Policies to Encourage Home Energy Efficiency Improvements

Comparing Loans, Subsidies, and Standards

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Abstract:

Residential buildings are responsible for approximately 20 percent of U.S. energy consumption, and single-family homes alone account for about 16 percent. Older homes are less energy efficient than newer ones, and although many experts have identified upgrades and improvements that can yield significant energy savings at relatively low, or even negative, cost, it has proved difficult to spur most homeowners to make these investments. In this study, I analyze the energy and carbon dioxide (CO2) impacts from three policies aimed at improving home energy efficiency: a subsidy for the purchase of efficient space heating, cooling, and water heating equipment; a loan for the same purchases; and efficiency standards for such equipment. I use a version of the U.S. Energy Information Administration’s National Energy Modeling System, NEMS-RFF, to compute the energy and CO2 effects and standard formulas in economics to calculate the welfare costs of the policies. I find that the loan is quite cost-effective but provides only a very small reduction in emissions and energy use. The subsidy and the standard are both more costly but generate emissions reductions seven times larger than the loan. The subsidy promotes consumer adoption of very high-efficiency equipment, whereas the standard leads to purchases of equipment that just reach the standard. The discount rate used to discount energy savings from the policies has a large effect on the welfare cost estimates.

Key Words: energy efficiency, building retrofits, welfare costs, cost-effectiveness

JEL Classification Numbers: L94, L95, Q40
Policies To Encourage Home Energy Efficiency Improvements: Comparing Loans, Subsidies, and Standards

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Introduction

Commercial and residential buildings account for 42 percent of total U.S. energy consumption, with residential buildings alone responsible for half of this amount. Building codes, appliance standards, and general technological improvements have vastly improved the energy efficiency of new homes. But older homes lag behind. A home built in the 1940s consumes, on average, 50.8 thousand British thermal units (Btu) per square foot, even with improvements made since it was built. An average home built in the 1990s, on the other hand, consumes only 37.7 thousand Btu per square foot (U.S. Department of Energy [DOE/EIA] 2008). With 75 percent of the existing housing stock built before 1990, making a serious dent in residential energy consumption requires policies that target retrofits and upgrades to existing properties.

Experts have disagreed over the best approaches for spurring retrofits, and current policy takes a somewhat scattershot approach. Since the mid-1980s, the federal government has set mandatory minimum efficiency standards for a variety of appliances and equipment. In addition, it operates the voluntary Energy Star certification program for equipment and new homes that reach even higher levels of efficiency. Many state and local governments encourage building retrofits in a variety of ways. Approximately 250 energy efficiency financing programs are in operation at the state, local, and utility level (Palmer et al. 2012). These programs provide low-interest loans to consumers (and businesses) who upgrade their properties. Recently, some cities have adopted energy disclosure requirements for commercial and multifamily residential buildings; the rationale is that better publicly available information will lead building owners to make improvements to secure higher rents and increase occupancy rates.

Studies of the effectiveness and cost-effectiveness of policies that focus on end-use energy efficiency are limited. The oft-cited McKinsey & Company (2009) report identifies a number of building retrofit options with discounted streams of energy savings

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that more than offset the up-front costs of the improvements. These measures would purportedly yield 12.4 quadrillion Btus in energy savings in 2020, 29 percent of predicted baseline energy use in buildings in that year. The study does not describe or analyze policy options that will bring these changes about, however. Brown et al. (2009) do focus on policies; they look at building codes, energy performance ratings systems, mandated disclosure of energy use, and “on-bill” energy efficiency financing programs, as well as three policies targeted to utilities. The authors estimate energy savings and costs for each option, but these estimates are based on the authors’ assumptions and results from other studies, not from detailed statistical or simulation modeling. Krupnick et al. (2010) estimate the costs and effectiveness of a variety of policies to reduce energy use and carbon dioxide (CO₂) emissions, including four end-use energy efficiency policies: building energy codes; building energy codes combined with other policies, as specified in the 2009 Waxman–Markey climate bill (H.R. 2454); and two smaller-scale policies, one using a subsidy and the other a loan, for the purchase of geothermal heat pumps (GHPs). Krupnick et al. (2010) use a version of the National Energy Modeling System (NEMS), the market equilibrium simulation model used by the U.S. Energy Information Administration (EIA) for its short- and long-term energy forecasts (DOE/EIA 2011) to have a consistent framework with which to evaluate energy and CO₂ reductions across policies. They then use standard methodologies from public economics to calculate the welfare costs of each policy.

This study takes an approach similar to that of Krupnick et al. (2010), using a version of NEMS, NEMS-RFF, to analyze three policy options to reduce home energy use—two incentive-based instruments and a command-and-control approach. The study focuses on heating and air conditioning equipment and water heaters, which together account for approximately 70 percent of an average home’s energy use. I compare a subsidy for the purchase of high-efficiency equipment with a zero-interest loan of the same initial amount. I then contrast these two economic incentive-based policies with a policy that is of a more command-and-control nature—an efficiency standard for new equipment.

NEMS-RFF has a high level of technological detail in the four end-use energy sectors—residential, commercial, industrial, and transportation—as well as the electricity sector, and thus allows for detailed modeling of alternative policies. By using a consistent modeling framework with the same baseline assumptions for comparison, I am able to make a fair and accurate comparison of the three policy options. I also can compare to baseline forecasts that are consistent with EIA’s Annual Energy Outlook (AEO). I use
model output to calculate the welfare costs of the policies, using standard Harberger triangle formulas for welfare costs (Harberger 1964, 1971; Hines 1999; Just et al. 2004). This allows for an estimate of the cost-effectiveness of each of the policies in reducing CO₂ emissions—that is, the welfare costs per ton of emissions reduced.

I find the loan policy to be more cost-effective than the subsidy, and with low enough discount rates, the costs are even negative—that is, the discounted stream of future energy savings offsets the deadweight loss in the equipment market to generate an overall negative welfare cost. The loan achieves only a very small reduction in energy use and CO₂ emissions, however. The financial incentive to switch to high-efficiency equipment options is simply not that great because the loan has to be repaid. Consumers respond more to the subsidy and thus energy and emissions reductions are much greater with this policy. CO₂ reductions are more than seven times greater than with the loan. However, this policy comes with higher welfare costs; thus policymakers face a trade-off.

My modeling results show the efficiency standard generating emissions and energy reductions approximately equal to those of the subsidy, but the costs of this policy option are much greater. This finding highlights the importance of using a measure of welfare costs to analyze the costs of policy. Because a standard essentially removes a large number of product choices from the marketplace—all of the relatively low-efficiency space heating and cooling and water heating equipment—it generates a larger deadweight loss than the subsidy. Moreover, because the subsidy incentivizes purchases of all high-efficiency equipment, including the very high-efficiency but higher-cost options, it generates somewhat greater emissions reductions per dollar of welfare cost. The standard leads to more equipment that is just at the level of the standard.

The loan and subsidy policies compare favorably on a cost-effectiveness basis with the policies analyzed in Krupnick et al. (2010). In particular, they are more effective than building energy codes—that is, they provide a greater reduction in CO₂ emissions—primarily because they have a more immediate effect, whereas building codes provide energy and CO₂ reductions more gradually as new buildings replace older ones. On a cost-effectiveness basis, the building codes and subsidy policy are very similar. The subsidy is less cost-effective than some other approaches, such as a clean energy standard, but the very low cost of the loan option makes it compare favorably with almost all of the other options analyzed in the Krupnick et al. (2010) study. Again, though, it achieves very small reductions in emissions. In practice, energy efficiency loan programs have had low participation rates so it is possible that the NEMS-RFF modeling results are too optimistic. More research is needed into the efficacy of the financing approach. A
case study on energy efficiency subsidies and loans in the Krupnick et al. study looked at these options applied only to GHPs. Interestingly, these more narrowly applied heating and cooling equipment policies were more cost-effective than the more broadly applied policies analyzed here. These results suggest that careful targeting of energy efficiency policies may be appropriate from a cost-effectiveness standpoint.

The paper proceeds as follows. The following section describes NEMS, with special attention to the residential module and how heating and air conditioning equipment and water heaters are incorporated in the model. The subsequent section shows baseline results—forecasts of annual residential sector energy consumption and CO₂ emissions to 2035 and the distribution of technologies in use over the period under a business-as-usual scenario. The next section describes the specific loan and subsidy policies and shows results from the model, along with the welfare cost calculations. I then compare the subsidy results with an equivalent technology standard. The penultimate section compares my cost-effectiveness results for the three energy efficiency policies with cost-effectiveness estimates for alternative policies from other studies. The final section provides some concluding remarks.

The NEMS-RFF Model

Model Overview

NEMS is the primary model EIA uses in its AEO forecasts of future energy prices, supply, and demand (DOE/EIA 2011). The version of NEMS used in this study was run by OnLocation, Inc. for Resources for the Future. Some model modifications were made to represent the policy cases, thus we refer to the model throughout as NEMS-RFF.¹ NEMS-RFF is an energy systems model, also often referred to as a bottom-up model. As in most energy system models, NEMS-RFF incorporates considerable detail on a wide spectrum of existing and emerging technologies across the energy system, while also balancing supply and demand in all (energy and other) markets of the economy. The model is modular in nature (Figure 1), with each module representing individual fuel supply, conversion, and end-use consumption for a particular sector. The model solves iteratively until the delivered prices of energy are in equilibrium. Many of the modules contain extensive data: industrial demand is represented for 21 industry groups, for example, and light-duty vehicles are disaggregated into 12 classes and are

¹ The views expressed in this paper do not necessarily reflect the views of EIA or DOE.
distinguished by vintage. The model also has regional disaggregation, taking into account, for example, state electric utility regulations. It also incorporates existing regulations, taxes, and tax credits, all of which are updated regularly.

NEMS-RFF incorporates a fair amount of economic behavioral assumptions in its various modules. Utility maximization underpins the vehicle choice model as well as the choice of heating and cooling technologies in the residential module. This means that the model can be used to capture the impacts of various economic incentive-based policies, such as taxes and subsidies. It also will pick up impacts on some fuel and electricity prices as a result of policies that are of a more command-and-control nature, though it has some limitations in this regard. Price elasticities of demand, payback periods for capital investments, and other economic factors are chosen based on extensive reviews of the literature and evidence from equipment and fuel markets.

Figure 1. Visual Representation of NEMS

Source: DOE/EIA (2009a).
The Residential Module\(^2\)

The NEMS-RFF Residential Sector Demand Module starts with exogenously given population and housing construction input data from the NEMS Macroeconomic Activity Module. The module contains housing and equipment stock flow algorithms, a technology choice and housing shell efficiency algorithm, end-use energy consumption, and distributed electricity generation. Equipment purchases are based on a nested choice methodology with the first stage determining the fuel and technology—for example, an electric heat pump or a natural gas furnace for space heating—for both new and replacement equipment. Once the technology and fuel choice are selected, the second stage determines the efficiency of the equipment. Most equipment has several different efficiency types available in the model, and generally more-efficient equipment has a higher up-front cost. A log-linear function is used to estimate market shares of each type based on installed capital and operating costs; parameters of these functions are calibrated to market data. It is possible to calculate observed discount rates, or so-called hurdle rates, from the model based on the calibrations; these rates can reach as high as 30 percent. For the space heating, cooling, and water heating equipment, hurdle rates are approximately 20 percent. Thus, incentive-based policies directed at high-efficiency equipment are expected to have somewhat limited impacts on consumer purchase behavior. This is an intrinsic feature of the NEMS-RFF model.

For the policy analyses in this study, I am able to modify the capital and operating costs of the different types of heating, cooling, and water heating equipment, and this shifts the share of purchases toward the subsidized technology types (within the limits of the model structure). For the technology standard policy, I remove the lower-efficiency options from the choice set, as explained in more detail below. NEMS-RFF does not allow consumers to make earlier retrofits in response to the subsidy and loan policies; instead, consumers simply buy equipment that is more efficient than what they otherwise would have purchased when replacing equipment at the normal time. For this reason, NEMS probably underestimates the energy and emissions impacts of the policies, though the extent to which consumers would replace earlier in response to the policies is unclear.

\(^2\) For more detailed information, see DOE/EIA (2009b).
Space Heating and Cooling and Water Heating Technologies in the Model

The NEMS-RFF model incorporates six different fuel types for space heating (natural gas, electricity, liquefied petroleum gas (LPG), kerosene, distillate heating oil, and wood) and four different types of heating technologies (heat pumps, radiant heat, forced-air furnaces, and GHPs). In 2010, nearly 54 percent of the space heating equipment stock in place in the United States was natural gas forced-air furnaces. Electric heat pumps accounted for 9.5 percent, and other electric for 21.3 percent. The other technologies and fuels accounted for only 15.7 percent. By 2035, NEMS-RFF predicts that relatively more space heating will be supplied by natural gas furnaces and electric heat pumps—the shares rise to 55.4 and 14.1 percent, respectively—with all other types except GHPs falling.³

NEMS-RFF builds in five basic technology types for natural gas furnaces, each of which has different efficiencies and costs that vary somewhat over time and by region of the country. Specifically, the northern regions have slightly higher efficiencies than the south, and efficiency improvements occur at particular future dates as new standards are phased in. Improvements over time are also built in for most of the other space heating technologies in the model, including the four basic types of electric heat pumps and the four different types of central air conditioning systems. In addition, NEMS-RFF incorporates any federal tax credits that are in place for specific technologies (GHPs are an important example) and phases them out if the legislation specifies a particular date at which they sunset. NEMS-RFF also includes room air conditioners, which account for 41.6 percent of the cooling equipment stock in 2010. As I explain in the discussion of the policy scenarios below, the focus in this study is on forced-air furnaces, electric heat pumps, GHPs, and central air conditioning systems. I do not apply the policies to radiant heat, wood stoves, or room air conditioners. Table 1 shows a breakdown of the different technology types in the NEMS-RFF model for the major sources of residential space heating and cooling and water heating. The “high-efficiency” models are the targets of these policies.⁴

³ GHPs were less than 0.5 percent of the market in 2010, but are predicted to rise to 1.7 percent by 2035.
⁴ For ease of interpretation, I categorize the technologies, which in NEMS are distinguished by efficiency factors and costs, and give them the labels in Table 1.
Baseline Modeling Results

The baseline forecasts are consistent with the reference case in EIA’s 2011 AEO (AEO2011; DOE/EIA 2011). Real gross domestic product (GDP), a main driver of energy demand and prices, is assumed to grow by 2.2 percent annually through the 2035 forecast period, and oil prices rise an average of 0.11 percent per year to approximately $125 per barrel in 2035. Reliance on petroleum products declines over the forecast period in the reference case and the share of oil imports falls. Increased production of shale gas resources is an important part of this story. The AEO2011 reference case assumes that reduced drilling costs and technological improvements will lead to vastly more shale gas available than previous estimates suggest. As a result, natural gas consumption rises an average of 0.7 percent annually. Overall energy intensity in the economy also declines over the forecast period in the NEMS reference case. This is due to a variety of assumptions, including federal and state regulations such as building codes, appliance standards, and fuel economy improvements in the vehicle fleet. NEMS incorporates, to the greatest extent possible, all federal and state laws that directly affect energy markets.

All of these factors are important as they tend to dampen the rise in CO₂ emissions that would otherwise occur with economic growth over the forecast period. CO₂ emissions have fallen in recent years. Even with no policy changes, total CO₂ emissions increase slowly in the baseline forecast and do not return to 2005 levels until 2027. Emissions from the residential sector also grow slowly, and the sector’s share of total emissions falls over time—from 21.9 percent of total CO₂ emissions in 2010 to 19.4 percent in 2035.

Figure 2 shows the forecast of total energy consumption and residential energy consumption over the 2010–2035 forecast period under the baseline scenario. As the figure makes clear, residential sector energy use—both delivered energy and total residential, including electricity sector losses—is predicted to change very little, despite a forecasted growth of 28 percent in the number of U.S. households by 2035. Delivered energy consumption is only 5.2 percent higher in 2035 than in 2011. This relatively small increase is due to improvements in energy efficiency in the building sector over time. The improvements result from the replacement of older equipment and appliances with newer, more-efficient models and newly constructed houses that have improved building shells and other efficiency upgrades. Energy intensity in the residential sector—measured as millions of Btus of energy use per household—declines by more than 20 percent between 2010 and 2035. On a per-square-foot basis, energy intensity declines even more—by 31.3 percent over the 2010–2035 period.
### Table 1. Space Heating and Cooling Technologies in the NEMS-RFF Model

<table>
<thead>
<tr>
<th>Space heating and cooling equipment type</th>
<th>Energy efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heat pumps</strong></td>
<td><strong>HSPF</strong></td>
</tr>
<tr>
<td>Electric heat Pumps</td>
<td></td>
</tr>
<tr>
<td>Low-efficiency models</td>
<td>7.7</td>
</tr>
<tr>
<td>High-efficiency models</td>
<td></td>
</tr>
<tr>
<td>Current Energy Star</td>
<td>8.2</td>
</tr>
<tr>
<td>Very high-efficiency</td>
<td>~ 9.5</td>
</tr>
<tr>
<td>Ultra high-efficiency</td>
<td>10.7–10.9</td>
</tr>
<tr>
<td>GHPs (all high-efficiency)</td>
<td>11.9–17.1</td>
</tr>
<tr>
<td><strong>Natural gas, LPG, and oil furnaces</strong></td>
<td><strong>AFUE</strong></td>
</tr>
<tr>
<td>Low-efficiency models</td>
<td>80%–83%</td>
</tr>
<tr>
<td>High-efficiency models</td>
<td></td>
</tr>
<tr>
<td>Current Energy Star</td>
<td>90%</td>
</tr>
<tr>
<td>Very high-efficiency</td>
<td>96%</td>
</tr>
<tr>
<td><strong>Central air conditioners</strong></td>
<td><strong>SEER</strong></td>
</tr>
<tr>
<td>Low-efficiency models</td>
<td>13.0–14.0</td>
</tr>
<tr>
<td>High-efficiency models</td>
<td></td>
</tr>
<tr>
<td>Current Energy Star</td>
<td>14.5</td>
</tr>
<tr>
<td>Very high-efficiency</td>
<td>16.0</td>
</tr>
<tr>
<td>Ultra high-efficiency</td>
<td>23.0</td>
</tr>
</tbody>
</table>

**Notes:** HSPF, the heating seasonal performance factor, measures a heat pump’s energy efficiency over one heating season. It is heating output, in Btus, divided by total electricity consumed in watt-hours. AFUE, the annual fuel utilization efficiency, measures the amount of fuel converted to space heat in proportion to the amount entering the furnace; it is typically represented as a percentage. SEER, the seasonal energy efficiency ratio, is a measure of an air conditioner’s cooling output, in Btus, divided by total electric energy input in watt-hours. Information on Energy Star requirements for HVAC equipment, water heaters, and other equipment and appliances can be found at [http://www.energystar.gov/index.cfm?c=products.pr_find_es_products](http://www.energystar.gov/index.cfm?c=products.pr_find_es_products).
Some of the improvement in the residential sector is due to heating and air conditioning equipment replacement and new water heaters. All newer models are more efficient than older ones and some particularly inefficient technologies are no longer available in the future as standards ramp up. In addition, the high-efficiency models that are the focus of the policy scenarios below see their market share rise over time. As Figure 3 shows, in 2010, the high-efficiency cooling equipment and heating equipment options accounted for 13.7 and 15.3 percent of all purchases, respectively; by 2035, they are expected to account for 23.4 and 24.1 percent even without any new policies. Less improvement is seen in water heater efficiencies in the baseline, which could be due in part to the equipment I characterize as efficient; these options have significantly higher efficiencies than the other technology options in NEMS-RFF. The percentage of efficient water heater purchases rises from 0.93 percent in 2011 to 3.75 percent in 2035.

These overall efficiency improvements are important to keep in mind when evaluating the cost-effectiveness of energy efficiency policies. As the baseline improves, achieving additional energy and CO₂ reductions beyond the baseline will prove increasingly costly. I return to this point below.
Loan and Subsidy Policy Scenarios

This section compares a subsidy for high-efficiency equipment to a zero-interest loan. The subsidy and loan are applied to all high-efficiency options, as specified in Table 1 and the high-efficiency water heaters. The modeled subsidy lowers the up-front capital cost of new and replacement equipment by 50 percent over the baseline NEMS-RFF assumptions. This means that the dollar amount of the subsidy is larger for higher-cost equipment and that the subsidy falls in size if costs come down over time, as occurs for some of the technologies in NEMS-RFF. I choose a subsidy of this magnitude in an effort to spur a significant move toward high-efficiency purchases in the policy scenarios, while acknowledging that a government subsidy (or tax credit) that would reduce prices by 50 percent may be unrealistic.

The loan policy reduces the capital cost by exactly the same amount as the subsidy, 50 percent of the baseline cost, but assumes that the loan is fully paid back over a three-year period with no interest. The three-year period is arbitrary, but because the loan amounts are not large and zero interest is charged on the loan, a relatively short payback period seems appropriate. Most energy efficiency loan programs that cover a wide range of home retrofits and upgrades do not have a 0 percent interest rate; in fact,

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5 Because it is time-consuming and costly to run NEMS-RFF for alternative scenarios, I was unable to conduct sensitivity analyses with different-sized subsidies. In the results below, however, I do discuss how the cost-effectiveness varies with discount rates, loan default rates, and other factors.
some loans have rates as high as 14 percent. Thus, this is a generous feature of the policy. On the other hand, three years is a relatively short term for the loan. Most energy efficiency financing programs have terms of around 10 years, though these are typically for much larger loans (Palmer et al. 2012). In the NEMS–RFF model, the subsidy simply lowers the up-front equipment cost, leaving annual operating costs unchanged; the loan lowers the up-front cost by the same amount as the subsidy but effectively increases operating costs for the first three years of the equipment’s life. I assume a 2 percent default rate on loans. As discussed below, existing loan programs have average default rates below 2 percent, but they tend to serve customers with very high credit scores. In a national program available to all consumers, one would expect the default rate to be higher. I carry out sensitivity analyses on the default rate and discuss those findings below.

Policy Modeling Results: Loans Versus Subsidies

By lowering the purchase cost of high-efficiency heating, cooling, and water heating equipment, the subsidy and the loan both shift purchases of new equipment toward the more-efficient options over time. Figure 4 shows all efficient equipment purchases as a percentage of total equipment purchases over the 2011–2035 time period. With the subsidy, more than half of all cooling equipment and nearly half of heating equipment purchased during this 25-year period are high-efficiency models; just less than 40 percent of water heaters are high-efficiency models. These are significant increases over the baseline case. Loans have less of an impact: high-efficiency cooling equipment purchases increase from 20.6 percent to 33.5 percent and high-efficiency heating equipment purchases increase from 22.2 percent to 29.5 percent. The loan policy has a much smaller effect on water heater purchases than does the subsidy.

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6 The Fannie Mae Energy Loan program is one example. Many state and utility programs use the Fannie Mae program but buy down the interest rate to a more acceptable level, often around 7 percent (Palmer et al. 2012).
As the new efficient equipment purchases gradually replace older equipment, energy use for heating and cooling declines relative to the baseline. Figure 5 shows residential delivered energy use over the 2011 to 2035 time period under the baseline and the two policy cases. The subsidy has a much larger impact on residential energy use than does the loan. In fact, the loan is almost indistinguishable from the baseline. Neither of the policies has a large impact on energy use, however.\(^7\) By 2035, delivered energy use under the subsidy is 0.66 quadrillion btus below the baseline, a difference of only 5.6 percent.

Energy use eventually increases in all three scenarios because of population growth, but with the subsidy, total energy use in 2035 is slightly below the 2011 level. Energy use falls, on a per-household basis, by 16.8 percent in the baseline between 2011 and 2035, by 17.4 percent with the loan, and by 21 percent with the subsidy. Thus the energy efficiency policies work in reducing residential energy use, and accompanying CO\(_2\) emissions, but the forces of population and economic growth offset much of those gains.

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\(^7\) Note that the scale of the vertical axis is compressed in Figure 5 so that the differences show up. By contrast, the scale in Figure 2 is much wider.
Cumulative energy-related CO\(_2\) emissions reductions over the 25-year forecast period from the subsidy are 672.5 million metric tons (mmtons), seven times greater than the 94.9 mmton reduction from the loan. With economywide emissions over the same time period in the baseline case at 148 billion metric tons, however, neither of these residential energy efficiency policies makes a major dent in the problem, reducing emissions by less than 0.5 percent in the case of the subsidy and the standard and by a much smaller percentage with the loan. This result is expected: with heating, cooling, and water heating responsible for approximately 70 percent of the energy consumed in a residential building, and the residential sector as a whole accounting for approximately 20 percent of total energy use, these kinds of targeted energy efficiency policies can make only a small contribution toward U.S. climate reduction goals. Nonetheless, in the absence of an economywide carbon tax or cap-and-trade program, sector-specific policies may be the next-best solution, thus it is important to assess their potential.

**Welfare Costs and Cost-Effectiveness of Loans and Subsidies**

Although many energy policy studies calculate a form of policy costs, most do not estimate true welfare costs. Often they calculate direct expenditure changes from scenarios in which one fuel substitutes for another or one more energy-efficient technology replaces another, less-efficient one (McKinsey and Company 2009; Brown et al. 2009). Studies that look at broad-based policies often assess changes in GDP. Although such metrics provide important information, they usually do not reflect the true
economic burden of the policy. In this study, I focus on welfare costs, which measure the costs imposed on society when resources are diverted toward the production of high-efficiency heating, cooling, and water heating equipment and away from other sectors in the economy. This is the prevailing approach used by economists when measuring costs (Just et al. 2004; Hines 1999).

Measuring such costs is not always easy. I use standard formulas from public economics based on the work of Harberger (1964, 1971) and others and estimate the deadweight loss of the subsidy in the market for efficient heating, cooling, and water heating equipment, as shown in Figure 6. The figure shows the demand and supply of high-efficiency equipment. The subsidy is shown as a horizontal shift downward in the supply curve. It lowers the net price to consumers and leads to a greater quantity purchased in equilibrium. The consumer surplus increases with the transfer of government subsidy payments, but the shaded blue triangle, ABC, illustrates the additional subsidy payments above and beyond the gain in consumer surplus. This area represents the resources pulled from elsewhere in the economy that were more valuable in other uses and is a measure of the welfare cost associated with the subsidy.

I treat the loan policy as having exactly the same effect in the market for high-efficiency equipment, but the loan shifts the supply curve downward by a smaller amount than does the subsidy. Rather than shifting it down by the per-dollar subsidy amount, it shifts it down by the discounted present value of the forgone interest earnings on the loan. I compute this value using a 5 percent interest rate and the three-year loan term. I calculate the deadweight loss of the subsidy and the loan for each of the forecast years and compute the discounted present value of these losses using a 5 percent social discount rate.9

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8 The supply is drawn as perfectly elastic. This simplifies the analysis and is consistent with the NEMS-RFF model, which does not include increasing marginal costs of production and changes in equilibrium prices as a result of demand shifts. In addition, for ease of graphical exposition, I show a single market for high-efficiency equipment, but the NEMS-RFF model, as explained above, contains multiple different equipment types.

9 Although the subsidy may shift demand and supply curves in other markets, these pecuniary effects are not part of the standard deadweight loss formula (Harberger 1971; Hines 1999). In this case, for example, the demand for low-efficiency equipment options should decrease in response to the subsidy, but changes in this market are not part of the welfare calculations.
One final adjustment to the welfare cost calculations is important. If one believes that a market failure exists in the market for energy efficiency because of information barriers, myopic consumers, credit rationing, risk and uncertainty over new types of equipment, or any of a host of other reasons for the so-called efficiency gap, or energy paradox (Jaffe and Stavins 1994; Gillingham et al. 2009; Alcott and Greenstone 2012), then these welfare costs in the equipment market may overstate the true welfare costs of the policies. To allow for the possibility of these market failures, I calculate the discounted stream of future energy savings from the policies under alternative discount rate assumptions. A 20 percent rate, consistent with the NEMS model, implies no market failure—in other words, the relatively high rate may capture hidden costs associated with the high-efficiency equipment, such as reduced quality, performance, or durability. Even though high-efficiency equipment yields energy savings, these savings are assumed to be accurately reflected in consumers’ decisionmaking. In this case, the deadweight loss triangle in the equipment market is a full measure of welfare costs. I even allow the rate to go as high as 25 percent to account for extra hidden costs. At the other end of the spectrum, I calculate energy savings using a 5 percent social discount rate. This implies
that the efficiency gap is due completely to market failures.\footnote{Krupnick et al. (2010) provide a detailed discussion of the market failure versus hidden costs debate with respect to the energy efficiency gap and how varying the discount rate used to calculate the present value of energy savings can capture these different beliefs.} I also calculate costs for discount rates between these two extremes.\footnote{These alternative rates are applied only to the energy savings component of the welfare cost calculations. The normal discounting associated with converting future dollars to a present value, which is necessary for computing the discounted present value of welfare costs, remains at a 5 percent social rate throughout this analysis.}

Table 2 shows the total present discounted value of the net welfare costs over the 2011–2035 period for the two policy options under three alternative discount rates—5 percent, 10 percent, and 20 percent—as well as the net welfare costs per ton of CO$_2$ emissions reduced. Figure 7 shows the cost-per-ton numbers graphically, over the full range of alternative discount rates.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|}
\hline
& PDV welfare costs, 2011–2035 (in billions of 2009$) & & Cost per ton CO$_2$ reduced & \\
\hline
\multirow{3}{*}{Discount rate} & Subsidy & Loan & Subsidy & Loan & \\
\hline
5\% & $-$16.1 & $-$10.7 & $-$24 & $-$113 & \\
10\% & 22.9 & $-$1.2 & 34 & $-$13 & \\
20\% & 44.3 & 4.0 & 66 & 42 & \\
\hline
\end{tabular}
\caption{Welfare Costs and Cost-Effectiveness of Subsidy and Loan Policies Using Alternative Discount Rates for Energy Savings}
\end{table}

The discount rate has a profound effect on both the total welfare costs and the cost per ton of CO$_2$ emissions reduced for both policies. A 5 percent discount rate, which reflects the belief that the market for residential high-efficiency equipment contains significant market failures, leads to negative policy costs—that is, the discounted stream of future energy savings offsets the deadweight losses the policies impose in the equipment market. In the case of the loan, the energy costs far outweigh the deadweight loss in the equipment market: the policy generates a net gain to society of $113 per ton of CO2 emissions reduced. Higher discount rates lead to higher costs for both policies, though the loan option still has negative costs at a 10 percent discount rate. The estimated cost per ton of emissions reduced becomes positive only for the loan policy at a discount rate of approximately 11.5 percent. The subsidy’s cost per ton becomes positive at a 6 percent discount rate.
As Figure 7 shows, increasing the discount rate increases the cost per ton of CO₂ reduced, but does so at a decreasing rate. At lower discount rates, the stream of energy savings has a relatively larger effect on the overall cost calculation, thus changes in that component of welfare costs can have a large impact. At higher discount rates, on the other hand, the deadweight loss in the equipment market is relatively more important, and this component is insensitive to the discount rate. Figure 7 also shows that the costs of the loan policy increase by a greater amount than do those of the subsidy as the discount rate is increased; gradually, the two policies’ costs per ton approach one another.

The loan policy has lower costs per ton of CO₂ reduced than does the subsidy over the range of discount rates for two reasons. First, because it provides a smaller financial incentive than the subsidy, the loan induces less switching to high-efficiency equipment; this keeps down the cost of the policy (though it also limits the benefits in terms of energy and emissions reductions). Second, because the loan is repaid, the deadweight loss triangle in the equipment market is calculated using only the forgone interest earnings on the money that is loaned to consumers. Clearly, this is significantly less than the full subsidy amount.¹²

¹² I used a 5 percent interest rate to calculate those forgone earnings, which is consistent with the social rate used to discount future equipment costs and a reasonable rate in today’s economic environment. Importantly, however, the loan policy costs could be higher if a higher interest rate is used to compute these forgone earnings. I do not include any administrative costs for either policy.
The loan achieves a far smaller reduction in CO₂ emissions, however, as shown above. This highlights the policy trade-off: the loan is more cost-effective at reducing emissions, but much less effective. It is unlikely that any loan policy would ever have as great an impact on energy use and CO₂ emissions as a subsidy. This message appears to be lost in some of the discussions about energy efficiency financing as a policy approach. Some advocates for efficiency financing—from the government sector, the financial industry, and the environmental community—seem to hold out hope that widespread availability of low-cost loans will spur significant reductions in energy use (Hayes et al. 2011; Hinkle and Schiller 2009). My results suggest that, although loans may provide emissions reductions with very low costs to the economy—perhaps even negative costs—those emissions reductions are relatively small.

One final point about the loan policy concerns the default rate. The numbers in Table 2 and Figure 7 assume a 2 percent default rate—in other words, 2 percent of the value of the loans is assumed to be lost to society each year because borrowers fail to repay. The 2 percent figure is somewhat arbitrary as it is unclear how high default rates would be on consumer loans of this type in a national program. Palmer et al. (2012) report on the most detailed information available on default rates in current programs. Pennsylvania’s Keystone HELP program had an average default rate across all loans made between 2006 and 2010 of just 0.60 percent. However, the default rate varies greatly by borrowers’ credit scores. Most borrowers in the program have FICO scores above 700, but borrowers with a FICO below 650 have an average default rate of 4.33 percent. Approximately 30 percent of U.S. adults with credit rates have FICOs below 650 (State and Local Energy Efficiency Action Network 2011), thus it is possible that a widely available energy efficiency loan program would tap into a higher risk market than would the Pennsylvania program.

Table 3 shows estimated welfare costs per ton of CO₂ emissions reduced for the loan policy under alternative default rates and using a 10 percent discount rate. These calculations essentially assume that consumers who take out loans anticipate that they will pay them back—thus the NEMS results remain the same—but they unexpectedly default, and this raises the cost of the loan policy. For comparison, I include the subsidy cost in the final row of the table and note that the default rate would have to be as high as 25 percent for the loan policy’s cost per ton of emissions reduced to rise as high as that of
the subsidy. In other words, even if defaults are much higher than in current programs, the loan policy option might still be relatively cost-effective.

### Table 3. Cost-Effectiveness of Loan Policy with Alternative Loan Default Rates

<table>
<thead>
<tr>
<th>Default rates</th>
<th>Cost per ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>−$17</td>
</tr>
<tr>
<td>2%</td>
<td>−$13</td>
</tr>
<tr>
<td>5%</td>
<td>−$7</td>
</tr>
<tr>
<td>25%</td>
<td>$33</td>
</tr>
<tr>
<td>Subsidy cost per ton</td>
<td>$34</td>
</tr>
</tbody>
</table>

*Note: Costs are calculated using a 10 percent discount rate for energy savings.*

### A Policy Alternative: Efficiency Standards

The loan and subsidy policies provide financial incentives for consumers to change their behavior. By lowering the costs of high-efficiency heating and cooling equipment and water heaters, the policies spur greater purchases of those types of equipment and thereby reduce energy use and emissions. Some efficiency advocates view the incentive-based policy approach with some skepticism and prefer instead that government tighten efficiency standards. Appliance and equipment standards have been in place since the mid-1980s in the United States and, by some estimates, have led to significant energy savings. Gold et al. (2011) estimate that energy use in 2010 was 3.6 percent below what it would have been in the absence of standards. In an earlier study, Meyers et al. (2003) combine energy prices with engineering estimates of energy savings from appliance standards in place over the 1987–2000 time period and find a cumulative net benefit of $17.4 billion (in 2003 dollars).

I use the NEMS-RFF model to investigate the impacts of tighter standards for heating, cooling, and water heating equipment and compare those results to my findings for the loan and subsidy policies. The standard I model sets a requirement that all new equipment purchases be high-efficiency. It removes the low-efficiency options in NEMS-

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13 Although my formula for welfare costs for the loan becomes identical to that of the subsidy with a 100 percent default rate, this does not mean that the costs are identical in that case. The loan leads to fewer purchases of high-efficiency equipment and a smaller reduction in energy consumption and emissions than the subsidy; thus, at a 100 percent default rate, the total welfare costs are lower than those of the subsidy, but the costs per ton of emissions reduced are much higher.
RFF from the choice sets, leaving only the high-efficiency options listed in Table 1 available for purchase. Multiple equipment options are available, but they all are above the minimum efficiency level set by the policy. The prices consumers face are the same as in the baseline—that is, the model does not allow one to adjust equipment prices in response to the removal of the low-efficiency technology. This is a limitation of the modeling framework. In reality, an increase in demand for the high-efficiency equipment, forced by removal of the lower-efficiency options, should increase prices. I am unable to capture these market movements in my framework.

Figure 8 shows residential delivered energy use over the 2011 to 2035 time period under the subsidy and the standard. (I leave off the loan for simplicity.) The difference in energy use between the two policies is quite small. The standard has a smaller impact on energy use than does the subsidy, but cumulative residential delivered energy consumption over the 2011–2035 period is only 1.2 percent higher with the standard than with the subsidy. Cumulative economywide CO₂ emissions are nearly identical for the two policies. The standard reduces emissions by 671.1 mmtons, compared with 672.5 for the subsidy. Prior to 2027, the standard reduces emissions by slightly more than the subsidy in each year; however, this outcome is reversed in the latter part of the forecast period, from 2027 to 2035. As a result, overall cumulative emissions are roughly the same.

These results may seem somewhat surprising at first glance. The standard forces all purchases of new equipment to be high-efficiency, whereas some consumers continue to purchase low-efficiency options in the subsidy case. On the other hand, the subsidy also incentivizes the purchase of extra high-efficiency equipment, whereas the standard does not. Even though 100 percent of new equipment is efficient with the standard, a much smaller percentage ends up being extra high-efficiency than in the subsidy case. The subsidy makes all of the efficient options (see Table 1) less expensive to the consumer, and thus encourages purchases of the extra high-efficiency options as well as the equipment that just meets current Energy Star requirements.
With the subsidy, the model predicts that 48 percent of cooling equipment and nearly 38 percent of heating equipment is extra high-efficiency (labeled “very” and “ultra” high in Table 1); the percentages are just 19 and 12, respectively, in the case of the standard. This highlights one of the drawbacks of technology standards in general: no incentives are provided to do better than the standard. These impacts are more pronounced over time because the low-efficiency options improve, and the differences in emissions between them and the current Energy Star options, the lowest of the “efficient” types of equipment, get smaller. This means the standard has less of an impact on emissions over time.

The important difference between the standard and the subsidy concerns the welfare costs. By removing the low-efficiency options from the marketplace, the standards create a deadweight loss in the low-efficiency equipment market, as shown in Figure 9. The equilibrium price and quantity of low-efficiency equipment in the baseline, no-policy case are $P_{L,0}$ and $Q_{L,0}$.\textsuperscript{14} Mandating that all equipment have the efficiency levels of the high-efficiency equipment effectively removes the low-efficiency options from the marketplace, which leads to a loss of consumer surplus illustrated by the shaded blue area in Figure 9. This loss is my measure of the welfare cost of the standards policy.

\textsuperscript{14} For ease of graphical exposition, I show a single market for low-efficiency equipment (as I did for high-efficiency equipment above), but the NEMS-RFF model contains multiple equipment types.
Calculating this area is not straightforward as I do not know the price at which the demand for low-efficiency equipment drops to zero. I assume it is equal to the equilibrium price of high-efficiency equipment—in other words, if consumers can buy high-efficiency equipment for the price of low-efficiency equipment, then demand for the latter should fall to zero. In the NEMS framework, this actually does not happen. The market shares specification in the residential module will keep some low-efficiency models in the market even if their prices rise above the price of higher-efficiency equipment. In this sense, my estimates understate the welfare costs. On the other hand, one would expect the price at which low-efficiency equipment demand falls to zero to be above the high-efficiency equipment price because the latter options have lower energy costs. I simply point out the great deal of uncertainty in this reservation price and thus in my welfare cost calculations.

Table 4 shows the present discounted value of welfare costs for the standard, as well as the welfare costs per ton of CO₂ emissions reduced for three discount rates. For comparison purposes, the results for the subsidy are shown as well.

Because the low-efficiency equipment purchases are forced to zero, the deadweight loss triangle in the equipment market is relatively large; this makes the welfare cost of the standard significantly higher than that of the subsidy for the same discount rate. In other words, forcing all consumers who would otherwise have purchased low-efficiency equipment to purchase high-efficiency options comes at a substantial cost. This assumption is in contrast to some studies of appliance and equipment standards.
such as the Meyers et al. (2003) study cited above, which come up with negative costs for U.S. appliance efficiency standards. But if consumers are heterogeneous in their choices of efficiency, then imposing uniformity through efficiency standards creates costs in the form of lost consumer surplus (Hausman and Joskow 1982). My scenarios with lower discount rates allow for some market failure in these purchase decisions, as I explain above. Again, I emphasize that more research is needed into these important questions about consumer behavior in the markets for energy-using equipment and appliances.

### Table 4. Welfare Costs and Cost-Effectiveness of Efficiency Standard and Subsidy Using Alternative Discount Rates for Energy Savings

<table>
<thead>
<tr>
<th>Discount rate</th>
<th>PDV welfare costs, 2011–2035 (billions of 2009$)</th>
<th>Cost per ton CO₂ reduced</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard</td>
<td>Subsidy</td>
</tr>
<tr>
<td>5%</td>
<td>$11.1</td>
<td>–$16.1</td>
</tr>
<tr>
<td>10%</td>
<td>$36.8</td>
<td>$22.9</td>
</tr>
<tr>
<td>20%</td>
<td>$50.8</td>
<td>$44.3</td>
</tr>
</tbody>
</table>

*Note: PDV is the present discounted value.*

### Comparing Cost-Effectiveness Estimates with Other Policy Options

Cost-effectiveness is a relative metric, thus it is useful to benchmark my estimates to estimates from other studies and/or for alternative policies. The recent study by Krupnick et al. (2010) provides the most useful benchmarks as it relied on the NEMS-RFF model (albeit an earlier version) and used similar welfare cost formulas. The authors assessed the costs and effectiveness of two building energy efficiency policies: (a) building codes as specified in the 2009 Waxman–Markey climate bill (H.R. 2454) and (b) the full set of building codes, building retrofits, and other efficiency requirements in Waxman–Markey. They also looked at a loan policy and a subsidy policy for heating, cooling, and water heating equipment, but one that targeted only GHPs. The study also analyzed a range of other options, including economywide carbon cap-and-trade policies and carbon taxes as well as various forms of clean energy standards for the electricity sector.

The Waxman–Markey building codes provision called for a 30 percent reduction in energy use in new buildings upon enactment of the law, a 50 percent reduction for residential buildings by 2014 and for commercial buildings by 2015, and a 5 percent
reduction at three-year intervals thereafter up until 2029 (residential) and 2030 (commercial). The retrofit provision required the U.S. Environmental Protection Agency to develop building retrofit policies to achieve the utmost cost-effective energy efficiency improvements; the programs were to be administered through the states, which would receive CO₂ emissions allowances under the cap-and-trade program in H.R. 2454 to help finance the programs. The bill also contained lighting provisions that created new standards for outdoor lighting, portable light fixtures, and incandescent reflector lamps and some provisions covering institutional appliances.

The results in Table 5 show the cumulative emissions reductions and cost-effectiveness of these two policy options. Interestingly, the building codes and full Waxman–Markey building energy efficiency provisions reduce cumulative CO₂ emissions by less than the heating, cooling, and water heating equipment subsidy and standard policies I analyzed here. But the building codes are slightly more cost-effective than the subsidy, and the full Waxman–Markey provisions have a cost-effectiveness estimate identical to my subsidy policy.

**Table 5. Estimated Emissions Reductions and Cost-Effectiveness of Alternative Policies**

<table>
<thead>
<tr>
<th>Policy</th>
<th>Cumulative CO₂ emissions reduced, 2011–2035 (mmtons)</th>
<th>Welfare cost per ton of CO₂ emissions reduced</th>
</tr>
</thead>
<tbody>
<tr>
<td>W–M building codes</td>
<td>249.6</td>
<td>$25</td>
</tr>
<tr>
<td>Full W–M energy efficiency provisions</td>
<td>298.8</td>
<td>$34</td>
</tr>
<tr>
<td>GHP subsidy</td>
<td>306.3</td>
<td>–$9</td>
</tr>
<tr>
<td>GHP loan</td>
<td>172.5</td>
<td>–$36</td>
</tr>
<tr>
<td>Clean energy standard</td>
<td>9,158</td>
<td>$15</td>
</tr>
<tr>
<td>Carbon cap and trade</td>
<td>14,839</td>
<td>$12</td>
</tr>
</tbody>
</table>


*Source:* Krupnick et al. (2010).
The cumulative emissions reductions from the building codes policy amount to only 37 percent of the reductions achieved with the heating, cooling, and water heating equipment subsidy; the full Waxman–Markey provisions’ emissions reductions are 44 percent of the reductions achieved with the subsidy. I believe that the primary reason for these findings is the long time frame necessary for building codes to have an effect because they apply only to new construction.15

At $25 per ton of emissions reduced, the building codes policy has a lower cost per ton than the subsidy, which is $34 per ton—identical to the full Waxman–Markey energy efficiency provisions. I have shown only the results for a 10 percent discount rate in Table 7, but the comparisons with the results in this study hold for other discount rates as well, although the variance in costs per ton for the subsidy is greater than for the building codes and full Waxman–Markey policies.

Interestingly, the GHP subsidy is more cost-effective at reducing CO₂ emissions than the broader equipment subsidy I analyze here, and likewise, the GHP loan is more cost-effective than my broader loan policy. These findings suggest that targeting subsidies and loans to very high-efficiency options might be a more cost-effective approach. The GHP subsidy achieves smaller emissions reductions than the broader subsidy policy, but the GHP loan achieves slightly larger reductions.16

Compared to the other policy options analyzed by Krupnick et al. (2010)—particularly the economywide cap-and-trade policies and the various types of clean energy standards in the electricity sector—these building energy efficiency policies are much less effective and, except for the loan policy, less cost-effective as well. Obviously, the cap-and-trade policy, or an equivalent carbon tax, is the most cost-effective instrument and the policy that generates the biggest reduction in emissions as it targets all sources of emissions.17 The clean energy standards evaluated in Krupnick et al. are the next best options. These standards require electricity generators to use “clean” sources for a specific share of the electricity they produce. Krupnick et al. (2010) found that a policy that incentivizes all fuels except coal—essentially, renewables, natural gas, and nuclear—

15 The full Waxman–Markey energy efficiency policy includes more than just building codes, but the codes are the primary driver in that policy; the other components are less important.
16 The subsidy and loan policies in Krupnick et al. (2010) are not exactly the same as the ones analyzed here. The GHP subsidy was $4,000 (above the amount applied to GHPs here) and the loan was financed at 0 percent for seven years, rather than the three years in this study.
17 Emissions reductions reported in the Krupnick et al. (2010) study have been adjusted from a 2010–2030 period to 2011–2035 to be consistent with the policies analyzed here.
provides the largest reduction in emissions and does so at a cost per ton that is close to that of cap and trade, $15 versus $12 for cap and trade. Cumulative CO₂ emissions reduced over the 2010–2030 period were estimated at 7,632 mmtons, roughly equivalent to 9,158 mmtons over the 2011–2035 period, far greater than the reductions achieved with my building energy efficiency policies.

**Concluding Remarks**

Energy experts have identified a number of improvements, upgrades, and retrofits that homeowners can adopt to reduce their homes’ energy use, and several of these changes seem to more than pay for themselves in the stream of energy savings they yield over time. Nonetheless, it has proved difficult to get homeowners to make these changes. One important barrier may be the up-front costs of new furnaces, additional insulation, more-efficient windows and doors, upgraded appliances, and other options. In this study, I analyzed two policies to reduce the up-front cost of high-efficiency heating, cooling, and water heating equipment—a direct subsidy and a zero-interest loan. Using the NEMS-RFF energy market simulation model, I find that a subsidy that reduces up-front costs by 50 percent would cause a substantial shift in purchases toward high-efficiency options: over the 2011–2035 forecast period, approximately half of all heating and cooling equipment purchases are predicted to be high-efficiency versus only about 20 percent in the baseline case. By 2035, the residential delivered energy use forecast is 5.6 percent below the baseline; on a per-household basis, the reduction is much larger, approximately 21 percent, but population growth offsets some of this impact. Because residential buildings account for only about one-fifth of total CO₂ emissions in the economy, economy-wide emissions over the 2011–2035 period are only 0.5 percent below the baseline.

The welfare costs of the subsidy policy are fairly large. I calculate standard Harberger deadweight loss triangles and obtain a welfare cost of $34 per ton of CO₂ emissions reduced when future energy savings are discounted at a 10 percent annual rate. The cost estimate is highly sensitive to this discount rate, however: at 5 percent, the cost is negative—that is, the discounted stream of energy savings offsets the deadweight loss from higher equipment costs—and at 20 percent, the cost is as high as $66 per ton of emissions reduced. The question of which discount rate is the right one depends on one’s belief about the extent to which the efficiency gap, or so-called energy paradox, is due to market failures. My 10 percent discount rate allows for the possibility of some market failure because that rate is higher than the 5 percent social discount rate but lower than
the 20 percent rate in NEMS that reflects actual consumer behavior. However, more research is needed into this important question.

The welfare costs are much lower for an energy efficiency loan policy. I analyze an option that reduces the up-front cost by 50 percent, just like the subsidy, but consumers must pay this money back over a three-year period at a 0 percent interest rate. I estimate welfare costs for this policy option of $13 per ton of CO₂ emissions reduced at a 10 percent discount rate, less than $100 per ton at 5 percent, and $42 per ton at 20 percent. The loan policy does not make a noticeable dent in energy consumption and CO₂ emissions, however: the reduction is one-tenth of the reduction that the subsidy accomplishes. Nonetheless, these results suggest that energy efficiency financing programs could be very cost-effective. In reality, such programs have not accomplished much thus far (Palmer et al. 2012), but it is possible that a large-scale national program could provide some emissions reductions at relatively low cost. More empirical research is needed into this question, using results from existing programs to investigate the low participation rates and to better understand the actual energy reductions achieved.

I compare these incentive-based approaches with a command-and-control option—an efficiency standard applied to heating, cooling, and water heating equipment. The specific policy I analyze removes the low-efficiency options from the marketplace, thus all consumers are forced to buy high-efficiency equipment (i.e., equipment that is at least as efficient as current Energy Star models). This option reduces CO₂ emissions by about the same amount as the subsidy but at a much higher cost. The welfare costs of a standard are higher because all consumers who purchase low-efficiency options in the baseline are now forced to buy high-efficiency equipment at a higher price. I estimate that emissions are reduced at a cost of $55 per ton when the discount rate is 10 percent, more than $20 higher than the cost of the subsidy.

The strength of the NEMS modeling framework is that it is benchmarked to national EIA forecasts and is continuously modified and updated to reflect current market and policy conditions. It captures economic behavior to some extent, thus one can see the incentive effects of policies that change effective prices. Moreover, by using a consistent modeling framework, I have an apples-to-apples comparison of my three policies. But like any simulation model, NEMS is not perfect. Some have criticized it for being conservative in its forecasts—that is, the responsiveness to policies is less than some believe is realistic. If this is the case, my cost-per-ton estimates are biased upward. In addition, because of its complexity, it is difficult to know what features of the model are central to the results one obtains. And because it is costly to run, I was unable to conduct
sensitivity analyses, changing the loan and subsidy amounts, for example, and comparing results. Also, my loan and subsidy policies targeted only heating, cooling, and water heating equipment; thus the results do not necessarily carry over to other equipment or to whole-house retrofits. A whole-house retrofit loan or subsidy policy would be difficult to model precisely in NEMS.

My findings about the relative effectiveness and cost-effectiveness of the loan, subsidy, and standard policy options are useful for providing a starting point for further discussions. In the absence of an economywide carbon tax or cap-and-trade policy, policymakers may be searching for options to deal with individual energy-using sectors one at a time. Improving the efficiency of residential and commercial buildings should be high on the list as these sectors account for over 40 percent of current energy use and many experts have identified a number of examples of low-hanging fruit in the buildings sectors. But the retrofit problem is a challenging one. Further analysis is needed, through modeling, case studies, and empirical econometric studies, to identify the most cost-effective and effective options for spurring building owners to adopt energy-saving retrofits and improvements.
References


