How Large Is the Cost-Effective Energy Savings Potential in U.S. Buildings?

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There is general agreement that energy use in buildings could be reduced through greater use of cost-effective energy efficient technologies--that is, technologies for which the value of the energy savings, appropriately discounted, exceeds the additional first cost. There is less agreement, however, on *how much* energy use in buildings could be reduced with cost-effective technologies. A study by the National Academies, for example, estimated that 45% of the electricity used in buildings could be saved at a cost lower than that of the electricity displaced; in contrast, a study by the national energy laboratories estimated that total energy use in buildings could be reduced 14% by 2010, relative to a 'business-as-usual' scenario, through the use of cost-effective efficiency. These very different answers to the same question confuse the policy process and obscure the debate about the effective potential of energy efficiency.

Unfortunately (but not surprisingly) there is no simple answer to the question 'how large is the gap?' If one is willing to grant certain assumptions, then one can generate a savings estimate. Greater attention to costs (especially indirect costs), market imperfections, and societal benefits, however, would help to bring some consensus to this important issue. In the absence of a better understanding of these factors, however, the existing evidence does suggest that there is a large opportunity to save energy and money through increases in energy efficiency in buildings, and policy changes to tap this potential could be considered.

Purpose/Introduction

There is general agreement that energy use in buildings could be reduced through greater use of cost-effective energy efficient technologies--that is, technologies for which the value of the energy savings, appropriately discounted, exceeds the additional first cost. There is less agreement, however, on *how much* building energy use could be reduced with cost-effective technologies. A study by the National Academy of Sciences, for example, estimated that 45% of the electricity used buildings could be saved at a cost lower than that of the electricity displaced (National Academies 1991); in contrast, a study by the national energy laboratories estimated that total energy use in buildings could be reduced 14% by 2010, relative to a 'business-as-usual' scenario, through the use of cost-effective efficiency (Carlsmith et al. 1990). These very different answers to the same question confuse the policy process and obscure the debate about the effective potential of energy efficiency.

This paper provides a user's guide to these and other widely varying estimates. The intent is not to provide the 'true' savings potential, because as will be shown the 'truth' is a function of one's assumptions as to market penetration rates, discount rates, naturally occurring change, and other factors. Rather, this paper describes and contrasts the various estimates, and attempts to show how and why they differ. The intent is to provide readers with sufficient knowledge to make informed choices as to which models and which results best serve their needs. Moreover a better understanding of these differences will help to pinpoint key areas of uncertainty needing further work.

Introduction to Forecasts

From a national policy perspective, forecasts of future energy demand can provide an analytical basis for policy decisions. For example, if forecasts of building energy use in the year 2015 show that most cost-effective opportunities for efficiency will have been taken due to market forces, then there may be little reason for policy change (such as extending minimum efficiency standards to commercial HVAC equipment). However, if forecasts for 2015 suggest a large gap between projected 'business-as-usual' consumption and consumption if economically justified technologies were implemented, then policy change may be needed to correct any 'market imperfections' leading to this gap. As a second example, if forecasts of building energy use in 2015 show that most new, highly efficient technologies have achieved high market penetration, then one might conclude that further efficiency gains would require increased R&D investments. Conversely, if forecasts show underutilization of available energy-efficient technologies, then policy attention to implementation, rather than just R&D, may be appropriate.

This paper covers forecasts of the *cost-effective energy savings potential in buildings*. Several attempts have been made to measure the gap between future energy use expected if current trends continue, and future energy use if greater use were made of 'cost-effective' technologies and practices. As discussed above, the existence of such a gap has important policy implications, as it may suggest that the market has imperfections that could be addressed by policy change. This paper focuses specifically on efforts to measure (or refute the existence of) this gap.

Bottom-Up or Top-Down?

There are two distinct approaches to modeling the potential of energy efficiency: 'bottom-up', also called technological costing; and 'top-down', also called economic modeling. Bottom-up models, which are the focus of this paper, start at the level of individual technologies and end-uses. For example, for residential space heating a bottom-up model begins with data on existing in-place technologies. The capital costs and energy savings of alternative technologies are then considered, and existing technologies are replaced over time with 'cost-effective' alternative technologies (the definition of cost-effective varies by model). Assumptions are made for technological change, fuel and technology switching (for example, the replacement of oil furnaces with gas furnaces), implementation rates of cost-effective technologies, and other factors.

Top-down models take an entirely different approach to energy efficiency modeling. These models typically integrate supply and demand considerations, and consider the relationship between energy and the economy as a whole. An example of such an approach is the Global 2100 model (Manne and Richels 1990). This is an economic simulation model, in which savings and investment decisions are made so as to maximize the discounted utility of consumption.[2] Three demand parameters (GNP growth, the elasticity of price-induced substitution between capital-labor and energy, and the autonomous [non price-induced] energy efficiency improvement rate) are key inputs to the model. This model has been used to estimate the costs of reducing CO_2 emissions through carbon taxes. In this model, energy efficiency improvements can be either price-induced (i.e., from a carbon-tax-induced energy price increase) or through the autonomous energy efficiency improvement (AEEI), which is intended to capture the effects of technological change and non-tax policy change.[3]

Each of these approaches has advantages and disadvantages. In bottom-up models, assumptions as to technology costs and performance are explicit inputs to the model, and therefore can be examined and modified as needed. These models are generally simple in structure, making it relatively easy to understand, critique, and improve the models. The technological assumptions are generally based on actual or predicted technical performance. This approach is especially useful in projecting the impacts of new technologies.

Bottom-up models also have several weaknesses. Perhaps most importantly, bottom-up models typically assume that direct technical costs are actual total costs. For example, the cost of a more efficient technology is assumed to be the incremental purchase cost--which ignores the time costs of locating and specifying this alternative, any additional installation costs, or the costs to manufacturers of retooling production lines. In addition, these models must account for interactions among end-uses (for example, the reduction in cooling load and the increase in heating load resulting from a lighting retrofit), although measured data on these interactions are scarce.

Bottom-up models do not easily incorporate behavior--for example, in these models the adoption of cost-effective technologies is usually set at a somewhat arbitrary penetration rate, for which there is often little empirical evidence. Price elasticity of demand (the possibility that consumers use a device more if it costs less to use), also known as 'takeback' or 'rebound', is often not well accounted for. These models consider only direct costs and energy savings and do not account for the many other factors (such as availability, differences in performance, or perceived risk) that influence consumer choice.

Bottom-up models typically do not capture supply-demand interactions--for example, a large increase in the use of energy-efficient technologies could lead to a significant drop in electricity demand, forcing utilities to raise prices to cover fixed investment costs. Instead these models require future energy prices as inputs. Finally, bottom-up models often cannot directly model the effects of policies, but must indirectly model policies through their effects on energy prices, penetration rates, or technical costs and/or performance.

Top-down models also have strengths and weaknesses. They are often historically calibrated, suggesting that they may be picking up many of the complex relationships between energy use, technological change, and price. However since they are based on historically observed relationships, they are less suited for analysis of new technologies--that is, technologies for which there is not a historical precedent. They often implicitly assume energy markets are well-behaved and do not explicitly account for existing regulatory structures, imperfect information, transaction costs, and the monopolistic structure of the electricity supply market. Therefore they are useful for modeling the effects of taxes, but are less able to model other policy options such as changes in utility regulation, appliance standards, or changes in R&D spending.[4]

For this discussion, perhaps the most important characteristic of top-down models is that they often assume (or imply) that cost-effective actions are already being taken. In these models, consumers are modeled to make choices so as to maximize individual utility, and in practice this is often translated to cost-minimizing behavior. Therefore there is no 'cost-effective gap', because if it were cost-effective to the consumer then it would already have happened.

Comparisons of the two approaches raise interesting questions as to the functioning of the market for energy efficiency, the existence of market imperfections, and the meaning of energy efficiency. Discussions of this issue frequently come down to basic ideological and philosophical beliefs about economics, and are therefore not treated in depth here (readers interested in this debate are referred elsewhere. See e.g. National Academies 1991 chapter 2, Montgomery 1991, and Williams 1990).

Neither approach is particularly adept at addressing the issue of social costs and environmental externalities. Bottom-up models can consider the cost-effectiveness of technologies at both private and social prices, but requires these prices as inputs. Top-down models can simulate the effects of changes in prices (for example, the effects of increasing prices to reflect environmental externalities), but again require these prices as inputs.

This paper focuses on bottom-up models as they directly address the question of the 'cost-effective gap' as we have phrased it,[5] however readers should recognize that for top-down models the answer to the question 'how large is the cost-effective efficiency gap' is often zero by definition.

The Forecasts--Description and Analysis

There have been many attempts to forecast the cost-effective savings potential in buildings. We present six such efforts (in chronological order) in some detail, and briefly summarize several others.[6]

The National Energy Research Laboratories

In 1989, five national energy laboratories (Oak Ridge National Laboratory, Argonne National Laboratory, Lawrence Berkeley Laboratory, Pacific Northwest Laboratories, and the Idaho National Engineering Laboratory) examined the potential for cost-effective energy savings in the United States. This study (Carlsmith et al. 1990, hereafter 'Labs') estimates residential and commercial energy consumption at 39.2 Quads (primary) in 2010 in the business as usual scenario, and at 33.8 Quads (primary) in 2010 in the cost-effective scenario; in other words, a 14% cost-effective savings potential by 2010 relative to the business-as-usual scenario. This study, like several others discussed below, uses a cost of conserved energy (CCE) criterion to determine cost-effectiveness. (The cost of conserved energy is defined as the incremental first cost multiplied by the appropriate capital recovery factor, divided by the incremental annual energy savings in physical units.) In this study measures with a CCE lower than that of the fuel they displace, using a real discount rate of 7%, are deemed cost-effective. The largest opportunities for energy savings are found in food refrigeration and adjustable-speed fan motors.

The Labs savings estimate of 14% is considerably lower than those of several other studies discussed below, which probably stems from several features of the Labs analysis. First, the study does not allow for energy savings due to improved lighting in either sector (Carlsmith et al. 1990, p.16). Lighting accounts for about 7% of U.S. residential energy use and 28% of commercial sector energy use, and there is convincing evidence that the potential for cost-effective savings in this end-use is significant (U.S. Congress 1992, p.50-57, also Piette et al. 1989). Second, the Labs study does not allow for residential retrofits in units constructed after 1980 (Carlsmith et al. 1990, p.17), although there may be opportunities for shell improvements in these residences. Third, the Labs study appears to be somewhat conservative in its assumptions of appliance efficiency. For example, the study projects new room air conditioner efficiency in 2000 at 9.3 (EER) in the cost-effective scenario (Carlsmith et al. 1990, p.66); however the national energy efficiency standard effective 1990 already requires a minimum efficiency of 9.0 (U.S. Congress 1992, p.112).

The Energy Information Administration

In 1990 the Energy Information Administration[7] published an assessment of the conservation potential in all end-use sectors of the United States (U.S. Department of Energy 1990, hereafter 'EIA'). This study, conducted in support of the Administration's National Energy Strategy, estimates three future consumption levels: 'reference (business-as-usual)', 'high conservation', and 'very high conservation'.

For the buildings sector, this study estimates that energy use in 2010 would be 20.4 Quads (site) in the reference case, 17.7 Quads (site) in the high conservation case, and 15.2 Quads (site) in the very high conservation case (U.S. Department of Energy 1990, p.29). The high conservation case assumes 'gradually increasing market penetration of cost-effective technologies', where cost-effective is defined as positive net present value (U.S. Department of Energy 1990, p.31).[8] The very high conservation case assumes full implementation of state-of-the-art technology (U.S. Department of Energy 1990, p.62) and is not limited by cost-effectiveness.[9]

Therefore the cost-effective savings estimate in the 'high conservation' case is 13% by 2010, relative to reference (business-as-usual) consumption. This estimate is at the low end of the range of cost-effective savings found in other studies, which is probably due to several reasons. First, the EIA study uses site, rather than primary, electricity conversion ratios; this would tend to reduce the estimated savings from improved electricity-using technologies. Second, the reference case assumes that 'building features and energy-using equipment will be chosen on the basis of life-cycle cost considerations (U.S. Department of Energy 1990, p.56).' Others have argued that energy-using equipment investment decisions are not made on a life-cycle cost basis due to capital constraints, poor information, mixed incentives (as in rented or leased space), and other reasons (U.S. Congress 1992). The EIA study, therefore, may be allowing for more efficiency in the reference case than is likely. This would lead to a low savings estimate in the high conservation case, relative to the reference case.

The National Energy Strategy

In February 1991 the Administration released its version of an energy future for the United States, called the National Energy Strategy (NES). The NES was supported in part by a modeling effort, which included an analysis of the buildings sector. The specific model used was a dynamic simulation model known as Fossil2. The existing documentation to the NES modeling describes two scenarios: a 'business-as-usual' baseline, and a NES scenario (U.S. Department of Energy May 1991). The NES scenario incorporates a number of demand- and supply-side options, including oil exploration in the Alaska National Wildlife Refuge (ANWR), licensing reform for nuclear power, and enhanced R&D. These options are modeled together, making it impossible to determine the incremental effects of the demand-side options alone (Fossil2 is an integrated demand-supply model, and supply-side options affect energy prices and therefore consumption in buildings). In other words, there is no 'cost-effective' efficiency-only scenario in the existing documentation to the NES.

The Fossil2 model shares characteristics of both top-down and bottom-up models, making it somewhat different from the other models discussed in this paper.[10] As far as consumer behavior, however, the Fossil2 model is clear: 'consumers choose the combination of fuels and end-use technologies that can provide services with minimum life-cycle costs (U.S. Department of Energy May 1991, p.D-5).' Therefore one could argue that there is no cost-effective gap in this model, since the model assumes consumers already take all cost-effective actions. On the other hand, Fossil2 does assume consumers use high discount rates--a hurdle rate of 60% for commercial lighting, for example (U.S. Department of Energy May 1991, p.A-7). In theory the Fossil2 model could be re-run with a lower discount rate (7%, for example), with the difference between the two runs providing a measure of the 'cost-effective gap'. However since the results of such an exercise were not provided in the existing documentation to the NES, there is no direct estimate of the cost-effective gap.[11]

The National Academies

The National Academies' study was driven primarily by concerns over climate change. (The National Academies are the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine). The HUD-Independent Agencies Appropriations Act of 1988 called for the Academies to examine the scientific consensus on the rate and magnitude of climate change, the projected impacts of such change, and policy options for both mitigation and adaptation.

The Academies study was conducted by four panels: mitigation, effects, adaptation, and synthesis. The mitigation panel considered several ways to mitigate climate change, such as reducing the emissions of greenhouse gases, reforestation, and altering the Earth's albedo to reflect more solar radiation back into space. Options to reduce emissions in several sectors were considered, including those for the residential and commercial sectors.

The Academies mitigation study (National Academies 1991) estimates that 45% of electricity and 50% of natural gas could be saved in existing buildings at a net financial savings, using a 6% real discount rate (National Academies 1991, table 3.7). All retrofits with a cost of conserved energy (CCE) below that of the energy displaced--7.5 cents/kWh for electricity and $5.63/MBtu for natural gas--are considered cost-effective (National Academies 1991, table 3.7). In estimating this savings potential, the mitigation panel assumed 100% overnight implementation of the efficiency options. Under these conditions, more than half of the electricity savings potential is estimated at a CCE of 2.5 cents/kWh or less.

As determined by a sensitivity analysis, the electricity savings potential of 45% is achievable at social discount rates of 3%, 6%, and 10%. However, applying a 30% discount rate lowers the electricity savings potential to 30%. The purpose of applying this higher discount rate was to estimate the potential savings based on rates of return that consumers expect, based on empirical estimates of consumer discount rates, for efficiency investments. In addition, the Academies estimated the effects of varying implementation levels (25%, 50%, and 100%) of the cost-effective measures; these results are expressed in carbon (not energy) terms, and they suggest that carbon reductions would occur at virtually the same levels as the implementation levels.

The Academies study has several features that may limit its use as a policy tool. First, the study assumes 100% overnight penetration of all cost-effective technologies. This is clearly not a realistic assumption. Second, some unspecified fraction of the savings estimated by the Academies will happen by themselves (that is, without policy change), therefore one cannot use the Academies results alone to argue that policy change is needed. For example, the 45% electricity savings estimate includes some savings expected from national appliance standards already established. Finally, the Academies model does not account for administrative and implementation costs. Technologies are deemed cost-effective if they cost less than the energy they replace, but the associated non-hardware costs of implementing the technologies are not estimated.

America's Energy Choices

In 1991 several national organizations, including the Alliance to Save Energy, the American Council for an Energy-Efficient Economy (ACEEE), the Natural Resources Defense Council (NRDC), and the Union of Concerned Scientists (UCS), released a comprehensive energy plan for the United States. This study, entitled America's Energy Choices (America's Energy Choices 1991, 1992, hereafter 'Choices'), emphasizes efficiency, renewables, and a movement away from fossil fuels. The Choices study considers several scenarios of future energy use, including a Reference (business-as-usual) case and a Market scenario assuming increased penetration of cost-effective technologies. The study is based on a comprehensive bottoms-up modeling effort. All end-use sectors are modeled. Results for residential and commercial consumption under the two scenarios in the year 2010 are 38.3 Quads (primary) in the Reference scenario and 27.5 Quads (primary) in the Market scenario, for a relative savings of 28% (America's Energy Choices 1992, pp. G-4, G-6).

The largest savings in the residential sector are found for space heating and for miscellaneous appliances, and for the commercial sector the greatest savings are in office buildings. The Choices study, similar to the Academies study, defines cost-effective in terms of the cost of saved energy (CSE). If the CSE (using a 3% real discount rate) of an efficient technology is less than the long-term cost of supplying the energy it saves, then it is deemed cost-effective.

The Choices study incorporates several factors, such as penetration rates and environmental externalities, which are admittedly important but for which there is little agreement as to their values. This is both a strength and a weakness. For example, in the market scenario it is assumed that 70% of all cost-effective residential building retrofits occur by 2010. This penetration rate is more realistic than the 100% penetration rates assumed in the Academies model. Therefore the Choices model savings estimates could be seen as achievable, in contrast to the Academies model estimates, which are better seen as a useful but probably unachievable end-point. On the other hand, the penetration rates assumed in the Choices study are, as the study makes clear, estimates for which there is little documentation. Similarly, in other scenarios the study uses a modified 'revealed preferences' methodology to set values for environmental externalities,[12] although there is considerable disagreement over whether this is the best methodology and over whose preferences should be revealed.

Finally, the Choices study attempts to incorporate program and administrative costs by adding 10% to the costs of all measures (*America's Energy Choices* 1992, p.A-2). This is an advantage in that these costs are surely non-zero, however documentation as to their actual value is limited. One analysis suggests that 10% is probably on the low side (Berry 1989, p.v).

The Congressional Office of Technology Assessment

In response to requests from several committees of the U.S. Congress, the Congressional Office of Technology Assessment (OTA) examined technologies and policies to increase energy efficiency in buildings (U.S. Congress 1992). As part of that effort OTA estimated that, in the absence of policy change, building energy use (that is, for the residential and commercial sectors combined) will reach 41.5 quads (primary) by 2015. OTA estimates that if all technologies with a positive net present value to the consumer (using a 7 percent real discount rate) were implemented, then building energy use would actually decrease in the future, to a level of 27.7 quads (primary) by 2015. This translates to a savings of 33%, relative to the business-as-usual scenario. Areas for major savings include shell improvements in residential buildings and commercial lighting.

A principal weakness of the OTA savings estimate is that, in the savings potential scenario, *all* actions with a positive net present value are implemented. Building retrofits are phased in over time starting in 1995, and equipment is typically replaced when it fails with cost-effective energy efficient equipment. Nevertheless it is probably not realistic to expect that this level of implementation can actually be achieved. Furthermore the OTA model has no explicit allowance for implementation, information, or transactions costs. For these reasons the OTA savings estimate should be seen as a useful end-point rather than an achievable level.

Other Studies

There are many additional studies that deserve mention, but that for one reason or another cannot be directly compared to those discussed above.

Several studies examine only one fuel, one sector, or a limited geographical area. Examples include an analysis of the potential for electricity savings in the residential sector in Michigan (Krause et al. 1988), in the residential electricity sector in the U.S. (Koomey et al. 1991), and in the residential, commercial, and industrial sectors in New York state (ACEEE 1989). All show a considerable potential for cost-effective savings, based on cost of conserved energy (CCE) calculations.

A study by the Electric Power Research Institute (EPRI) in 1990 estimated the electricity savings that would result from greater use of energy efficient electric end-use technologies (Barakat and Chamberlin 1990). This study did not consider cost-effectiveness, but rather estimates future consumption if the entire stock of electric end-use equipment were replaced with the most efficient commercially available equipment. EPRI estimates that, relative to a business-as-usual scenario, electricity savings of 27% to 46% in the residential sector, and 23% to 49% in the commercial sector, would result from greater use of efficient technologies (Barakat and Chamberlin 1990, p.3). The range reflects differing assumptions as to physical applicability and manufacturer production capabilities.

Discussion

The studies discussed above use varying assumptions and methods to address or estimate the extent of a cost-effective gap in building energy efficiency. (Five of the six studies discussed in detail are summarized in Table 1. The NES is not included in the table because it did not identify a cost-effective savings potential). Several studies do not address the question in the way we have conceived it. The EPRI study, for example, does not incorporate cost-effectiveness concerns but estimates energy consumption if all commercially available technologies, cost-effective or not, are implemented. The study by the National Academies does not account for naturally occurring efficiency improvements (that is, those expected from existing policies and incentives), and therefore does not distinguish between what will be and what could be. The National Energy Strategy study documentation does not provide data on the energy savings resulting from increases in building efficiency, but rather that resulting from a long list of demand- and supply-side measures.

Several studies do address the question of a cost-effective gap relative to a business-as-usual projection, but can be criticized based on their assumptions. The study by the National Laboratories does not allow for improvements in lighting efficiency, retrofits in residences constructed after 1980, nor large gains in the efficiency of some appliances, suggesting that their savings estimates are low. The EIA study assumes life-cycle cost-minimizing behavior in the reference case, leaving little room for cost-effective savings in the 'high conservation' case.

The OTA and Choices studies also suffer from shortcomings. The OTA study assumes 100% market penetration of cost-effective measures and does not account for administrative costs, both of which lead to over-estimation of the cost-effective savings potential. The Choices study

Table 1. Characteristics of Selected Models--Summary

Study:	LABS	EIA	NAS(3)	Choices	OTA
ASSUMPTIONS					
Definition of Cost-Effective	CCE below fuel costs	Positive NPV	CCE equal to or below fuel costs	CSE below cost of supply	Positive NPV
Penetration Rates	N/A	100%(2)	100% (immediate)	Variable(4)	100% by 2015
Discount Rate	7% real	7%	6% real	3% real	7% real
RESULTS					
Baseline					
Year	2010	2010	1989	2010	2015
Amount	39.2 quads (primary)	20.4 quads (site)	1627 BkWh	38.3 quads (primary)	41.5 quads (primary)
'Cost-Effective'					
Year	2010	2010	1989	2010	2015
Amount	33.8 quads (primary)	17.7 quads (site)	893 BkWh	27.5 quads (primary)	27.7 quads (primary)
% Savings	14(1)	13	45	28	33

KEY: BkWh = billion kilowatthours; CCE = cost of conserved energy; CSE = cost of saved energy; N/A = not available; NPV = net present value

(1) Due to modeling constraints, the Labs savings estimate excludes lighting savings, shows limited appliance improvements, and assumes no retrofits occur in post-1980 residences.

(2) The EIA 'High Conservation' (cost-effective) scenario assumes that, starting in 1992, all new appliances and equipment are replaced at historical turnover rates and achieve a positive net present value (using 7% discount rate); there is no premature scrappage. With the exception of advanced gas furnace technologies, the EIA analysis also suggests that all of the adopted technologies remain cost-effective at a discount rate of 10%.

(3) The 100% penetration rate assumed in the NAS study is immediate (i.e., overnight). The 45% savings represent electricity only. Also, estimated energy savings in buildings for natural gas and oil are 50% (an estimated potential savings of 5.2 quads from the 10.4 quads of these fuels used in 1989).

(4) The variable technological penetration rates of the 'Market' (cost-effective) scenario in the Choices model are the following: 50% in both new and existing commercial buildings, 59% in new residential buildings, and 70% in existing residential buildings.

attempts to adjust for these factors but data about them are scarce; as a result, the Choices assumptions for these factors can be seen as educated guesses rather than empirical estimates.

Clearly several important areas need further attention before there will be general agreement on the cost-effective savings potential. The most important is in the area of costs. Implementing energy efficiency usually does have first costs beyond the incremental hardware cost of the efficient device over the standard unit. These costs potentially include information costs of finding out about an efficient device or practice, time costs of requesting that a contractor install the efficient unit instead of the standard unit, or the costs of the rebate program needed to motivate consumers to ask dealers for highly efficient refrigerators. A better understanding of these indirect costs (administrative, information, time, implementation, and so on), based perhaps on the growing knowledge of demand-side management costs, would be beneficial.

A second area needing further attention is market imperfections. Capital constraints, mixed incentives (as in rental housing), high consumer discount rates, poor information, and other issues are commonly acknowledged, yet there is little evidence as to their relative importance or how they affect energy decisions. Stronger empirical evidence on market imperfections--what they are, how much they affect efficiency levels, and what it would cost to overcome them--would shed considerable light on the question of a cost-effective gap.[13]

An improved understanding of costs and market imperfections would help to bring bottom-up and top-down approaches together as well. As noted above, top-down models generally *assume*, rather than demonstrate, that there is no gap. Bottom-up models, on the other hand, equate direct costs with total costs. Neither assumption is ideal. There are market imperfections--such as imperfect information, capital constraints, and imperfect pricing--that can lead to consumers making sub-optimal choices. There are also implementation and information costs in addition to direct technical costs, and inclusion of these costs will affect calculations of cost-effectiveness.

A third area needing further study is societal benefits. This paper has focused on the costs of increased efficiency, yet the other side of the cost-benefit discussion deserves attention as well. Decreased environmental damage, reduced oil import dependence, increased economic competitiveness, and other benefits of efficiency are often mentioned yet rarely measured or clearly defined.

Conclusions

So is there a gap, and if so how large is it? Unfortunately (but not surprisingly) there is no simple answer. Table 1 summarizes the assumptions and results of the models. If one is willing to grant certain assumptions, then one can generate a savings estimate. Unfortunately, in our opinion, the studies discussed here do not provide a final answer to this question. Greater attention to costs (especially indirect costs), market imperfections, and societal benefits, however, would help to bring some consensus to this important issue.

However policy decisions cannot always wait for perfect understanding. As noted in table 1, savings estimates (defined as percent savings in the cost-effective case, relative to projected consumption) range from 13% to 45%. As discussed in the text, there is evidence suggesting that the low estimates (13% and 14%) may be underestimates and the high estimate (45%) may be an overestimate. Not surprisingly given our affiliation, we find the OTA estimate of 33% to be more reasonable than the very high and low estimates, as long as one recognizes that it assumes full implementation of all technologies that have a positive net present value at a 7% real discount rate, and does not incorporate indirect costs, the cost of overcoming market imperfections, or societal benefits. Incorporation of indirect costs and market imperfections (and the costs of overcoming them) would decrease the savings estimate, while incorporation of societal benefits would increase it. The net effect is unclear--but in the absence of a better understanding of these factors, the existing evidence does suggest that there may be a large opportunity to save energy and money through increases in energy efficiency in buildings, and policy changes to tap this potential could be considered.

Endnotes

1. The opinions expressed in this paper are those of the authors and do not necessarily reflect those of the Office of Technology Assessment, the United States Congress, or the United States Government.

2. Utility is used here in the economic sense, i.e., the value attached to a good or set of goods.

3. The AEEI can be defined as 'the postulated rate of increase in aggregate economic output per unit of total primary energy consumption beyond that induced by changes in energy prices' (Perry 1990, p.65). The Global 2100 initially assumes an AEEI of 0, but then analyzes a 'high efficiency' case of 1.0 percent per year (Manne and Richels 1990, p.51). Some argue that this is unnecessarily pessimistic, and that higher rates are feasible (Williams 1990).

4. One reviewer accurately noted that top-down models are often straight forecasting models that do not have a normative component. Our point here is that top-down models usually do not allow for exogenous changes in regulation, information, and so on; and therefore are of limited use in examining policy options related to these factors.

5. We do however include one model, Fossil2 for the National Energy Strategy, which shares characteristics of both top-down and bottom-up models.

6. Wherever possible we use primary energy units (that is, energy units which reflect losses associated with electricity production), however in some cases we were unable to determine the fraction of total consumption due to electricity and therefore use site energy units instead.

7. The Energy Information Administration (EIA) is an independent statistical and analytical agency within the U.S. Department of Energy (DOE).

8. A 7 percent discount rate was used for the residential sector analysis; it is not clear from the documentation if this discount rate was used for the commercial sector as well.

9. This is not to say that technologies used in the 'very high' case are not cost-effective; only that the model did not consider or assess their cost-effectiveness.

10. This model was included in this paper, however, due to its policy significance.

11. Interestingly enough, in a study of the costs of carbon emissions reduction, one Fossil2 model run was performed with a 5% discount rate and all NES actions, and the results compared to those obtained with a higher discount rate assumption. The results were given in terms of the different CO_2 tax needed to stabilize emissions. The 5% discount rate assumption reduced the carbon tax needed to stabilize emissions through 2000, relative to 1990, from about $140/mtC (metric tonnes of carbon) to about $0/mtC! (For documentation see U.S. Department of Energy September 1991, p.7.55.) Unfortunately these results cannot be directly translated to a 'cost-effective gap.'

12. "In this approach, existing and proposed environmental regulations are analyzed in order to estimate the value that society implicitly or explicitly places on environmental impacts." (America's Energy Choices: Technical Appendixes 1991, p.F-6).

13. A second category of market imperfections are those relating to pricing of energy--for example, the failure of energy prices to reflect the environmental damage (notably CO_2) associated with their use, and the fact that electricity is often priced at its average, rather than marginal, cost. The cost-effective gaps discussed in this paper, however, are found at market (that is, private rather than social) prices and are therefore due to non-price market imperfections.

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