Improving Energy Codes

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Abstract

Energy codes set efficiency standards for buildings in the majority of U.S. states. Under most energy codes, builders can comply by demonstrating that the projected private expenditures on energy bills for a proposed building are less than a certain threshold. Using theory and evidence, I show that energy codes would be improved if compliance was instead determined by the projected social damages. Relative to current practice, damage-based codes would likely provide stronger incentives for electricity than natural gas conservation, in most states. Implementation of damage-based codes would lead to substantial welfare gains.

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1 Introduction

Increased concerns about climate change have recently sparked renewed interest among policymakers for more aggressive energy efficiency policies. Much attention has been paid to policies related to buildings, which are responsible for 41% of U.S. energy consumption (US EIA, 2012b). In particular, policymakers have increasingly employed building energy codes to regulate the energy efficiency of buildings. Federal policymakers have provided incentives for state adoption of energy codes and have included provisions for a national energy code in major legislative proposals. As of 2013, 43 states have mandatory, statewide energy codes for residential and commercial buildings and most of these energy codes have seen recent increases in stringency (U.S. DOE, 2013).

The focus on building energy codes (henceforth, "energy codes") is perhaps warranted, given their potential for energy savings. According to policy projections made by the Energy Information Administration (EIA), a nation-wide increase in the stringency of energy codes, in combination with updated efficiency standards for appliances and other equipment, would lead to a 3.6 quadrillion BTU decrease in the amount of energy used by buildings (U.S. EIA, 2012a).[1] This figure exceeds the projections for policy-related energy savings from other sectors. For example, the announced increases in CAFE Standards, in combination with other transportation related policies, are projected to lead to a 3.2 quadrillion BTU savings by 2035.

Energy codes are unlikely to be the least-cost approach to addressing energy-related externalities because they focus on a single sector, do not provide marginal incentives for improvements in efficiency beyond the compliance threshold, and do not provide direct incentives for reduced consumption. Despite these potential sources of inefficiency, energy codes have been shown to be effective at reducing energy consumption (Jacobsen and Kotchen, 2013; Aroonruengsawat, Auffhammer, and Sanstad, 2012; Costa and Kahn, 2011) and appear likely to remain a central component of U.S. energy policy (Auffhammer and Sanstad, 2011). Given the continued use of energy codes, focus should shift toward improving energy code design.

This paper argues that energy codes would be improved if they were structured to provide relatively stronger incentives for conservation of energy types that are associated with

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[1] The EIA's projections report a 1.5 quadrillion decrease in delivered energy to buildings in 2035. I convert this figure to primary energy based on the share of savings from electricity and a 3.10 site-to-source multiplier to account for losses from generation, transmission, and distribution.

greater social damages, and that such incentives could be implemented by modifying the way in which codes determine compliance. In particular, I present a model that shows that energy codes would be improved if compliance was determined by the projected social damages associated with a building's design under normal usage patterns, as opposed to the projected private energy expenditures, as is current practice.[2] Buildings consume multiple types of energy (electricity, natural gas, and fuel oil) and structuring codes such that compliance was determined by social damages would provide relatively stronger incentives for conservation of energy types associated with greater social harm. Additionally, damage-based codes would allow codes to be responsive to regional differences in the sources used for electricity generation (e.g. coal, hydropower) because region-specific electricity damage rates could be employed based on the regional generation mix.

After presenting the model, I use state-level data on energy consumption, emissions rates, and energy prices, to evaluate how the outcomes under damage-based codes that were motivated primarily by concerns about climate change would differ from current practice within the residential sector of the United States. I find evidence that damage-based codes would lead to substantial welfare gains and would place greater emphasis on conservation of electricity, relative to natural gas, in most states. The relatively greater emphasis on conservation of electricity is especially prominent in the Central Plains where electricity is typically generated through coal-fired plants.

In addition to relating to the literature on energy codes (Jacobsen and Kotchen, 2013; Aroonruengsawat, Auffhammer, and Sanstad, 2012; Costa and Kahn, 2011), this paper relates to a recent literature that has evaluated how the optimal design and effectiveness of various energy policies depends on the regional electricity generation mix. Graff Zivin et al. (2012) find that the influence of electric vehicles on emissions levels depends on the regional electric generation mix and that, under certain scenarios, increasing the share of electric vehicles could lead to an increase in emissions levels. Holland and Mansur (2008) find that the environmental consequences of shifting to real-time electricity pricing depends on a region's electricity generation mix, leading to reduced emissions in certain regions, and increased emissions in others. Other studies have examined subsidies for renewable generation and have found that variation exists across regions in the net emissions reductions

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[2] As I describe in Section 5, the concept of a damage-based code can also be applied in the context of a prescriptive code that determines compliance based on a set of standards corresponding to individual building components.

achieved through increasing wind power, and that the variation is driven by differences in the existing electricity generation mix (Cullen, 2013; Kaffine, 2013; Novan, 2012). I contribute to this literature by showing that the impacts of energy codes are influenced by the regional electricity generation mix. This insight is arguably of at least equal policy relevance as the insights provided by previous studies due to the greater importance of energy codes in current U.S. energy policy relative to electric cars or renewable electricity (U.S. EIA, 2012a).

This paper also relates to the literature on "differentiated" policies for air pollution (Fowlie and Muller, 2013, Muller and Mendelsohn, 2009, Mendelsohn, 1986). Differentiated policies achieve welfare gains by placing greater weight on reducing emissions from sources, such as power or industrial plants, that operate in areas where emissions are associated with greater social damages. The present study contributes to the literature by providing the new insight that similar intuition can be applied to energy codes and that energy codes can be improved by providing differential incentives for conservation across energy types based on social damages.

This paper proceeds as follows. Section 2 presents background information on energy and energy codes. Section 3 provides a model of energy codes under alternative ways of determining compliance. Section 4 evaluates how marginal social damages per dollar of expenditure varies across energy types in different U.S. states. Section 5 discusses policy implications and concludes the paper.

2 Background on Energy and Energy Codes

Buildings consume energy in the form of electricity, natural gas, and petroleum (most often in the form of fuel oil) and these energies make up 69, 23, and 6 percent of total primary energy consumption in the residential sector, respectively (U.S. DOE, 2012).[3] Natural gas and fuel oil are primarily used for space heating or water heating, and electricity is used for a variety of end-uses.

Electricity is typically generated through coal-fired plants, gas-fired plants, oil-fired plants, hydropower, nuclear power, or other renewables sources (e.g., wind, solar). The manner in which electricity is generated varies substantially across regions. For example, the Midwest relies on coal-fired plants, whereas over half of the West Coast's generation comes from ei-

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[3] The remaining 2 percent comes from site-marketed and non-marketed renewables.

ther gas-fired plants or hydropower (eGrid, 2010). Generation of electricity is associated with negative externalities, which occur primarily through the production of carbon emissions and other pollutants, and the extent to which externalities occur varies across sources of generation. Coal-fired power is typically associated with the greatest social damages, renewable power is associated with the lowest social damages, and other sources fall toward the middle of the scale (Greenstone and Looney, 2011; National Research Council, 2010).

Policymakers regulate energy due to the negative externalities associated with its production and consumption, and the primary policies that regulate the energy consumption of buildings are energy codes. While energy codes are state-level policies, there is a strong degree of homogeneity across state energy codes. Most states adopt a version of the International Energy Conservation Code (IECC) for residential buildings and a version of the American Society of Heating, Refrigerating and Air Conditioning (ASHRAE) for commercial buildings (ACEEE, 2013). This homogeneity is driven, in part, by federal action. The Energy Conservation and Production Act, as amended in 1992, requires states to certify to the Department of Energy (DOE) that they have compared their energy codes to the IECC whenever the IECC is revised. More recently, the American Reinvestment and Recovery Act of 2009 requires that states commit to adopting an energy code that meets or exceeds the 2009 IECC and achieve 90% compliance of the code by 2017 as a condition of receiving part of $3.2 billion in State Energy Program grants. Federal policymakers have also considered implementing a national energy code standard, and any national standard would likely be based on the IECC code as well.[4]

While there are several ways to comply with the IECC, the compliance paths can generally be split into two groups: prescriptive and performance-based. The prescriptive compliance path requires that each individual component or system of a building's design meet a certain efficiency standard, as specified by the code. For example, the insulation used in a wood-framed wall must exceed a certain R-value and the windows must exceed a certain U-factor. In contrast, the performance-based compliance path determines compliance by the overall level of expected energy expenditures associated with a building's design.[5] In par-

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[4] If the American Clean Energy and Security Act of 2009 had passed the Senate, it would have led to the implementation of a national energy code. Provisions of the bill called for a 50% increase in stringency, relative to the 2006 IECC, by 2016.

[5] The specific language of the IECC reads, "Compliance based on simulated energy performance requires that a proposed residence (proposed design) be shown to have an annual energy cost that is less than or equal to the annual energy cost of the standard reference design. Energy prices shall be taken from a source approved by the code official, such as the Department of Energy, Energy Information Administration's State Energy Price

ticular, the expected annual energy expenditures of a proposed building must be less than the expected energy expenditures of a “baseline” building that is identical to the proposed building except that the components that relate to energy efficiency in the baseline residence are assumed to be identical to those outlined by the code. This level of expenditure is sometimes called the “energy budget”. Performance-based codes are appealing because the flexibility allows builders to identify low-cost ways of complying with the code and to respond to the preference of customers. Builders can use desirable components that do not meet the prescriptive requirements of the code so long as they compensate for the shortcoming elsewhere.

Software programs are available that have been deemed to comply with the IECC and can be used to show compliance to code officials. The RESCheck program is freely available from the U.S. Department of Energy. Another option is the REM/Rate software program, which is better able to take advantage of the flexibility built into different compliance paths, but is only available to professional Home Energy Rating System (HERS) raters.

3 A Model of Energy Codes Under Alternative Ways of Determining Compliance

This section presents a model of energy codes under alternative ways of determining compliance. I introduce the concept of a “damage-based code” that determines compliance by the total social damages associated with a building’s projected energy consumption and then evaluate how the outcomes induced by a damage-based code differ from the outcomes induced by a performance-based code that bases compliance on projected energy expenditures. I use the performance-based code as the point of comparison because it is the most appealing of the existing compliance paths due to its flexibility. For clarity, I will refer to performance-based codes based on private energy expenditures as “expenditure-based codes” for the remainder of this article.[6] Additionally, I used the term “optimal” in certain places to refer to the optimal design of energy codes. As discussed above, energy codes are likely not the first-best overall option for carbon reduction for numerous reasons, such as

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and Expenditure Report. (IECC, 2009).”

[6] Both damage-based codes and expenditure-based codes could be considered "performance-based" because they both determine compliance by a building’s overall score, as opposed to by evaluating each individual component of a building.

their focus on a single sector and because they do not provide direct incentives for carbon reduction.

The model is focused on energy, and assumes that decisions about energy are unrelated to other building decisions, such as the size of residence. Implicitly, the model assumes that builders determine the overall design of a residence and then make decisions about investment in energy efficiency based on the upfront costs of improving efficiency, future expenditures on energy consumption, and the constraints imposed by the energy code. The assumption that decisions regarding efficiency are made independently of other building decisions is supported because energy codes are designed such that the primary avenue to comply with the codes is through efficiency improvements. For example, builders cannot comply with the code by building smaller residences because the energy budget is adjusted for the size of the proposed building.

I further assume that efficiency improvements can be implemented that differentially target certain energy types. There are numerous types of efficiency improvements that lead to relatively greater savings for certain energy types. For example, investment in high efficiency lighting would exclusively save electricity. Other opportunities for differential electricity, natural gas, or fuel oil savings exist in large part because electricity is the exclusive energy source for space cooling, whereas natural gas and fuel oil are primarily used for space heating. Certain energy efficiency investments differentially impact energy demands for cooling and heating. For example, the solar heat gain coefficient (SHGC) is one of the primary parameters (in addition to the U-value) related to the efficiency of windows and it indicates the amount of energy entering through the window via solar radiation. A window with a lower-SHGC reduces demand for cooling, but increases heating demands. Builders can also differentially focus on cooling or heating demands by choosing roof or wall materials that are more reflective or that shed heat quickly (within the IECC, these concepts are capture more formally via the terms absorptance, emittance, and remittance). Materials that are more reflective or that shed heat more quickly lead to savings for cooling at the expense of heating. Radiant barriers, which are often installed outside of attic insulation or ductwork, also lead primarily to cooling-related savings.

The key result of the model is that damage-based codes are optimal and lead to welfare gains relative to expenditure-based codes unless the marginal social damage per dollar of expenditure is identical across all types of energy. The model is similar in many regards to the approached employed by Fowlie and Muller (2013) in their analysis of differentiated policies for air pollution. The key insight in the present model is that similar intuition can be applied to energy codes because buildings consume multiple types of energy, and these energies are associated with different damage rates.

3.1 Setup

Builders determine the expected energy consumption of a building by choosing which products will be used for different building components. For example, builders choose a type of wall insulation, a type of window, materials for the rooftop and for wall exteriors, the type of seals and insulation that will be used for the ducts, the lamps that will be used in permanent lighting fixtures, and the mechanical systems that will be used for heating, cooling, ventilation, and water heating. By selecting a set of components related to energy efficiency, the builder determines the expected energy consumption of the building. I denote a building's expected annual energy consumption by e_i, where i indexes energy types, $1,\ldots,K$, such as electricity, natural gas, and fuel oil, and all types of energy are measured in units of dollars, based on current prices.[7]

Builder's seek to minimizes total energy related costs, which consist of both upfront expenditures on energy efficiency and future expected expenditures on energy consumption.[8] For each energy type, total energy-related costs can be expressed as follows,

$$c_i(e_i) = f_i(e_i) + g_i(e_i).$$

where $f(e_i)$ represents upfront expenditures on energy efficiency and $g_i(e_i)$ represents the net present value of future expenditures on utility bills. The function $f_i(e_i)$ is decreasing in e_i because fewer upfront expenditures on components that increase energy efficiency are required when expected energy consumption is greater. Additionally, $f(e_i)$ is strictly convex in e_i, which follows from the conventional assumption that the costs of improving efficiency are strictly convex. The net present value of future energy expenditures, $g(e_i)$, are linearly increasing in e_i at a rate determined by expected energy prices. The form of $f(e_i)$ and $g(e_i)$ implies costs are strictly convex in e_i across all energy types. I further assume

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[7] Dollars are the common unit of measurement used by the IECC to compare different energy types.

[8] Builder's care about future expenditures because efficiency-related energy savings are capitalized in the price of buildings (Papineau, 2013; Brounen and Kok, 2011; Eichholtz et al., 2010).

that a building's costs are initially decreasing in e_i, that is $c'(0) < 0$, which rules out the non-sensible case of a building in which the optimal expected energy consumption is zero, and that there exists a value of e_i such that $c'(e_i) > 0$, which rules out the non-sensible case of a building in which the optimal expected energy consumption is infinite. Collectively, the setup described above indicates that total energy-related costs are U-shaped in e_i.

Absent the presence of an energy code, a builder seeks to minimize energy-related costs and solves,

$$\min_{e_1 \dots e_K} \sum_i c_i(e_i). \tag{1}$$

The first-order condition that defines the solution to (1) is

$$c_i'(e_i) = 0 \quad \forall i. \tag{2}$$

This condition holds when the marginal decrease in upfront expenditures on efficiency equals the marginal increase in future expenditures on utility bills.[9]

Policymakers seek to minimize the total energy-related social costs, which include both private costs, $c_i(.)$, and the social damages associated with energy consumption, such as increased climate-change-related harms from increased greenhouse gas emissions. The net present value of the social damages associated with e_i is denoted by $d_i(e_i)$, which is increasing in e_i. A policymaker solves,

$$\min_{e_1 \dots e_K} \sum_i c_i(e_i) + d_i(e_i). \tag{3}$$

The first-order condition that defines the solution to (3), denoted by $\mathbf{e}^*$, is

$$-c_i'(e_i^*) = d_i'(e_i^*) \quad \forall i. \tag{4}$$

The policymaker chooses levels of e_i that equate the marginal decrease in private costs with the marginal increase in social damages. Note that the social optimum is less than the private optimum for all energy types if marginal damages are positive, as is assumed.

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[9] Condition 2 could be written as $f_i'(e_i) = g_i'(e_i)$, however for ease of exposition, I employ a single cost term, $c_i(.)$, for the remainder of the model.

3.2 Comparing Alternatives for Determining Compliance

Now consider two policy scenarios that restrict energy consumption. In the first scenario, which represents a “damage-based” code, policymakers require that builders cannot choose a level of energy consumption that has social damages exceeding $\sum d_i(e_i^*)$. With the new constraint, builders solves,

$$\min_{e_1 \dots e_K} \sum_i c(e_i) \tag{5}$$

$$s.t. \quad \sum d_i(e_i) = \sum d_i(e_i^*)$$

The conditions that define the solution to (5), denoted by $\bar{\mathbf{e}}$, are,

$$-\frac{c_1'(\bar{e}_1)}{d_1'(\bar{e}_1)} = -\frac{c_2'(\bar{e}_2)}{d_2'(\bar{e}_2)} = \dots = -\frac{c_K'(\bar{e}_K)}{d_K'(\bar{e}_K)} \tag{6}$$

.

$$\sum d_i(\bar{e}_i) = \sum d_i(e_i^*). \tag{7}$$

The above conditions require that $\bar{\mathbf{e}} = \mathbf{e}^*$, leading to the following proposition.[10]

Proposition 1 *Under damage-based codes, the builder’s solution is the social optimum.*

Now consider a second policy scenario, which represents an “expenditure-based” code, in which policymakers require that builders choose a level of energy consumption no greater than $\sum e_i^*$.[11] Under this scenario, builders solve,

$$\min_{e_1 \dots e_K} \sum_i c(e_i) \tag{8}$$

$$s.t. \quad \sum e_i = \sum e_i^*.$$

The conditions that define the solution to (8), denoted by $\hat{\mathbf{e}}$, are

$$c_1'(\hat{e}_1) = c_2'(\hat{e}_2) = \dots = c_K'(\hat{e}_K) \tag{9}$$

$$\sum \hat{e}_i = \sum e_i^*. \tag{10}$$

The builder’s solution is not identical to the socially optimal solution unless marginal social damage per dollar of energy expenditure are equal across all energy types. If marginal social damages per dollar are not equal, then the builder’s solution involves too much consumption of the energy types associated with the greatest damages, and too little consumption

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[10] Proof in Appendix.

[11] To reiterate, expenditure-based codes reflect the current performance-based compliance path under the IECC.

of the the energy types associated with the lowest damages, relative to the social optima, leading to the following proposition.[12]

Proposition 2 *Under expenditure-based codes, the builder's solution is the social optimum if and only if the marginal social damages per dollar of expenditure are equal across all energy types.*

3.3 Graphical Exposition of the Two Energy Case

Figure 1 illustrates the difference between an expenditure-based code and a damage-based code in the simple case of two energy sources in a given region and constant marginal social damages. One energy, e_h, is associated with high marginal social damages and one energy, e_l, is associated with low marginal social damages. The width of the figure is the total energy budget, which equals $e_h^* + e_l^*$, and under an expenditure-based code a building's expected energy cannot exceed this level. The projected amount of energy from the high damage source increases when moving from left to right on the horizontal axis, and the projected amount of energy from the low damage source increases when moving from right to left.

The builder's solution under an expenditure-based code, $\hat{e}_h$ and $\hat{e}_l$, falls where $-c_h'$ intersects $-c_l'$. The social optima, e_h^* and e_l^*, fall at the point where $-c_i'$ equals d_i'. Additionally, e_h^* and e_l^* both fall at the intersection of the $-c_h'/d_h'$ and $-c_l'/d_l'$ curves, which also identifies the builder's solution under a damage-based code. Comparing the outcomes, the builder's solution under an expenditure-based code involves a greater amount of the high damage energy than optimal, and a correspondingly lesser amount of the low damage energy. The rectangle that consists of the combined black and gray shaded regions represents the relative decrease in social damages under a damage-based code, and the black triangle indicates the relative increase in private costs. The combined gray regions are the net gain in social welfare under a damage-based code.

Before moving to the empirical section, two additional points are worth making. First, damaged-based codes should only be based on damages that are unaccounted for by other policies, and energy codes may not be necessary at all in certain policy environments. For example, a cap-and-trade program that fully internalized the damages from carbon would eliminate the need for energy codes, at least from the with regard to carbon mitigation. If the

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[12] Proposition 2 follows immediately from substituting condition 4 into condition 9.

cap were set too leniently, then a code would still be appropriate, but the damage rates for each energy type should only reflect the extent by which the damages from consumption of the energy exceed the carbon price imposed on the energy by the cap-and-trade program. Secondly, the concept of a damage-based code could also be applied to the context of a prescriptive code and would involve setting more stringent standards for components that were linked to consumption of more damaging energy sources. For example, the prescriptive standards for components that are strongly related to space cooling may be set more stringently in regions where electricity, which is the sole energy used for space cooling, is associated with a relatively high damage rate.

4 Examining Marginal Damages per Dollar of Expenditure Across Energy Types and States

In this section, I examine how marginal damages per dollar of expenditure varies across energy types in the residential sector, and how this variation differs across states. Variation in the marginal damages rate across energy types determines the extent by which a damage-based code will differ from a expenditure-based code. The analysis focuses on social damages from carbon because it is one of the least regulated pollutants associated with energy consumption, and because recent legislative proposals to increase building code stringency have largely been motivated by climate change (e.g., ACES, 2009).[13]

The analysis is based on data on energy expenditures, energy prices, and carbon emissions factors. Energy expenditures and prices data are for the residential sector, and were obtained from the State Energy Data System (SEDS). While the data in the SEDS are based on buildings that have already been constructed and energy codes are most relevant to new construction, the expenditure patterns in the SEDS data are likely to be reasonably representative of patterns for new construction. According to the Residential Energy Consumption Survey for 2009, the average share of expenditures on electricity, natural gas, and fuel oil across all homes in the sample (which range in year of construction from 1920-2009) are 71%, 25%, and 3%, respectively. For the limited subsample of recent homes built after 2005, the figures are similar at 77%, 21%, and 1%, respectively.

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[13] While a comprehensive national policy for carbon emissions does not exist, certain state programs do exist, such as California's AB32 program, and the participation of many Northeastern states in the Regional Greenhouse Gas Initiative (though at present, the RGGI cap is not binding (Ramseur, 2013)).

Marginal emissions factors for electricity were obtained from Graff Zivin et. al (2012) and represent the average marginal increase in emissions, in pounds, from 1 kWh of increased electricity demand in a NERC region. Emissions factors vary by region depending on the generation mix used to meet regional demand. Emissions factors are available for each of eight National Electricity Reliability Council regions, and for each state I employ the marginal emissions factor for the state's NERC region.[14] Emissions factors for direct combustion of natural gas and fuel oil are assumed to be constant across the country and reflect the EPA's Final Mandatory Reporting of Greenhouse Gases Rule (2009). These emissions factors are 53.02 kg CO_2 per mmBtu and 73.96 kg CO_2 per mmBtu for natural gas and oil, respectively.

Rates of carbon emissions per dollar of expenditures on electricity, gas, and fuel oil for each state are reported in Table 1, as well as the difference between the electricity and natural gas rates, and the electricity emissions factor for each state's NERC region. The table is sorted by the difference between the electricity and natural gas rates such that those with the greatest difference appear first.[15] In the context of reducing carbon emissions, most states would benefit from providing stronger incentives for conservation of electricity in their energy codes, and states listed at the top of the list would experience the greatest benefits. These states tend to be located in the Midwest and Central Plains areas where electricity emissions rates are high. In contrast, states listed at the bottom of the list would benefit from providing stronger incentives for conservation of natural gas in their energy codes. These states include a number of Western and New England states. While electricity emissions rate are a significant factor in explaining the observed patterns, local energy prices are also important. For example, Colorado ranks at the bottom of the table not only because it is in a region with low emissions rates, but also because it has very low natural gas prices. This low price, in effect, limits the incentives for conservation of natural gas under expenditure-based codes.

Calculating the precise extent by which damage-based codes would differ from expenditure-based codes requires additional assumptions about the marginal cost curves and marginal damage curves and is beyond the scope of this paper. However, to shed light on the potential welfare gains from damage-based codes, I calculate the expected reduction in carbon-

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[14] More details regarding marginal emissions factors for electricity are provided in the Appendix.

[15] I focus on a comparison of electricity and natural gas because fuel oil is not the highest emissions energy type for any state and because fuel oil constitutes a small share of total expenditure for most states.

related social damages under two scenarios related to reduced energy consumption. In one scenario, I calculate the decrease in carbon-related damages from a 10 percent decline in expenditures across all energy types, and in a second scenario I calculate the decrease in carbon-related damages from a 10 percent decline in total expenditures that was targeted at the energy type with the greatest emissions rate. I assume a linear damage rate and use a social cost of carbon value of $36 per ton (Interagency Working Group on the Social Cost of Carbon, 2013).

Table 2 reports estimates of the changes in social damages associated with these two scenarios. States with large populations and large difference between the emissions rate of the most-damaging energy and the expenditure-weighted mean emissions rate see the largest differences between the two scenarios. The total row reports the total decline in carbon-based damages across the two scenarios. Targeted reductions yield an additional $524 million in reduced damages across all states, or 14% relative to the baseline of $3.8 billion. Note that the reduction in damages would be a recurring annual benefit and is for the residential sector alone.[16] I report results in per capita terms in the rightmost column of each panel, and these results highlight differences that are driven by variation in the emissions rate of the most-damaging energy and the mean expenditure-weight emissions rate. The greatest differences per capita are primarily in the Central Plains due to the high electricity emissions rate of the MRO NERC region.

As a final note, it is worth mentioning that the estimates reported in Table 2 do not address the rebound effect, which refers to an increase in the demand for energy services following an improvement in energy efficiency. Rebound effects can occur through direct, indirect, or macroeconomic channels (Borenstein, in press; Gillingham et al., 2014).[17] The implication of the rebound effect is that improvements in efficiency that are naively projected to lead to a 10 percent decrease in expenditures may actually lead to a smaller reduction than expected in both expenditures and damages. Barker (2009) finds evidence that the worldwide total rebound effect is about 50 percent, which, in combination with the figures reported in Table 2, suggests that a projected 10 percent decline in expenditures that failed

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[16] The pattern of results would differ somewhat in the commercial sector due to different consumption patterns and energy prices.

[17] The direct rebound effect refers to an increase an energy consumption due to the lower the price of energy services. The indirect rebound effect relates to a response through an effective increase in household income due to energy savings. The macroeconomic price effect refers to a response that occurs through a change in the equilibrium price of energy.

to account for the rebound effect would only be associated with a $2.15 billion decline in damages, and that the relative savings from damage-based codes would be reduced to $262 million.[18]

5 Policy Discussion and Conclusion

Building energy codes are a prominent component of energy policy in the United States and policymakers have recently considered significantly expanding their role. Despite the prominence of energy codes, the current design of energy codes creates incentives that lead to sub-optimal investment in energy efficiency. In particular, energy codes do not prioritize conservation of certain energy types even though substantial variation exists in the nature and magnitude of the negative externalities associated with different energy sources. In theory, a code could lead to conservation of a relatively benign energy while ignoring conservation of another energy associated with large social damages.

In this paper, I present theory and evidence indicating that energy codes would be improved if compliance was determined by the projected social damages associated with a building's design under normal usage patterns. An implication of damage-based codes is that the extent to which a code rewards conservation of a certain type of energy will depend on the electricity generation mix of the NERC region in which the code is operational. For example, in NERC regions with relatively dirty sources of generation, such as coal, a damage-based code would place a greater weight on conservation of electricity relative to conservation of natural gas than states with cleaner sources of generating electricity. I find evidence that, in most areas, damage-based codes that were motivated by climate change would lead to stronger incentives for conservation of electricity than is currently provided by codes for residential buildings.

The costs of implementing damage-based codes should be minimal. Software programs for code compliance are already available that project the energy use associated with a building's design, translate the usage figures into overall expenditures based on state energy prices, and compare the projected expenditure level of the proposed buildings to that of the baseline building. Implementation of damage-based codes would only require that state-specific damage rates be substituted for state energy prices within these programs.

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[18] Substantial uncertainty remains about the size of the total rebound effect (Borenstein, in press; Gillingham et al., 2014).

The concept of a damage-based codes could also be applied in the context of a prescriptive code, and would involve setting stricter standards for components that primarily lead to conservation of more damaging energy types.

In comparing the outcomes induced by expenditure and damage-based codes in this paper, I focused exclusively on social damages imposed through carbon emissions, and these results are directly of interest if energy codes are primarily motivated by carbon mitigation. However, policymakers could choose to employ damage rates that are calculated based on a broader array of public concerns, such as regional air pollution, energy security, or energy reliability. The general point in this paper is that codes should prioritize energy conservation based on social damages and that the damage rate associated with each energy type depends on state-specific factors such as the electricity generation mix. Consideration of other factors beyond the social cost of carbon would likely increase the gains from damage-based codes.[19]

Energy codes are a major component of energy policy in the United States and appear likely to remain so. This paper his described a relatively straightforward, yet seemingly unrecognized way in which energy codes could be improved. Implementation of damage-based codes that prioritize conservation of the most damaging forms of energy consumption would likely lead to substantial reductions in damages from energy related externalities, minimal administrative costs, and significant net benefits.

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[19] The difference in the damage rate across energy types is likely to increase when other factors are considered because energy types that are associated with high carbon levels are typically associated with greater amounts of other forms of externalities (Knittel and Sandler, 2011).

6 Appendix

Details regarding the marginal emissions factors for electricity. The emissions factors in Graff Zivin et. al (2012) are based on a regression procedure that estimates emissions factors for each region using hourly data on generation levels and emissions from recent years. The approach they implement accounts for trading of electricity across NERC regions and thus the estimates represent how overall emissions levels increase when *demand* in each NERC region increases. Siler-Evans et al. (2012) also calculate marginal emissions rates for NERC regions and arrive at comparable results.

A state's assignment to NERC regions is presented in Figure 2, along with a map of actual NERC regions. If a state's boundaries overlap multiple NERC regions, I use plant-level data from eGrid (2010) to calculate the share of generation within a state occurring in each NERC region and assign the state to the NERC region that makes up the greatest share of in-state generation. Twenty-two states overlap NERC regions, but the proportion of generation that takes place out of the primary NERC region is very minor for most of these states. To examine the sensitivity of the results to measurement error, I re-compute the welfare gains reported in Table 2 under the assumption that the appropriate state electricity emissions rate is the average emissions rate across all NERC regions that are represented within a state. I find nearly identical overall results.

An alternative to using NERC emissions factors is to use the average emissions factor from the plants located within each state, but due to the substantial trading of electricity that occurs across state borders, the increase in emissions associated with increased production within a state does not necessarily reflect the increase in emissions from increased demand within a state.

Proof of Proposition 1. Consider a vector, $\mathbf{e}$, that satisfies conditions 6 and 7. If c_j increases then some other energy, c_{-j}, must decrease in order to satisfy condition 7. However, if c_j increases and c_{-j} decreases, then $-\frac{c'_j(\bar{e}_j)}{d'_j(\bar{e}_j)} \neq -\frac{c'_{-j}(\bar{e}_{-j})}{d'_{-j}(\bar{e}_{-j})}$, which is a violation of condition 6, due to the strict convexity of $c_i(.)$ and linearity of $d_i(.)$. It follows that there cannot be more than one bundle that satisfies conditions 6 and 7. The social optimum, $\mathbf{e}^*$, satisfies conditions 6 and 7, hence the builder's solution under damage-based codes is the social optimum ($\bar{\mathbf{e}} = \mathbf{e}^*$).

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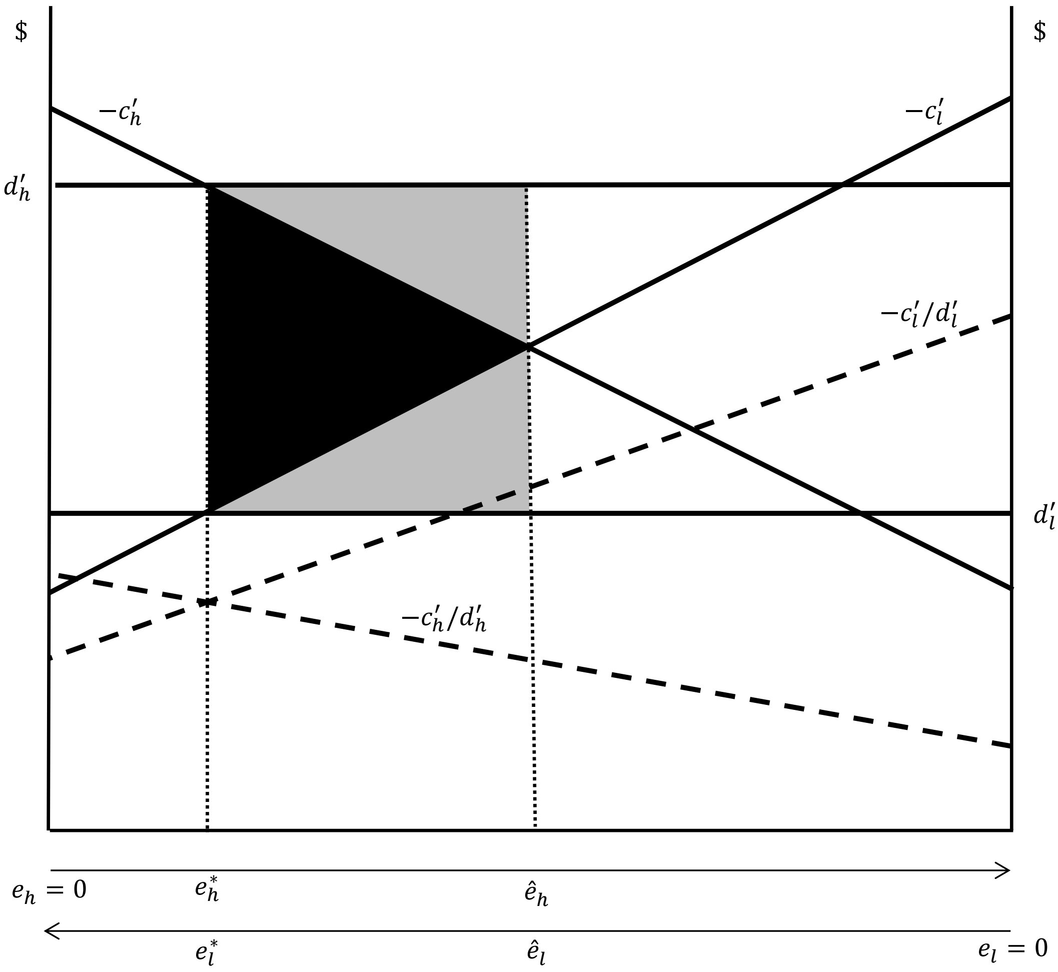


Figure 1: **Outcomes under a damage-based code and an expenditure-based code.** The width of the figure is the total energy budget under an expenditure-based code. The amount of projected energy from the high (low) damage source, e_h (e_l), increases (decreases) when moving from left to right on the horizontal axis. The $-c'$ and d' functions represent the marginal private cost savings and the marginal external damages, respectively, from the projected consumption level of the corresponding energy. The vector $\hat{\mathbf{e}}$ represents the builder's solution under expenditure-based codes and $\mathbf{e}^*$ represents both the social optimum and the builder's solution under a damage-based code. The rectangle that consists of the combined black and gray shaded regions represents the relative decrease in social damages under a damage-based code, and the black triangle indicates the relative increase in private costs. The combined gray regions are the net gain in social welfare under a damage-based code.

Table 1: CO_2 emissions (lbs.) per dollar of residential expenditures by energy type and state

		CO_2 per dollar						CO_2 per dollar			
State	Elec. Emissions	Elec.	Gas	Oil	Elec. - Gas	State	Elec. Emissions	Elec.	Gas	Oil	Elec. - Gas
North Dakota	2.30	30.61	11.60	6.85	19.01	Oklahoma	1.09	11.99	9.73	6.88	2.26
Nebraska	2.30	29.23	10.79	6.81	18.44	Michigan	1.29	12.01	10.05	6.91	1.95
South Dakota	2.30	27.80	10.59	6.91	17.21	Maryland	1.29	9.32	7.46	6.47	1.86
Iowa	2.30	24.23	10.07	6.81	14.17	Delaware	1.29	9.26	7.46	7.05	1.80
Minnesota	2.30	23.63	10.62	6.88	13.00	Illinois	1.29	11.66	9.93	6.70	1.72
Wisconsin	2.30	19.98	9.36	6.93	10.62	Washington	0.80	10.61	9.18	6.20	1.42
West Virginia	1.29	18.27	8.26	6.58	10.00	Maine	1.28	7.90	6.86	6.68	1.04
Kentucky	1.15	14.48	8.66	6.78	5.81	Arizona	0.80	7.79	6.81	6.40	0.98
Missouri	1.15	14.37	8.98	6.90	5.40	New Hampshire	1.28	8.16	7.29	7.00	0.87
Florida	1.29	11.07	5.69	6.66	5.38	Oregon	0.80	9.42	8.63	7.34	0.79
Indiana	1.29	14.54	9.48	6.77	5.06	Idaho	0.80	11.44	10.83	6.88	0.61
Georgia	1.15	11.59	6.57	6.78	5.02	New Jersey	1.29	8.24	7.88	6.42	0.35
North Carolina	1.15	12.08	7.23	6.76	4.85	Massachusetts	1.28	7.24	6.98	6.69	0.26
Ohio	1.29	12.83	8.25	6.76	4.57	Rhode Island	1.28	7.34	7.10	6.54	0.24
Virginia	1.15	11.96	7.41	6.85	4.55	New York	1.28	7.00	7.15	6.56	-0.15
South Carolina	1.15	11.63	7.12	6.66	4.51	Connecticut	1.28	6.55	6.72	6.63	-0.17
Alabama	1.15	11.06	6.55	6.70	4.50	Texas	0.96	7.36	8.72	6.56	-1.36
Tennessee	1.15	12.90	8.44	6.72	4.46	Montana	0.80	8.76	10.47	7.10	-1.71
Pennsylvania	1.29	11.36	7.39	6.71	3.97	New Mexico	0.80	7.99	9.80	6.64	-1.81
Arkansas	1.15	12.40	8.51	6.57	3.89	Wyoming	0.80	9.74	11.80	6.82	-2.06
Louisiana	1.15	11.18	7.74	6.70	3.44	Nevada	0.80	6.71	9.00	6.34	-2.29
Kansas	1.09	12.27	9.22	6.83	3.05	California	0.80	5.79	9.40	6.30	-3.61
Mississippi	1.15	11.06	8.59	6.51	2.47	Utah	0.80	9.69	13.32	6.78	-3.63
Vermont	1.28	8.84	6.55	6.37	2.29	Colorado	0.80	7.90	12.27	6.90	-4.37

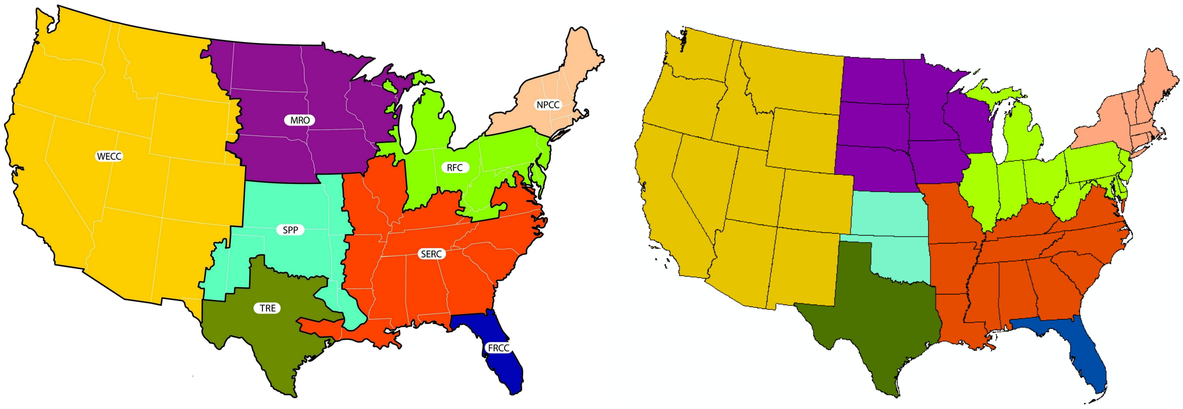
Notes: Electricity emissions are reported in lbs. of $CO_2$2 per kWh

Table 2: Reduced annual damages from carbon emissions associated with a uniform versus targeted 10 percent reduction in residential energy expenditures

State	Uniform	Targeted	Diff.	Diff. Per. Cap.	State	Uniform	Targeted	Diff.	Diff. Per. Cap.
North Dakota	19.17	26.05	6.88	10.75	Oklahoma	51.88	54.89	3.01	0.83
Nebraska	44.99	59.41	14.42	8.10	Michigan	140.95	155.27	14.33	1.43
South Dakota	19.49	24.67	5.18	6.46	Maryland	77.79	83.83	6.04	1.07
Iowa	67.99	89.69	21.71	7.25	Delaware	12.16	12.90	0.75	0.85
Minnesota	113.53	152.47	38.94	7.44	Illinois	190.05	206.05	16.01	1.25
Wisconsin	113.18	150.29	37.11	6.59	Washington	65.65	69.38	3.73	0.57
West Virginia	30.69	38.13	7.44	4.10	Maine	18.78	20.53	1.76	1.33
Kentucky	62.89	70.52	7.63	1.78	Arizona	50.95	52.03	1.08	0.17
Missouri	88.94	102.54	13.60	2.28	New Hampshire	16.92	18.13	1.22	0.92
Florida	243.10	246.02	2.91	0.16	Oregon	35.72	36.77	1.06	0.28
Indiana	102.30	119.19	16.89	2.64	Idaho	16.89	17.42	0.53	0.35
Georgia	127.81	145.70	17.90	1.85	New Jersey	115.04	119.95	4.90	0.57
North Carolina	119.71	130.09	10.38	1.12	Massachusetts	90.74	93.65	2.92	0.45
Ohio	175.73	211.87	36.14	3.14	Rhode Island	14.22	14.87	0.65	0.62
Virginia	105.54	119.76	14.22	1.83	New York	221.25	227.20	5.95	0.31
South Carolina	61.36	64.90	3.53	0.79	Connecticut	54.65	55.60	0.95	0.27
Alabama	67.85	72.95	5.10	1.09	Texas	237.94	274.84	36.89	1.52
Tennessee	92.55	99.91	7.36	1.18	Montana	10.58	11.88	1.31	1.35
Pennsylvania	181.97	222.17	40.20	3.20	New Mexico	14.99	16.88	1.89	0.95
Arkansas	39.66	42.86	3.20	1.12	Wyoming	6.18	6.95	0.77	1.45
Louisiana	61.53	64.82	3.29	0.74	Nevada	23.59	29.08	5.49	2.10
Kansas	37.61	42.17	4.55	1.63	California	215.21	289.57	74.35	2.03
Mississippi	39.02	40.37	1.35	0.46	Utah	24.42	28.75	4.33	1.59
Vermont	8.10	9.48	1.39	2.23	Colorado	49.39	62.21	12.82	2.60
					Total	3780.64	4304.69	524.05	1.74

Notes: All units are million dollars, except for the per capita figures, which are in dollars per capita.

Appendix Figures



(2.1) NERC Regions

(2.2) State assignment to NERC Regions

Figure 2: NERC regions are displayed in the left panel (Source: 2010 NERC Electricity Supply and Demand Database). The NERC region to which each state was linked is displayed in the right panel.