from that broader perspective, rather than from the narrow perspective of constraining energy-efficiency decisions. Taking this broader perspective leads one to focus more directly on the real problem—climate change associated with CO_2 emissions—rather than constraining available technology options.

Technology Invention, Innovation, Diffusion, and Use

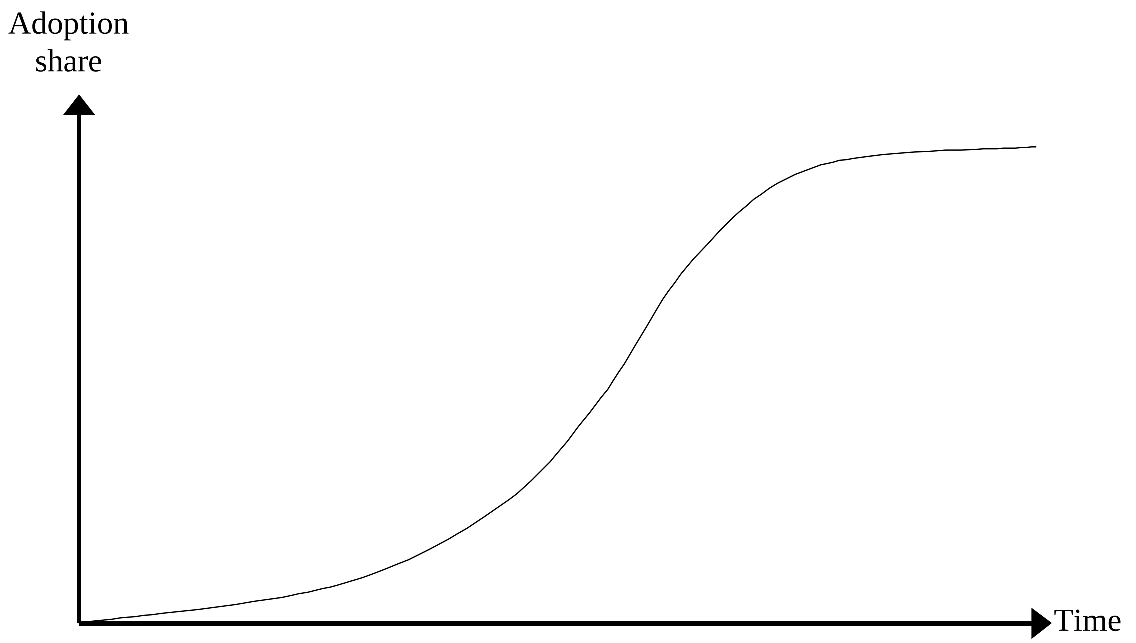
To understand the potential for public policy to affect energy efficiency, we also need to understand the process through which technology evolves: invention, innovation, diffusion, and product use. Policies can affect each stage in specific and different ways. Invention involves the development of a new idea, process, or piece of equipment. This activity takes place inside the laboratory. The second step is the process of technology innovation, in which new processes or products are brought to market. Another way of describing this stage is commercialization. The third step is diffusion, the gradual adoption of new processes or products by firms and individuals, who then also decide how intensively to use new products or processes. From this perspective, we can now think of the energy-efficiency gap discussed earlier as a debate mainly about the gradual diffusion of energy-saving technologies that *seem* to be cost-effective.

Tying this all together, we could, for example, think of a fundamentally new kind of automobile engine being invented. This might be an alternative to the internal combustion engine, such as a system dependent upon fuel cells. The innovation step would be the work carried out by automobile manufacturers or others to commercialize this new engine, that is bring it to market, offer it for sale. The diffusion process, then, would reflect the purchase by firms and individuals of automobiles with this new engine. Finally, the degree of use of these new automobiles will be of great significance to demand for particular types of energy. The reason it is so important to distinguish carefully among these different conceptual steps—invention, innovation, diffusion, and use—is that public policies can be designed to affect various stages and will have very specific and differential effects. Both economic incentives and conventional regulations can be targeted to any of these stages, but with greatly varying likelihood of success.

Diffusion

The s-shaped diffusion path shown in Figure 2 has typically been used to describe the progress of new technologies making their way into the marketplace. The figure portrays how a new technology is adopted at first gradually and then with increasing rapidity, until at some point its saturation in the economy is reached. Some natural questions are: “What generates this typically observed gradual path of diffusion? How can public policy affect it? How might public policy accelerate it?” The explanation for this typical path of diffusion that has most relevance for energy-conservation investments is related to differences in the characteristics of adopters and potential adopters. This includes differences in the type and vintage of their existing equipment, other elements of the cost structure (such as access to and cost of labor, material, and energy) and their access to technical information. Such heterogeneity leads to differences in the expected

Figure 2. The Gradual S-Shaped Path of Technology Diffusion



returns to adoption and, as a result, only potential adopters for whom it is especially profitable will adopt at first. Over time, however, more and more will find it profitable as the cost of the technology falls, its quality improves, information about the technology becomes more widely available, and existing equipment stocks depreciate.

Jaffe and Stavins investigated technology diffusion in the context of energy efficiency by carrying out econometric analyses of the factors affecting the adoption of thermal insulation technologies in new residential construction in the United States between 1979 to 1988. They examined the dynamic effects of energy prices and technology adoption costs on average residential energy-efficiency technologies, that is average “R-values,” in new home construction. The effects of energy prices can be interpreted as suggesting what the likely effects of taxes on energy use would be and the effects of changes in adoption costs can be interpreted as indicating what the effects of technology adoption subsidies would be. They found that the response of mean energy efficiency to energy price changes is positive and significant, both statistically and economically.

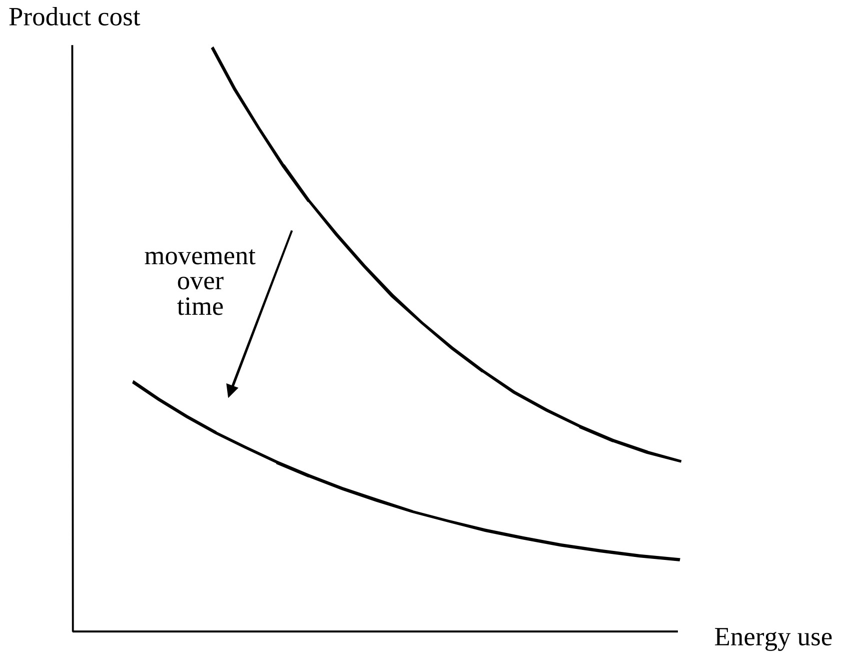
Interestingly, they also found that equivalent percentage cost subsidies would have been about three times as effective as taxes in encouraging adoption, although standard financial analysis would suggest they ought to be about equal in percentage terms. This finding does, however, offer confirmation for the conventional wisdom that technology adoption decisions are much more sensitive to up-front cost considerations than to longer-term operating expenses. In a study of residential conservation investment tax credits, Hassett and Metcalf also found that tax credit or deductions are many times more effective than “equivalent” changes in energy prices—about eight times as effective in their study. They speculate that one reason for this difference is that energy price movements may be perceived as temporary. One downside to efficiency subsidies, however, is that they do not provide incentives to reduce utilization, as do energy price increases. In addition, technology subsidies and tax credits can require large public expenditures per unit of effect since consumers who would have purchased the product even in the absence of the subsidy will still receive it. In a time of fiscal constraints on public spending, this raises questions about the feasibility of subsidies that would be sizable enough to have the desired effect.

Jaffe and Stavins also examined the effects of more conventional command-and-control regulations on technology diffusion, in the form of state building codes. However, they found no discernable effect. It is possible, of course, that stricter codes (that were more often binding relative to typical practice) might have an effect, but this itself ought to remind proponents of conventional regulatory approaches that although energy taxes, for example, will always have some effect, typical command-and-control approaches can actually have little effect if they are set below existing standards of practice.

Innovation and Invention

Now we can move back in the process of technological change from diffusion to innovation. In the energy efficiency area, it is helpful to think of the innovation process as affecting improvements in the characteristics of products (see Further Readings by Newell, Jaffe, and Stavins). In Figure 3, we represent this process as the shifting inward over time of a curve representing the tradeoffs between different product characteristics for the range of products available on the market. On one axis is the cost of the product, and on the other axis is the energy flow associated with a product, that is, its energy intensity. The downward slope of the curves indicates the tradeoff between equipment cost of energy efficiency. Innovation means an inward

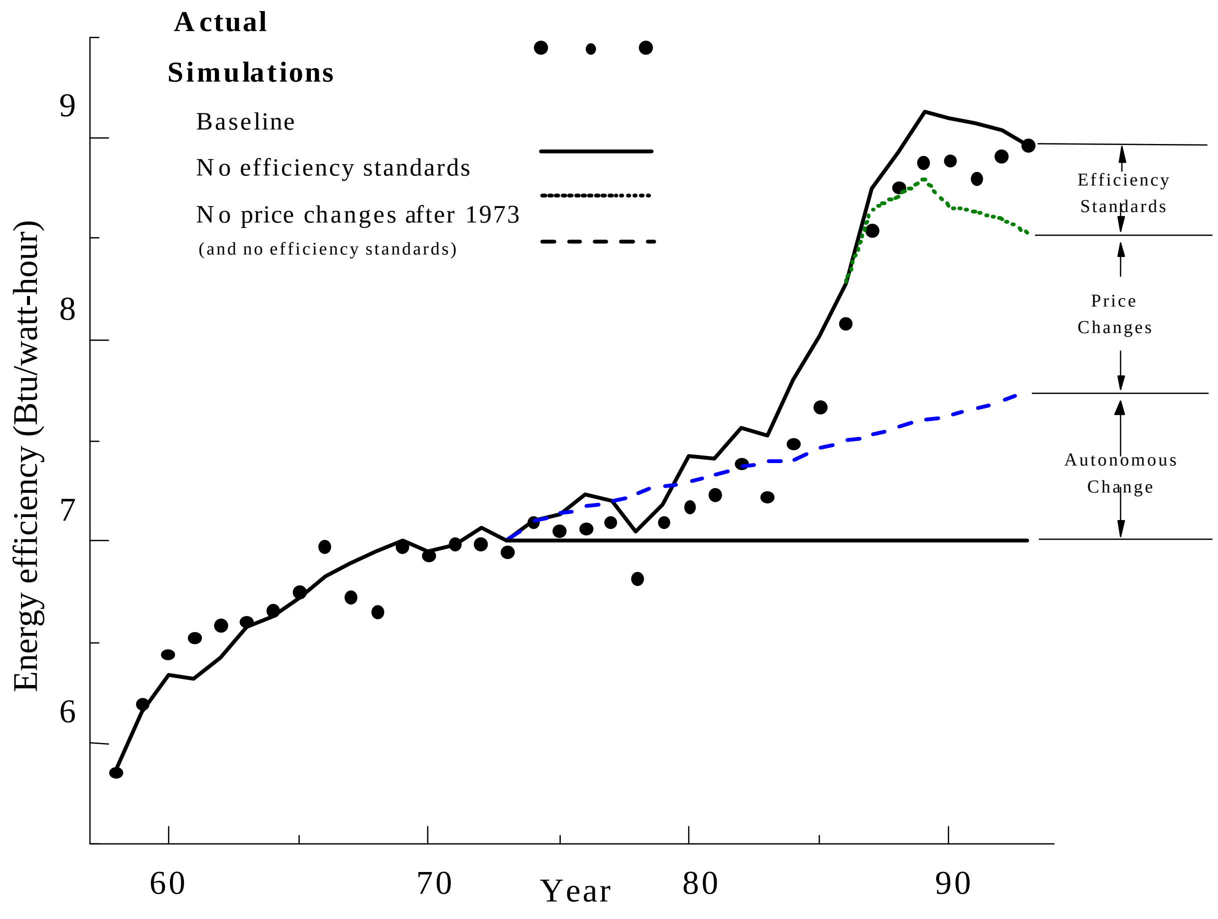
Figure 3. Innovation in Product Characteristics



shift of the curve—greater energy efficiency at the same cost, or lower cost for a given energy efficiency.

Using data from 1960–1990, Newell, Jaffe, and Stavins statistically estimated these characteristic transformation curves for a number of energy-consuming durables. By constructing a series of simulations, we can examine the effects of energy price changes and efficiency standards on average efficiency of the menu of products over time. As can be seen in Figure 4—which illustrates the findings for room air conditioners—a substantial amount of the improvement is what we would describe as autonomous (that is, associated with the passage of time), but significant amounts are because of changes in energy prices and changes in energy-efficiency standards. Energy price changes induced both commercialization of new models and elimination of old models. Regulation, however, works largely through energy-inefficient models being dropped, since that is the intended effect of the energy-efficiency standards (models below a certain energy efficiency may simply not be offered for sale).

Figure 4. Historical Simulations of Energy Efficiency: Room Air Conditioners



Moving back even further in the process of technological change to examine invention, Popp analyzed U.S. patent application data from 19 energy-related technology groups from 1970–1994, finding that the rate of energy-related patent applications was significantly and positively associated with the price of energy. All of these studies suggest that the response of innovation to energy price changes can be surprisingly swift, typically less than five years for much of the response in terms of patenting activity and introduction of new model offerings. Substantial diffusion can take significantly longer depending on the rate of retirement of previously installed equipment. The longevity of much energy-using equipment reinforces the importance of taking a longer-term view toward energy-efficiency improvements—on the order of decades (see box on capital stock turnover).

Technology Diffusion and the Rate of Capital Stock Turnover

Technology diffusion is closely related to the concept of "capital stock turnover," which describes the rate at which old equipment is replaced and augmented by new. New equipment can be purchased either to replace worn out and obsolete units or as a first-time purchase. A primary driver of replacement purchases for durable energy-using goods is the goods useful lifetime. The rate of economic growth is also important, especially for first-time durable goods purchases; the rate of home construction is particularly relevant for residential equipment. The typical lifetimes for a range of energy-using assets are given below, illustrating that the appropriate timeframe for thinking about the diffusion of many energy-intensive goods is on the order of decades.

Type of asset	Typical Service Life (years)
Household appliances	8–12
Automobiles	10–20
Industrial equipment/machinery	10–70
Aircraft	30–40
Electricity generators	50–70
Commercial/industrial buildings	40–80
Residential buildings	60–100

Energy, Technology, and "Market Reform" Policies

Aside from market influences, public policies also can affect the diffusion of more energy-efficient technologies. Policies that raise the cost of energy will induce the diffusion of extant energy-efficient technology as well as the development of new technology. This opens the question of whether additional nonprice policies are needed to promote energy-efficient, "climate-friendly" technology advance and investment. Here the debate mirrors that over the energy-efficiency gap discussed above. Proponents of such policies argue that economic incentives are not adequate to change behavior. They advocate public education and demonstration programs; subsidies for the development and introduction of new technologies; institutional reforms, such as changes in building codes and utility regulations; and technology mandates, such as fuel economy standards for automobiles or use of renewable energy sources for power generation.

No one doubts that such approaches might eventually increase energy efficiency and reduce greenhouse gas emissions. At issue is the cost-effectiveness of such programs. Advocates of technology mandates often argue that the subsequent costs are negligible because the realized energy cost-savings more than offset the initial investment costs. But as we noted earlier, this view ignores a variety of factors that impinge on technology choices. Most economic analysis recognizes that energy use suffers from inefficiencies, but remains skeptical that large no-regret gains exist. Economic analyses also acknowledge a role for government when consumers have inadequate access to information or if existing regulatory institutions are poorly designed. This can include subsidies to basic research and development to compensate for an imperfect patent system; reform of energy sector regulation and reduction of subsidies that encourage uneconomic energy use; and provision of information about new technological opportunities.

Conclusions and Implications for Climate Policy

In this essay we have provided an overview of how to address the question of the appropriate role for government in energy conservation. In doing so, it is essential to decide first on the objective of government policy in this area—economic efficiency or energy efficiency per se. We find that market signals are effective for advancing the diffusion process, whereas minimum standards may not be unless they are "technology forcing." We also find that market signals can have effects on the direction of innovation and invention, promoting increased energy efficiency when energy prices are rising. The bottom line is that technological studies that demonstrate the existence on the laboratory shelf of particular energy-efficiency technologies are a useful first step. But such studies are not sufficient to address important policy questions. It is necessary to examine whether and how specific policies will affect the processes of invention, innovation, diffusion, and intensity of use of products, and how much they will cost.

Although continued research is needed to pin down the precise magnitudes, it seems clear that economic motivations—operating directly through higher energy prices and indirectly through falling costs of technological alternatives due to innovation—are effective in promoting the expanded market penetration and use of more energy-efficient, GHG-reducing technologies. Some policies that support and enhance the effects of market signals, like information provision and support for basic research and development, can be useful. In contrast, there are many more questions about the efficacy of conventional regulatory approaches, at least in developed market economies, where such policies are more likely to produce limited behavior changes or to incur excessive costs. There are good reasons to doubt the existence of a vast pool of cheap energy-reducing opportunities that offer a "free lunch" in reducing GHGs.

Regarding efficiency subsidies and tax credits, we found that although they may provide relatively strong incentives for the marginal purchaser, they can also require large overall public expenditures per unit of effect since consumers who would have purchased the product even in the absence of the subsidy will still receive it. In a time of fiscal constraints on public spending, this raises questions about the feasibility of subsidies that would be sizable enough to have the desired effect. Energy-efficiency improvements can certainly be relevant for climate policy; however, it is also important to remember that primary fuels differ substantially in terms of their greenhouse gas emissions per unit of energy consumed. Policies focused on energy use rather than greenhouse gas emissions run the risk of orienting incentives and efforts in a direction that is not cost-effective. In particular, policies focused on energy efficiency ignore the other important way in which greenhouse gas emissions can be reduced, namely by reducing the carbon content of energy. Economists generally prefer to focus policy instruments directly at the source of a market failure. Policies focused on carbon emissions—such as tradeable carbon permits or carbon fees—will provide incentives for conserving particular fuels in proportion to the fuels' greenhouse gas content. These policies would, for instance, raise the price of oil by a higher percentage than the price of natural gas, thereby targeting incentives for energy-efficiency improvements to oil-fired furnaces relatively more than to gas furnaces. In addition, policies focused on greenhouse gases rather than energy per se, would also provide incentives for the purchase of gas rather than oil-fired furnaces.

There may be market failures other than the environmental externality of global climate change associated with energy-efficiency investments. If the magnitude of these nonenvironmental market failures is large enough and the cost of correcting them small enough to warrant policy intervention, an argument can be made for attacking these other market failures directly. Any attendant reduction in greenhouse gases, can then be viewed as an extra bonus—a "no regrets" policy. This is, in fact, a line of argument often used by proponents of energy efficiency policy in the context of climate change policy discussions. It becomes crucial therefore, to investigate the magnitude of these other market failures—in particular cases—and to assess which policies (if any) would be most cost-effective in addressing them. There is a need to emphasize policies that create clear incentives for changes in energy use and technology by raising the price of GHG emissions, as well as targeting those institutional and other market failures that do represent opportunities for cost-effective improvements in market performance.

Further Readings

General

Geller, Howard and Steven Nadel. 1994. “Market Transformation Strategies to Promote End-Use Efficiency.” In *Annual Review of Energy and the Environment* 19: 301–346, J. M. Hollander, ed. Palo Alto: Annual Reviews Inc.

Hassett, Kevin A. and Gilbert E. Metcalf. 1993. “Energy Conservation Investment: Do Consumers Discount the Future Correctly?” *Energy Policy* 21(6): 710–716.

Hourcade, J. C., et al. 1995. “A Review of Mitigation Cost Studies.” In *Climate Change 1995: Economic and Social Dimensions of Climate Change* (eds. J. P. Bruce et al). 263–366. Cambridge, UK: Cambridge University Press. Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change.

Jaffe, Adam B. and Robert N. Stavins. 1994a. “The Energy-Efficiency Gap: What Does It Mean?” *Energy Policy* 22(1): 804–810.

Levine, Mark D. Jonathon G. Koomey, James E. McMahon, and Alan H. Sanstad. 1995. “Energy Efficiency Policy and Market Failures.” In *Annual Review of Energy and the Environment* 19: 535–555, J. M. Hollander, ed. Palo Alto: Annual Reviews Inc.

Metcalf, Gilbert E. 1994. “Economics and Rational Conservation Policy.” *Energy Policy* 22(10): 819–825.

Metcalf, Gilbert E. and Donald Rosenthal. 1995. “The ‘New’ View of Investment Decisions and Public Policy Analysis: An Application to Green Lights and Cold Refrigerators.” *Journal of Policy Analysis and Management* 14(4): 517–531.

Sutherland, Ronald J. 1991. “Market Barriers to Energy-Efficiency Investments.” *The Energy Journal* 12(3): 15–34.

Technical

Hassett, Kevin A. and Gilbert E. Metcalf. 1995. “Energy Tax Credits and Residential Conservation Investment: Evidence from Panel Data.” *Journal of Public Economics* 57: 201–217.

Hassett, Kevin A. and Gilbert E. Metcalf. 1996. “Can Irreversibility Explain the Slow Diffusion of Energy Saving Technologies?” *Energy Policy* 24(1): 7–8.

Hirst, E. 1986. “Actual Energy Savings After Retrofit: Electrically Heated Homes in the Pacific Northwest.” *Energy* 11: 299–308.

Jaffe, Adam B. and Robert N. Stavins. 1994b. “The Energy Paradox and the Diffusion of Conservation Technology.” *Resource and Energy Economics* 16(2): 91–122.

Jaffe, Adam B. and Robert N. Stavins. 1994c. “Energy-Efficiency Investments and Public Policy.” *The Energy Journal* 15(2): 43–65.

Jaffe, Adam B. and Robert N. Stavins. 1995. “Dynamic Incentives of Environmental Regulations: The Effects of Alternative Policy Instruments on Technology Diffusion.” *Journal of Environmental Economics and Management* 29: S-43–S-63.

Koomey, Jonathan G., Alan H. Sanstad, and Leslie J. Shown. 1996. “Energy-Efficient Lighting: Market Data, Market Imperfections, and Policy Success.” *Contemporary Economic Policy* 14(3): 98–111.

Metcalf, Gilbert E. and Kevin A. Hassett. 1997. “Measuring the Energy Savings from Home Improvement Investments: Evidence from Monthly Billing Data.” *The Review of Economics and Statistics* 81(3): 516–528.

Newell, Richard G. 1997. *Environmental Policy and Technological Change: The Effects of Economic Incentives and Direct Regulation on Energy-Saving Innovation*. Ph.D. thesis, Harvard University, Cambridge, MA.

Newell, Richard G., Adam B. Jaffe and Robert N. Stavins. 1999. “The Induced Innovation Hypothesis and Energy-Saving Technological Change.” *Quarterly Journal of Economics* August: 941–975.

Popp, David. 1999. “Induced Innovation and Energy Prices.” Working Paper. University of Kansas.

Ruderman, Henry, Mark D. Levine, and James McMahon. 1987. “The Behavior of the Market for Energy Efficiency in Residential Appliances Including Heating and Cooling Equipment.” *The Energy Journal* 8(1): 101–124.

Sanstad, Alan H., Carl Blumstein, and Steven E. Stoft. 1995. “How High Are Option Values in Energy-Efficiency Investments?” *Energy Policy* 23(9): 739–743.

Sebold, Frederick D. and Eric W. Fox. 1985. “Realized Savings from Residential Conservation Activity.” *The Energy Journal* 6(2): 73–88.