U.S. ELECTRIC END-USE EFFICIENCY:

POLICY INNOVATION AND POTENTIAL ASSESSMENT

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U.S. ELECTRIC END-USE EFFICIENCY:

POLICY INNOVATION AND POTENTIAL ASSESSMENT

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SUMMARY

Electric end-use efficiency is attracting more and more attention from energy users as well as utility companies and policy-makers. In the transition to a more energy efficient economy, states continue playing a leading role in saving energy while spurring economic growth and benefiting the environment. However, it remains unclear what factors are driving state policy innovation to improve energy efficiency (EE). Controversy exists over the effectiveness of energy efficiency programs and skeptics question whether state policies have significant impact in reducing energy use. Researchers tend to agree that there is potential in future energy efficiency improvement, but they disagree on the magnitude of the efficiency potential and what are the best approaches to harness America's untapped energy efficiency opportunities. Understanding the dynamics between state policies and energy efficiency is important to utility planning and policy decision-making when faced with the challenges of climate mitigation. Several critical problems are facing U.S. policymakers: state differences in energy efficiency performance, estimating the impacts of energy efficiency policies, explaining the state differences in policy adoption, and exploring potential that can be achieved with energy efficiency policies.

This dissertation investigates the relationship between policy and the energy efficiency by answering the following research questions:

- What factors drive the states taking distinct strategies in policy innovation?
- What are the impacts of policy innovation on states' electricity efficiency performance?
- What is the achievable potential in electric end-use efficiency driven by efficiency programs and policies?

It first explores the factors that influence the adoption of energy efficiency policies using Internal Determinants models. State decisions of policy adoption is quantified as policy innovations, and state socioeconomic factors, state fiscal capacity, ideology, and constituent pressure are assumed to affect policy innovation. The impact of policy innovation on energy efficiency is evaluated using historical data on state level electricity productivity. The relevance of policy innovation on future efficiency improvement is also examined with the estimation of policy-driven potential in energy efficiency. Figure ES.1 summarizes the conceptual framework of this dissertation.

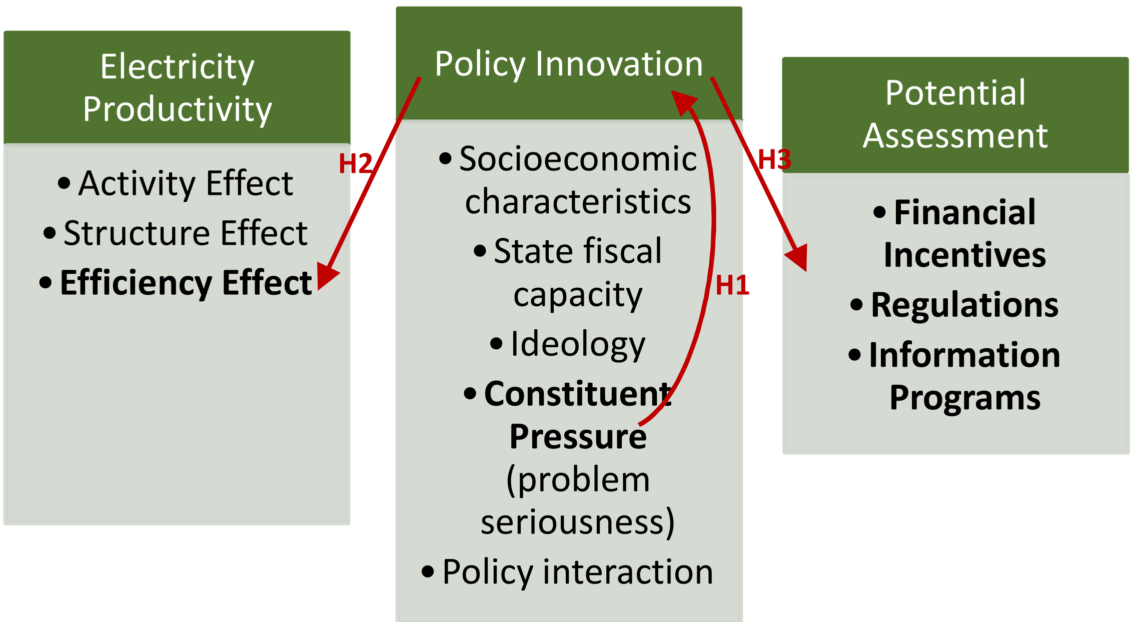

Figure ES.1 Conceptual Framework for Analyzing the Relationship between Policy Innovation and Electricity Efficiency

The internal state characteristics are used to explain policy adoption. The Internal Determinants model with fixed effects was used to examine an array of internal factors: state socioeconomic factors, state fiscal capacity, ideology, problem seriousness, and the interaction among the energy efficiency policies and programs. The variables of problem seriousness measure constituent pressure in dealing with problems of high electricity price, excessive electricity consumption, high unemployment rate, and CO_2 emissions. Chapter 4 tests for the first hypotheses related to the factors of policy innovation:

H1. Constituent pressure is related to policy innovation.

The findings suggest that financial incentives are significantly related to electricity consumption and state unemployment rates. States with high unemployment rates also invest large amount of money in energy efficiency programs. States with high electricity consumption invest less in energy efficiency programs and are less likely to adopt building energy codes.

Other constituent interests in electricity price and CO_2 emissions have no significant impact on policy innovation. In addition, the adoption of EERS, Decoupling and the Lead by Example program is not influenced by any of the constituent pressures. Rather, the policies are affected by other internal state determinants, such as GSP, state fiscal capacity, environmental awareness, and state government ideology.

Policy innovations are found to be correlated with each other. State spending/budget on energy efficiency programs are positively related to EERS targets and building codes. In addition, EERS is also positively correlated with the stringency of building energy codes. However, EERS targets are negatively related to the adoption of Lead by Example programs. The adoption of Decoupling is not significantly related to any other energy efficiency policies, while being affected by many of the internal state characteristics.

This dissertation evaluates the impact of policy innovation on energy efficiency by decomposing electricity productivity on the state level. Chapter 5 tests for the significance of policy impact on energy efficiency.

H2. Three types of policy innovations increase state electricity productivity: regulation, financial incentives, and information programs.

The underlying efficiency component of electricity productivity was separated from the activity and the structure effect. The effects of energy efficiency programs and policies are examined using fixed effect models to account for the unobserved effects fixed to the states. The time-lagged effects of the policies are tested to explain the impacts of regulations. Results from the one-way fixed effect models are compared with results from two-way fixed effect models and a feasible generalized least squares model. The findings suggest that financial incentives and building energy codes have significant impacts on state electricity productivity, controlling for the activity and structure factors. Other regulations tend to have mixed effects. Adopting decoupling mechanisms helps improve electricity productivity, while high annualized targets tend to have time-lagged effects of the Energy Efficiency Resource Standard (EERS).

This dissertation also provides a sophisticated assessment of the achievable potential for improving electric end-use efficiency in the U.S. The cost-effective potential of electricity savings that can be achieved with policy efforts is assessed through modeling of the energy efficiency policies with the National Energy Modeling System (NEMS). Cost estimations, policy impacts on the electricity market and CO_2 emissions were analyzed following the potential assessment. This approach is applied in Chapter 6 to test for the relevance of policy innovation to future efficiency improvements.

H3. The potential of electric end-use efficiency is achievable with financial, regulatory, and information policies.

The results suggest significant energy savings can be achieved with policy effort. The estimation of levelized cost of electricity from each policy scenario also suggests this achievable potential is cost-effective. More specifically, the information and regulatory policies are highly cost-effective, while the levelized cost for financial incentives are higher than the other selected policies (Table ES.1).

Table ES.1 The LCOE and Electricity Savings by Policy Type

Policy Type	LCOE in cents/kWh[a]	Electricity Savings in 2020 (TWh)	Electricity Savings in 2035 (TWh)
Financing	6.2-6.4	93.8 (3.3%)	190.8 (5.9%)
Regulation	1.3-1.8	69.9 (2.4%)	168.8 (5.3%)
Information	2.1-3.0	188.8 (6.6%)	292.8 (9.1%)

a. The lower bound is calculated based on the 3% discount rate for public and private costs. The upper bound is calculated based on the 7% discount rate for private costs and 3% discount rate for public costs.

Overall, this dissertation offers an in-depth diagnosis of energy efficiency related issues in the U.S. It explains why states take distinct strategies in improving energy efficiency with constituent pressure and other political, economic and social factors. It provides a rigorous statistical analysis covering the most important energy efficiency policies. It represents the first attempt to evaluate policy impact by decomposing electricity productivity. However, the statistical models and energy models are subject to limitations and future research is needed to improve the models.

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CHAPTER 1

INTRODUCTION

Demand-side management (DSM), especially end-use energy efficiency, has long been treated as one of the most effective way to conserve non-renewable resources, such as coal, natural gas and other fossil fuels. The potential for electric end-use efficiency has drawn broad attention and has continuously evoked great interest for the past few decades because "the cheapest megawatt hour of electricity is the one that is not produced" (Croucher, 2011). In 2005, electricity accounted for 57% of total energy consumption from non-transportation end-use sectors. Electricity generation is also the biggest sector responsible for energy-related carbon dioxide emissions (39.8%) in the country (U.S. Energy Information Administration (EIA), 2014). Reducing electricity demand through energy efficiency measures not only helps conserve fossil fuel, but also helps cut down carbon dioxide emissions.

Energy efficiency is also seen as an important demand-side resource to utility companies for capacity planning. Utilities have been encouraged to conduct Integrated Resource Planning (IRP) since the Energy Policy Act (EPACT) of 1992. IRP is usually defined as the multiple-purpose process of planning to meet the consumers' need for energy. Minimizing the environmental impacts of electricity generation and consumption is always one of the IRP objectives. IRP takes energy efficiency, along with demand response, as one important mechanism for ensuring reliable and secure electricity supply (Nadel, Yang, & Shi, 1995; Swisher, Jannuzzi, & Redlinger, 1997; Tennessee Valley Authority, 2011).

Even with IRPs, energy efficiency programs are still not very attractive to utilities because electricity sales are typically bundled with revenue and profit. Now with decoupling policies that separate sales from revenue, energy efficiency programs are gaining more and more popularity since utilities are granted the opportunity to earn money by promoting end-use efficiency (Eto, Stoft, & Belden, 1997; Lesh, 2009; Natural Resources Defense Council (NRDC), 2012). With decoupling policies, utility companies are able to work with their consumers to explore end-use efficiency opportunities, which reward both the consumers and the suppliers. Decoupling enables utility companies to actively work on programs that can cut down end-use service demands, which in return keep them from building up new generation capacities, reduce reserve margins (redundant capacities) and thus significantly cut down the marginal generation cost.

Meanwhile, possible national climate regulations make utility companies pay closer attention to energy-related carbon emissions. In order to avoid the disadvantages and risks in case of possible future rigorous climate and environmental regulations, some of the utility companies take strategic actions to exploit energy efficiency potentials that were previously ignored. Utilities favor energy efficiency and demand-side options because of the low cost.

Currently, the lowest cost of power production in the U.S. is around 5 cent/kWh, which is primarily driven by power plants using natural gas combined cycle (Bloomberg New Energy Finance, 2014). Other conventional supply side technologies, such as coal and nuclear, generally have slightly higher levelized cost of electricity (LCOE). Renewable energy, such as solar, wind and geothermal, have much higher LCOEs than fossil fuels in electricity generation. Comparing with renewable energy resources and other supply-side approaches, energy efficiency has relatively low cost in providing environmental benefits (Figure 1.1). In fact, energy efficiency is usually seen as the least cost solution to climate mitigation.

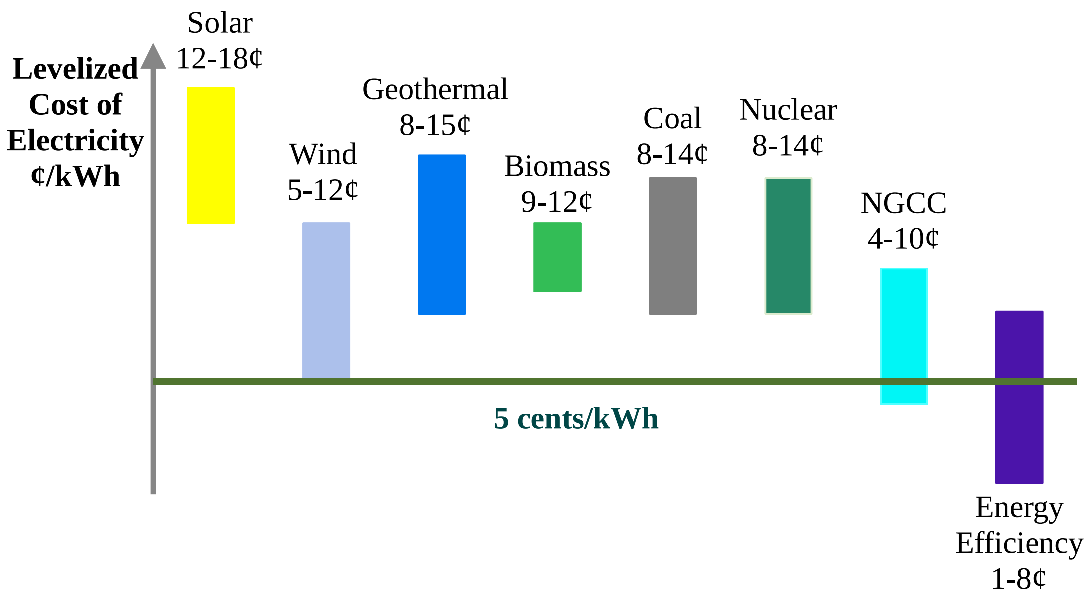

Figure 1.1 Levelized Cost of Electricity by Resource Type[1]

Over the past three decades, energy efficiency has been serving as the most important fuel of the U.S. economy, although often ignored (Figure 1.2). The domestic energy supply falls far below the actual level of energy demand, requiring large amount of energy being imported from other countries. Thanks to the improvement in energy efficiency, the U.S. economy is able to avoid significant amount of energy usage, leading to a much lower level of energy import. Energy efficiency is considered as the "hidden fuel" easing the burden of energy import for our society, while some advocates claim it as the "first fuel" which helps power up our economy and alleviates the burden of our environment (Steven Nadel, Shipley, & Elliott, 2004).

[1] Data source:(Bloomberg New Energy Finance, 2014).

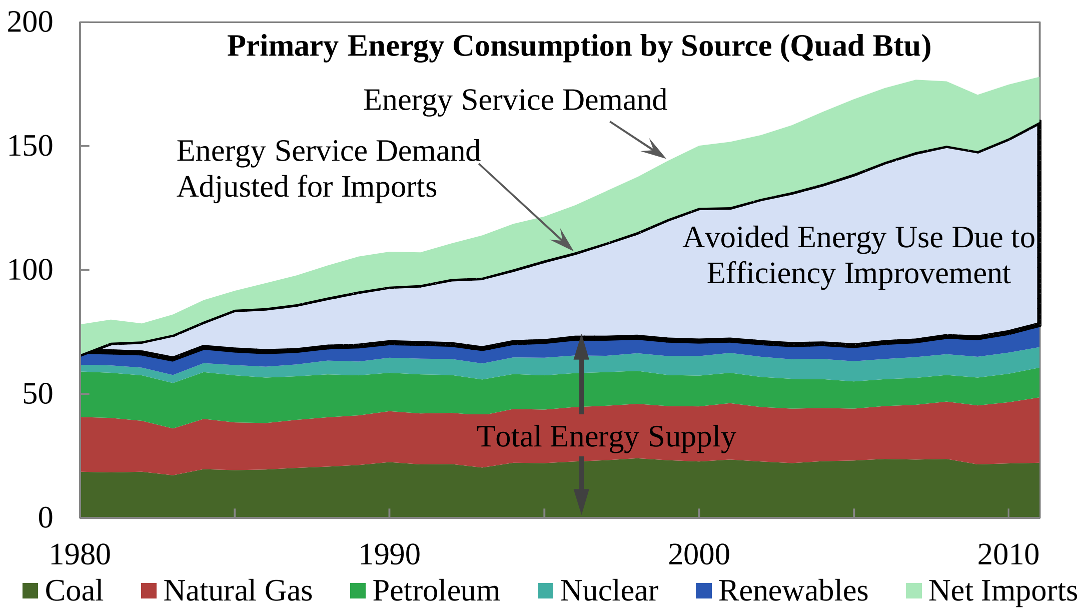

Figure 1.2 Total Energy Supply and Demand, 1980-2010

The great potential in energy savings and other social benefits have started to draw policy makers' attention to energy efficiency as well. State governments have devoted great efforts to improving energy efficiency with a broad set of programs and policies. States have adopted various levels of building energy codes with shell efficiency requirements for new residential and commercial buildings. Many states have imposed appliance standards on end-use equipment manufactures to require minimum efficiency for their products. Currently, over 20 states have adopted energy efficiency resource standards (EERS) and goals aiming at end-use electricity savings from end-uses (Database of State Incentives for Renewables & Efficiency (DSIRE), 2014). There are a broad set of financial incentives targeting efficient appliances and equipment provided by state and local governments. Many states run educational and demonstration programs to assist energy users with the adoption of emerging technologies.

Utilities also started to play an important role in promoting energy efficiency. To engage their customers, utility companies provide a variety of financial incentives to reduce the cost of energy efficiency measures, including rebate programs, low-interest loans, and other financial programs. These programs usually target high-efficiency appliances and equipment in residential and commercial buildings, building envelope improvements, lighting improvements, combined heat and power systems, high-efficiency electric motors, drives, and controls, solar water heaters, and distributed generation, etc. Most of the financial resources currently available to consumers for efficiency improvements are offered by local utility programs, including over 1,000 rebates and over 100 loan program (DSIRE, 2012).

Complementary to state and local efforts, federal government and agencies have enacted policies and run diverse programs to promote energy efficiency. The Energy Policy Act of 2005 (EPA 2005) requires the U.S. Department of Energy (DOE) to set appliance efficiency standards for residential and commercial products. The Energy Independence and Security Act of 2007 (EISA) established new standards for general service lighting in buildings and sets minimum efficiency requirement for motors that are used for various industrial systems. Financial incentives are also available where federal funds are provided for renewable energy and energy efficiency through the nationwide Property Assessed Clean Energy (PACE) financing program (Coley & Hess, 2012).

No doubt that energy efficiency is attracting more and more attention and getting greatly boosted with support from both the private and the public sectors. Also, state governments are getting attracted to adopting policies to promote energy efficiency. However, it remains unclear whether the policies do lead to energy efficiency improvements and what are the factors influencing state decisions in policy adoption. How do the states perform on electric end-use efficiency and what are the potentials? Are current policies effective and sufficient in improving electric end-use efficiency? This dissertation tries to do cross-state comparisons in efficiency performance and assess the electric end-use efficiency potential. It aims at capturing the actual policy impacts on promoting energy efficiency and explaining why states take different approaches in policy innovation. It also estimates the achievable potential driven by a set of well-designed policies for the nation as a whole.

The dissertation is organized as follows. The second chapter summarizes the relevant studies in the literature to lay out the background of the state-level study on policy innovation. Chapter 3 explains the methodology, the conceptual framework, and the selected policies being involved in the assessment. Chapter 4 explains the differences in state strategies with constituent pressure and other internal factors. Chapter 5 presents the findings from the fixed effect model estimating the impact of policy innovation on state electricity productivity. Chapter 6 presents the assessment of the achievable potential in energy efficiency with energy modeling. Although the study will be largely U.S. focused, the findings can be generalized and applied to other regions of the world. For instance, the relationships between policy, energy price and energy efficiency, and the policy impact in an energy crisis scenario may hold true in other countries with different effect sizes but same directions.

CHAPTER 2

LITERATURE REVIEW AND PURPOSE OF STUDY

There exists a growing body of literature studying energy efficiency and state energy policies. This chapter summarizes the most important theories and studies relevant to the models and concepts used in this dissertation. The first section introduces the energy efficiency gap and the market barriers causing this gap. The second section summarizes the decomposition theory for energy efficiency indicator, followed by the studies assessing the potentials in future energy efficiency improvements. The next part introduces the concept of policy innovation and policy diffusion theories.

The demand for electricity is derived demand since individuals and businesses do not generally demand electricity directly. We consume electricity as an intermediate energy form because the goods and service (output) we desire generally require electricity as an input in their production. Electric end-use efficiency is different from energy conservation which focuses on reducing energy input by adjusting the overall output decision. The concept of energy efficiency refers to reducing energy input required for a given output by improving the energy conversion and utilization process of energy-using durables. Energy efficiency is improved by reducing the energy-intensity of the production process when highly efficient equipment is used to perform the required output functions with relatively low energy input.

In order to reduce energy expenditures, energy users have the incentive to purchase affordable efficiency technologies to reduce energy consumption. But energy efficient technologies have not gained the expected popularity in the marketplace. The actual penetration rate is much lower than theoretical penetration rate for efficiency equipment even when the cost is in the affordable range for average customers. An energy efficiency gap exists when the penetration rate is low for cost-effective energy efficiency measures.

2.1 The efficiency gap and barriers to efficiency

The term of efficiency gap was first mentioned by Eric Hirst and Marilyn Brown in a paper entitled "Closing the Efficiency Gap: Barriers to the Efficient Use of Energy" in 1990. Hirst and Brown argue that a large untapped potential exists between real world efficiency and the cost-effective efficiency given government policies and programs (Hirst and Brown, 1990). This article briefly summarizes the structural barriers and behavioral barriers to energy efficiency. Then, four years later, Jaffe and Stavins (1994) published a paper ‘The energy Efficiency Gap, What does It Mean?’, defining the efficiency gap as the difference between the actual and optimal energy use for given outputs. The article marks the existence of an “energy paradox” that energy efficiency is not widely adopted, and tries to explain the energy efficiency gap by market failures (lack of information and the principal-agent problem) and non-market failures (high discount rate, cost of adoption, population heterogeneity, and behavior inertia). Grounded in economic theory, the hypothetical optimal efficiency can be achieved by removing the uncertainties, market failures, cost barriers and environmental externalities. The paper is frequently cited and generally recognized as the study which inspires a broad set of subsequent studies.

Realizing the existence of an energy efficiency gap, many studies focus on its explanation by identifying barriers to energy efficiency. There is a cluster of studies investigating the technical, market, and behavioral barriers. Energy efficiency measures generally bear high initial costs, while rewarding the adopters with low energy expenditures during their lifetime. By looking at the net present value (NPV), many energy efficient technologies are cost-effective with net savings based on life-cycle cost analysis. In economics, a rational consumer would adopt energy efficiency technologies when they are cost-effective. But in practice, adoption usually happens in the replacement stage, that is, when households and businesses have to replace their broken or ill-functioning equipment. If individuals are not at the replacement stage and want to adopt the energy efficiency technologies, they have to bear additional cost by foregoing some years of lifetime of the current equipment (Croucher, 2011). Given that many energy-using appliances and equipment are durable goods, this 'broken then fix/replace' phenomenon helps explain the limited penetration rate of energy efficiency technologies.

The impact of high discount rate - as one of the major barriers to energy efficiency - is also broadly discussed (Hausman, 1979; Howarth, 2004; Koopmans & te Velde, 2001). By studying household behavior in purchase of energy efficient appliances, Hausman (1979) estimates the discount rate to be about 20% in the trade-off between capital cost and operating costs associated with energy durables. High discount rates largely diminish the impact of future energy savings and make efficient technologies not cost-effective in the NPV sense. Households and businesses apply high discount rate in energy efficiency investments due to two reasons. First is the uncertainty about future energy prices and savings in energy expenditure. The second reason is the irreversibility (or high sunk cost) of efficiency investment (Jaffe & Stavins, 1994). Croucher (2011) suggests that offering financial incentives is an effective way of improving the rate of return of efficiency investments.

To make an investment in energy efficiency measures, a consumer must be aware of the available efficiency options, possess enough capital, motivation and know-how, and be able to make the investment decision (Reddy, 1991). Energy efficiency technologies are under-invested because sometimes the consumers are not aware of their existence, while search cost is usually high for new technologies. Even with the awareness of new technologies, consumers may not have the knowledge of installing, using and maintaining new equipment. Lack of information and expertise is a general barrier to energy efficiency (Howarth & Andersson, 1993).

Another general barrier is that consumers do not have the capital to invest in energy efficiency equipment that is relatively expensive. A significant percentage of consumers may not be able to afford efficient technologies due to the high up-front costs (Nagesha & Balachandra, 2006). Even when loans are available, a relatively high borrowing interest rate may prevent consumers from adopting these technologies (Wang, et al, 2008).

Many consumers lack adoption motivation either because they are indifferent to efficiency improvement or because of the loss aversion behavior. For consumers who can afford efficiency improvement but take no action, purchasing energy efficiency equipment may only be a small part of their consumption decision and they do not care about potential energy savings. Loss aversion behavior can also explain the inertia of capable consumers where they place a greater emphasis on adoption costs than the future savings in energy expenditure. They are more satisfied by avoiding the adoption costs than taking the risk and make an efficiency investment (Brown, Chandler, & Lapsa, 2010).

In many occasions, energy users do not have the capacity to make the adoption decision because of the principal-agent problem, where the individual who make the investment decision is not the individual who benefits from future energy savings (Vernon & Meier, 2012). For instance, the landlord makes the decision of whether or not adopt energy efficiency appliances and equipment, while the tenant who pays the energy bills benefit from the energy expenditure savings. Another classic example is the home builder - buyer relationship. Home builders are the usually ones who make installation decisions about building envelope and large equipment for space heating, air-conditioning and ventilation (HVAC) in a new house. Although home buyers are the one who will live in the house and pay energy bills, they generally have no option of choosing building shell and HVAC equipment at the point of sale (Brown & Sovacool, 2011).

Other than the barriers facing energy consumers, barriers also exist in other segments of the market preventing the adoption of energy efficiency. Efficiency improvement usually decreases sales of end-use equipment due to high first costs of new technologies. End-use equipment manufacturers and retailers response to the first cost sensitivity by mainly supplying low cost (usually low efficiency) equipment in the marketplace, leaving consumers few choice of high-efficiency products (Reddy, 1991). For most utility suppliers and distributors who have no decoupling policies, more electricity / energy sales means more revenue and more profit. Thus utility companies have little motivation to promote end-use efficiency either (Eto et al., 1997; Lesh, 2009).

Although there are many policies specifically designed for promoting energy efficiency, there exist policies creating complexities and difficulties to efficiency improvements. In fact, the U.S. energy market is the victim of multiple-level, heavy regulations, which make the efficiency measures hard to stand out in the marketplace. There is a pretty chaotic regulatory body on the energy flow chain from suppliers and distributors to consumers. Energy regulations are composed of rules from federal agencies, such as Federal Energy Regulatory Commission (FERC) and Federal Power Marketing Administrations (FPMA), state and local regulations, policies of utility companies and balancing authorities, as well as non-government statutory organizations such as North American Electric Reliability Corporation (NERC). Multi-level regulations create complications that impede the expansion of efficiency measures. A group of studies suggest deregulation in the U.S. electricity market (Goto & Tsutsui, 2008; Horowitz, 2006; Sueyoshi & Goto, 2011).

Generally speaking, there are numerous potential barriers to energy efficiency which can explain the slow adoption of efficiency measures. Some of the barriers can be overcome by policy interventions, while others may remain insurmountable due to their inertial nature. The study of energy efficiency gap and barriers are valuable in guiding policy-makers to creative policy instruments that can help shrink the efficiency gap.

2.2 Energy consumption patterns and energy efficiency indicators

In order to construct an appropriate index for electricity efficiency, one must understand the pattern of electricity consumption in individual end-use sectors. Many studies characterize the energy uses in residential and commercial buildings and industry. For commercial buildings, energy consumption is usually affected by weather/climate factors, building characteristics (for example, HVAC system design and indoor temperature setting), and many other socio-economic factors, such as occupancy pattern and building use (Carvalho, et al, 2010; Escrivá-Escrivá, et al, 2012; Kua & Wong, 2012; Monts & Blissett, 1982). For residential buildings, household income, family composition and other household demographics are common explanatory factors for residential energy consumption other than building characteristics (Brounen, et al, 2012; Cayla, et al, 2011; Joyeux & Ripple, 2007; Yun & Steemers, 2011). For instance, Poyer, et al (1997) demonstrated that Latino households consume significantly more energy than households of other ethnic groups.

On the aggregated level, energy consumption in the building sector is affected by many socio-economic factors. A cross-sector study on state energy intensities shows that residential consumption efficiency (energy per capita) is significantly affected by disposable income, employment per capita, electricity and gas prices and climate. In the commercial sector, energy efficiency (energy per gross state production) is largely influenced by business structure (e.g., retail trade/health/financing industries as the share of commercial activities), energy price and climate (Bernstein, et al, 2003). Other studies find building equipment, floor space and lifestyle as significant explanatory factors for energy consumption in the building sector (Murakami et al., 2009; Zhang, et al, 2010).

Energy consumption pattern is much more complex in the industry sector, the most diversified economic sector, than that in the building sector. The U.S. industrial sector, which encompasses diverse manufacturing and non-manufacturing activities, has energy requirements for all kinds of fuel types. Manufacturing industries dominate the energy demand in this sector, while the top energy consuming industries do not necessarily generate top values of production (Bureau of Economic Analysis, 2009; Manufacturing Energy Consumption Survey, 2006).

Industrial electricity consumption is always tied with specific industrial processes (National Research Council, 2009). In the iron and steel industry, energy consumption mainly goes to iron making systems, including blast furnace, coking, balling and for sintering (Guo & Fu, 2010). In the meat industry, the main use of electricity is cooling, compressed air, lighting and machines (Ramirez, Patel, & Blok, 2006). In the cement industry, electric power is mainly used for cement grinding, raw material grinding, and clinker burning and cooling (Schneider, et al, 2011). The industrial process is so diversified and complex that energy consumption usually needs to be decomposed within the industrial sector, or even within sub-sectors (B. Ang, 1994; B.

Ang, Mu, & Zhou, 2010). There are also several cross-cutting industrial technologies that are key to improving electricity efficiency, especially motors and combined heat and power (Brown, et al., 2014).

It is reasonable to assume that policies also have the capability to influence end-use energy consumption. In fact, there is continuous attention paid to the policy issues of improving energy efficiency in end-use sectors (Beerepoot & Beerepoot, 2007; Iwaro & Mwasha, 2010; Liu, et al, 2009; Uihlein & Eder, 2010). Some of the studies have been focusing on the regulations and policies in the U.S. (Lee & Yik, 2004; McClelland & Cook, 1983). But few studies have evaluated the policy impacts on the pure efficiency effect. Rather, most of the estimated policy impacts are based on indicators of energy efficiency. The policy impact needs further investigation on the true underlying efficiency effect.

Generally speaking, end-use electricity usage is affected by a broad set of socio-economic factors, making the indicator of energy efficiency take various forms in application. Energy efficiency indicators are indices representing the level of efficiency by measuring the energy input for a given output. An intensity index is usually used to reflect the efficiency level. Energy intensities normally used are ratios of energy per physical or monetary values (Bor, 2008). For example, energy intensity in the residential sector usually means energy per capita or energy per household, while energy intensity in commercial buildings is usually measured in energy per unit floor space. In the industrial sector, energy intensity is typically measured by energy per industrial GDP, while its inverse form, GDP per energy, is called energy productivity.

Users of energy efficiency indicators must be aware of two problems: the rebound effect and the efficiency versus comfort problem. Rebound effect in the energy efficiency field refers to the phenomenon that consumers tend to use more energy with more-efficient equipment (Sorrell

& Dimitropoulos, 2008). A simple economic explanation is that consumers tend to increase the amount of energy usage when the marginal cost of energy goes down with efficiency improvements. Although studies find rebound effects to be small, it is likely that energy savings from efficiency programs are compromised to some extent by this takeback phenomenon (Greening, et al, 2000; Bentzen, 2004; Sorrell, et al, 2009).

The second problem is related to the general assumption of efficiency that providing the same service using less energy input. One may argue that in some cases efficiency measures compromise human comfort to save energy. For instance, Pitts & Saleh's study (2007) suggests that energy efficiency improvements can be achieved by allowing a modest relaxation of the comfort standards in building transition spaces. Similarly, energy efficient lighting creates higher illumination with the same energy but may lead to increased risk of discomfort glare (Linhart & Scartezzini, 2011).

But there is evidence pointing to the opposite direction that energy efficiency improvements generate energy savings as well as increased health and comfort (Boardmand, 1994; Clinch & Healy, 2001). One simple example is homes with improved insulation which can generate savings in heating bills with reduced energy use. Or, the occupants can increase their comfort level by allowing indoor temperature to rise and forgoing part of the potential energy savings. It is possible that improved insulation benefits the homeowner with both low heating bills and increased comfort (relative high indoor temperature) in the winter. With proper building and plant operation, energy efficiency can be achieved without lowering thermal comfort level (Clinch & Healy, 2001; Tham, 1993).

Studies also find visual comfort not compromised by efficiency improvements. Technology improvements in high-efficiency lighting bulbs have been able to untangle some of the issues of unpleasant visual comfort associated with early compact fluorescent bulbs. The Linhart & Scartezzini (2011) study finds that efficient lighting increases lighting power density without jeopardizing visual comfort and performance. Other energy efficiency improvements, such as glass windows using solar film coating, are found to be able to reduce energy consumption in both cooling and lighting, while sustaining thermal and visual comfort for occupants (Li, et al, 2008). Moreover, good building facade design improves energy efficiency by utilizing natural daylight instead of artificial lighting (Pitts & Saleh, 2007). In general, energy users do not need to make trade-offs between efficiency and comfort. But rather, efficiency can be achieved without compromising comfort (Linhart & Scartezzini, 2011; Tham, 1993).

Energy efficiency indices can be applied on different geographic levels: regional, national and supranational level, and applied on different aggregation levels: the whole economy, end-use sectors, and subsectors (Bor, 2008). One trend of the energy efficiency indicator studies is to decompose the index to a deeper disaggregation level. The other trend of this field of study, on the opposite direction, is to construct an efficiency index for the whole economy to do cross-country, and/or cross-region comparisons.

Decomposing energy consumption into subsectors or end-uses provides great insights for studying the changes in energy efficiency over time and conducting cross-region comparisons (Ang, Mu, & Zhou, 2010; Filippini & Hunt, 2012; Haas, 1997). Structural decomposition analysis (SDA) based on input-output models and index decomposition analysis (IDA) are the two popular ways of understanding energy efficiency changes (Choi & Ang, 2012; Weber, 2009). For IDA, Laspeyres index and Dividia index are widely used for decomposition calculations, while many advanced indices are developed based on their multiplicative or additive forms, such as Logarithmic Mean Divisia Index I (LMDI I), Logarithmic Mean Divisia Index II (LMDI II), Arithmetic mean Divisia index (AMDI), Fisher Index, etc (Ang, 2004; Ang et al., 2010; Ang & Liu, 2007).

By decomposition, changes in energy consumption or energy efficiency can be explained by factors such as structural effect, activity effect and intensity effect. Table 2 illustrates some of the recent studies investigating energy efficiency changes and trends using decomposition methods. Many recent studies decompose energy consumption and efficiency in the residential and industrial sectors, using the LMDI method (Ang et al., 2010; Choi & Ang, 2012). In reviewing these decomposition studies, this dissertation does not focus on the calculation methods. But rather, the purpose is to identify the underpinning factors on energy consumption and to distinguish the drivers for efficiency changes.

Table 2.1Decomposition Studies on Energy Consumption and Efficiency

Publication	Application			Indicator Used	Decomposition	
	Area	Period	End-use sector		Method	Factors
Zhao, et al (2012)	China	1998-2007	Residential (urban)	Energy per capita	LMDI	Energy prices, structure effects (energy expenditure share on household products, energy share of total living expenditure), per capita living expenditure, and population
Hojjati & Wade (2012)	U.S.	1980-2005	Residential	Energy per household	LMDI-II	Activity (# households), structure(the mix of housing types, the regional distribution of households, and the floor area per household), intensity (energy/square foot), and weather effect (% change in heating and cooling degree-days)
Hasanbeigi, et al (2012)	California, U.S.	1997-2008	Industry	Energy per value added	LMDI	Activity (value added of each industry sector), structure (industry subsectors), and intensity (energy/value added)
Filippini & Hunt (2012)	U.S.	1995-2007	Residential	Frontier demand / consumption	Stochastic frontier analysis	Income, energy price, household size, heating and cooling degree-days, the share of detached houses, and 'underlying energy efficiency'
Cahill & Ó Gallachóir (2010)	European countries	1995-2007	Industry	Energy per value added	Laspeyres, LMDI, AMDI, Fisher & VALDEX	Structure, intensity, and activity effects
Dong, et al (2011)	China	1985-2007	Economy wide	Standard coal / GDP	Laspeyres indexes	Industry structure adjustment, technological advancement and openness, and household energy consumption
Weber (2009)	U.S.	1997-2002	Economy wide	The ratio of energy use to economic output	SDA and LMDI I	Energy intensity, production structure, consumption structure, aggregate consumption volume (GDP), population and household consumption, trade deficit in manufacturing goods, etc.
Wachsmann, et al (2009)	Brazil	1970-1996	Industry & Residential	Total energy consumption	SDA	Affluence, population, inter-sectorial dependencies, energy intensity and per capita residential energy use
Mairet & Decellas (2009)	France	1995-2006	Service	Total energy consumption	LMDI I	Structure effect (share of sectorial output), labor productivity, equipment rate, substitution effect, and intensity effect
Lescaroux (2008)	U.S.	1974-1998	Manufacturing industry	Energy Intensity	Geometric mean Divisia index	Industrial structure effect (structural evolution), sectorial intensities effect (efficiency gains at the sectorial level), and optimized energy-mix
Unander (2007)	IEA countries	1973-1998	Manufacturing industry	Energy per unit output	Laspeyres indexes	Manufacturing outputs (value added), industrial mix, and the energy intensity of each sub-sector

The decomposition studies have tested the impacts of a broad set of factors on energy consumption changes. For residential buildings, energy efficiency is affected by affluence, energy prices, population, the number of households, household size, weather, energy mix, housing type mix and other structural factors (Filippini & Hunt, 2012; Hojjati & Wade, 2012; Wachsmann, et al, 2009; Zhao, et al, 2012). For service, manufacturing and other industries, energy consumption is affected by sector output (physical or monetary outputs), industrial structure, energy mix, labor productivity, equipment or technology advancement, energy intensity, etc. (Cahill & Ó Gallachóir, 2010; Hasanbeigi, et al, 2012; Lescaroux, 2008; Mairet & Decellas, 2009; Unander, 2007). The decomposition studies are able to provide great information to identify underlying factors driving energy consumption and efficiency changes in the building and industrial sectors.

On the other hand, economy-wide energy efficiency indices generate a cluster of studies using a non-parametric method, data envelopment analysis (DEA). Unlike the energy intensity or productivity indicators which use single metrics for calculation, DEA is capable of handling multiple inputs and multiple outputs. For given GDP and other outputs, the DEA method calculates the optimal level of energy requirements by fixing the level of non-energy inputs, such as labor and capital. The ratio of estimated optimal level of energy input and the real energy consumption is the indicator of energy efficiency (Hu & Wang, 2006; Mukherjee, 2008; Zhang, et al, 2011). Energy efficiency indices computed using the DEA method allows researchers to do cross-country and cross-region comparisons.

2.3 Assessment of energy efficiency potential and cost estimation

The potential for energy efficiency can be defined in multiple ways. Assessment studies on energy efficiency potential generally exercise three different definitions for their estimation: technical, economic and achievable potentials (Figure 2.1). The technical potential refers to the energy saving potential by all technically feasible improvement without considering economics. Technical potentials are sometimes referred to as engineering estimates (McKane & Hasanbeigi, 2011). Economic potential, sometimes called as cost-effective potential, is usually defined as the potential from economically profitable investments. Economic potentials are reached by technologies that pass a cost test, for example, a positive net present value with benefits exceeding costs (Granade et al., 2009; McKane & Hasanbeigi, 2011).

The achievable potential estimates the efficiency potential from cost-effective measures with policy efforts. The maximum achievable potential is associated with cost-effective improvements that can be reasonably achieved through policy efforts. Sometimes the maximum achievable potential goes beyond the economic potential when some non-profitable measures are adopted under aggressive policies, for instance, incentives that cover over 50% of incremental costs. The moderate achievable potentials are estimates of 'reasonable' potential with policy incentives no more than 30% of the incremental costs (Tonn & Peretz, 2007; Brown, Gumerman, et al., 2010).

In spite of the three major efficiency potential types, the naturally occurring potential is the estimated potential savings with energy efficiency improvements that are adopted in business-as-usual scenarios. Naturally occurring potential is referred to as the efficiency level expected to be achieved with current policy and typical rate of technology advancement. The baseline forecast of energy consumption usually takes into account naturally occurring efficiency improvement and thus excluding it from potential assessments.

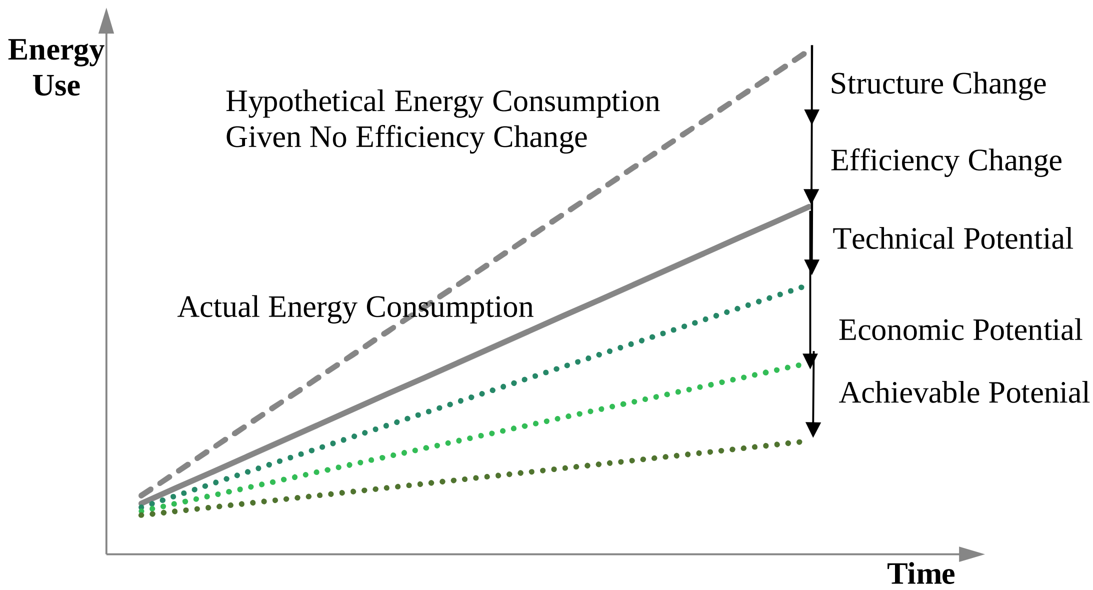

Figure 2.1 Energy Efficiency Potentials

The definition of energy efficiency potential varies from study to study. For example, technical potential generally represents the theoretically maximum potential, while some assessments add the condition of cost-effectiveness to technical potential. Economic and achievable potentials can also be defined otherwise. Some assessments even do not define their potential explicitly (Nadel, Shipley, & Elliott, 2004; Koopmans & te Velde, 2001). Clarifying the potential definition is critical when doing comparisons of assessment studies.

The assessments of energy efficiency potential, especially assessment studies with cost estimations, provide valuable information about future electricity demand for utility planning of generation capacity. By studying a broad set of energy efficiency measures, these assessments also offer great value to policy-makers with insight into the most cost-effective options. With the valuable information from these studies, policy-makers are better equipped to design energy efficiency programs and policies based on the costs estimates of a variety of energy efficiency technologies and programs.

However, many of the assessment studies focus on the cost-effective potentials based on a portfolio of energy efficiency measures, without taking into account policy context (Table 2.2). Only a few studies investigate the saving potential achieved by energy efficiency programs. One of the recent studies explores policy options promoting energy efficiency (Brown, Gumerman, et al., 2010). Two of the recent studies estimate the achievable potential driven by efficiency programs (Scott, et al, 2008; Tonn & Peretz, 2007). Potential assessment and cost estimation by specific policy or policy design is needed by policy-makers.

Table 2. 2 Energy Efficiency Potential Assessments

Publication	Application		Potential Assessment		Cost Estimate	Policy Relevance
	Area	End-use sector	Type	Estimation		
Azevedo, et al. (2013)	U.S.	Residential	Technical	23-38%	$1.7-1.9 Trillion	
Navigant Consulting, Inc. (2013)	U.S. Eastern Interconnection	Building and Industry	Achievable	9% in 2030 [b]		Assessment based on utility energy-efficiency programs
Annual Energy Outlook (EIA, 2013a)	U.S.	All Sectors	Economic	9.3% in 2040		
Laitner, et al. (2012)	U.S.	All Sectors	Technical	42-59% by 2050		
Sadineni, et al. (2011)	U.S.	Residential	Economic	42.5%		
Saygin, et al. (2011)	U.S.	Chemical and petrochemical industry	Economic	10.9-24%		
Brown, et al. (2010)	U.S. South	Residential, Commercial and Industry	Achievable	9-12% in 2020; 13-18% in 2035	Levelized cost of electricity: 0.9-15 cent/kWh	Explores 8 policy options promoting efficiency
Kneifel (2010)	16 cities in the U.S.	Commercial	Economic	20-30% for new buildings		
EPRI (2009)	U.S.	Building and Industry	Achievable	8-11% in 2030		Utility DSM programs
McKinsey & Co. (2009)	U.S.	Building and Industry	Economic	23% by 2020	Average annualized cost: $4.4/MMBtu	
Scott, et al. (2008)	U.S.	Residential and Commercial	Achievable	27% of expected growth by 2030		Impacts of the 2005 Building Technology program

a. All assessments are for total energy savings, except for the EPRI (2009) study which estimates the potential for electricity savings.
b. The potential energy savings is derived from the difference between the reference case and the Best Available Demand Technology case.

The assessment of energy efficiency potential is derived from both theories/simulation models and real world practices. A study by the American Council for an Energy-Efficient Economy (ACEEE) did a meta-review on assessments in both approaches in the U.S. (Nadel et al., 2004). A summary of electricity efficiency potential from this ACEEE study indicates that the median technical potential is 33%, median ecomic potential is 20%, and the median achievable potential is 24%. The median achievable potential is 1.2% savings per year, with similar savings from each end-use sector. The number of years estimated and the type of potential estimated vary largely from study to study, making the median numbers relatively unreliable estimations. This study also summarizes the electriciity savings actualy achieved by utilities in some of the leading states based on historical data. The leading utilities were estimated to achieve 0.5-2.0% of electricity savings annually.

A state-level study estimates the achievable potential driven by standard residential and industrial energy efficiency programs to be 20-30% over a 20-year period. The programs studied in the article are generally cost-effective with benefit to cost ratios exceeding 3:1(Tonn & Peretz, 2007). In a McKinsey study of energy efficiency programs in non-transportation sectors, the economic potential, defined by net present value positive options, is estimated to be 9.1 quadrillion Btu (23% of projected energy consumption) in 2020 (McKinsey & Co., 2009). A report focusing on the southeast part of the U.S. estimates the potential energy savings to be 9-12% in 2020 and 13-18% in 2035. The estimated potential can be achieved by cost-effective policies and programs promoting energy efficiency in the South (Brown, et al., 2010).

There are also many potential assessments based on specific economic subsectors in the literature. A study on pulp and paper industry estimated the savings due to 17 process technologies for improving energy efficiency up to 2035. The economic potential assessed is 16% for electricity and 21% for all fuels (Fleiter, et al, 2012). An assessment based on Best Practice Technology in the chemical and petrochemical industries estimate the potential energy savings for the U.S. to be about 24% using a top-down approach and about 10.9% using a bottom-up approach (Saygin, et al, 2011). The energy efficiency for industrial motor systems is estimated for both cost-effective and technical potential in McKane and Hasanbeigi's study (2011). The assessment is 14-49% as the cost-effective potential, and 27-57% as the technical potential. These assessments are relatively aggressive compared with an earlier work, which estimated the policy driven potential for industry to be 7-17% by 2020 from different policy scenarios (Worrell & Price, 2001). A review of assessments on the U.S. industry sector shows a wide range of estimates of energy efficiency potential within and across industries in 2020: 3% – 18% savings for chemical industry, 5% - 23% for petroleum refining industry, and 6% - 37% for pulp and paper industry (Brown, Cox, & Cortes, 2010).

In addition to the industry sector, energy efficiency measures applied to residential and commercial buildings are also studied by many researchers. A recent study on energy efficiency in residential buildings estimates the cost-effective potential to be 42.5%, with encouraging benefit/cost ratios (Sadineni et al., 2011). A simulation of 12 prototypical buildings in 16 cities provides the basis for assessing the energy efficiency potential in commercial buildings, with the cost-effective estimation of 20-30% on average for new buildings and up to over 40% for some building types and locations

(Kneifel, 2010). DOE estimated the impacts of its energy efficiency programs and found that the 2005 Building Technology program could save about 27% of energy in residential and commercial buildings by 2030. These savings were evaluated to have the potential of increasing employment and reducing the need for capital stock in the energy sector (Scott, et al, 2008).

Energy efficiency potential assessments are usually coupled with cost estimations, especially in studies investigating the cost-effective potential. Cost estimations for energy efficiency measures vary widely due to the different cost accounting methods applied in different studies. By reviewing several studies, Gellings, Wikler, & Ghosh (2006) found that efficiency cost estimates from different studies range from 0.8 -22.9 cents/kWh. In the McKinsey report (McKinsey & Co., 2009), the average annualized cost for energy efficiency measures ranges from $0.4-16 /MMBtu, averaging at $4.4 per MMBtu end-use energy saved (McKinsey & Co., 2009). An achievable potential study conducted by the Electric Power Research Institute (EPRI) found the potential energy saving achieved by energy efficiency programs to be 398-566 billion kWh (8-11%) in 2030, with estimated levelized cost from $0.022-0.032/kWh (Electric Power Research Institute (EPRI), 2009). With cost estimates, many studies are able to draw an energy conservation supply curve, also called energy efficiency supply curve to identify the most cost-effective options for the 'low hanging fruit' - energy efficiency (Gellings et al., 2006; Koopmans & te Velde, 2001; McKinsey & Co., 2009).

In case of rapid fuel price increase or electricity shortage, the need for energy conservation and efficiency improvements is usually high (Archibald & Reece, 1977; Rosa & Lomardo, 2004; Ruble & Nader, 2011). Policies and legislation are frequently recommended to improve market penetration for emerging technologies and promote energy efficiency adoptions (Bachrach, 2003; Rosa & Lomardo, 2004; E Vine, 2002). This dissertation is interested to study the role of policy for promoting energy efficiency in the case of energy crisis.

2.4 Policy Innovation and Diffusion Theories

One critical question in policy study is related to the factors influencing the decision-making process of policy adoption. The policy diffusion theory is a popular school of thoughts studying the adoption behavior of policies. Many studies in policy diffusion investigate the policy adoption on the state level. The American states are usually seen as the laboratory of policy experiments (Brandeis, 1932). However, policy treatment is seldom seen as natural experiment due to the dynamics among state governments and the interactions among state officials. State policies are often treated as quasi-experiments in policy analysis.

Grounded in the quasi-experiment assumption, the policy diffusion theory studies the diffusion of policy innovations. Policy innovation is defined as the adoption of a policy which is new to the state adopting it (Berry & Berry, 2007). It is different from policy invention – the creation and design of a policy new to all states. Policy innovation characterizes the behavior of policy adoption.

The policy diffusion theory argues that policy innovation is affected by state actions and interactions with other states and the federal government, as well as internal state characteristics. Researchers set up several diffusion models and the Internal Determinants model to explain policy innovation. The application of these models to energy policies have been seen in many studies.

The Internal Determinants model is one of the powerful models that can be used to explain the adoption of energy policies (Matisoff, 2008). This model is developed based on the theory of organizational innovation. L. Mohr (1969)argues that organizational innovation is determined by three major factors: the motivations to innovation, the obstacles to innovation, and the resources to overcome the obstacles. The Internal Determinants model assumes that internal state characteristics determine policy innovation. Political events, constituent pressure, internal economics and social characteristics are the key to policy decisions.

More specifically, bigger states that are more economically advanced, have better resources, and have more political/institutional structure will be more likely to enact policies. Constituent pressure – the pressure of constituent interest – is an important measurement of the motives or obstacles to policy innovation. The concept of constituent pressure is used to quantify the relevant constituent interests for a given policy issue during a given period.

In the Internal Determinants model, states are considered to be independent from outside forces. Outside actors or the interactions among states have no effect on policy within a state. The limitation of this model is ignoring the possibility that state policies may be influenced by factors outside of the state.

CHAPTER 3

HYPOTHESES AND METHODOLOGY

3.1 Research Questions and Hypotheses

It is not unusual to hear people say that we are inefficient because we don't have good policies to promote energy efficiency. Whether it is true or not, this statement renders four related questions about energy efficiency: how efficient or inefficient are we? What are the potentials for energy efficiency? Can policies make a real difference in promoting energy efficiency? And how do policies affect efficiency? It is clear that energy efficiency is not only important to energy users, but also an essential part of integrated resource planning for utilities. Given the continuous attention on electric end-use efficiency, this study tries to investigate the efficiency problem from the policy perspective for the U.S. states. The purpose is to assess electricity efficiency potential and explore the policy impact on states' efficiency performance. This dissertation focuses on the policy – efficiency dynamics by asking the following questions:

- What factors drive the states taking distinct strategies in policy innovation?
- What are the impacts of policy innovation on states' electricity efficiency performance?
- What is the achievable potential in electric end-use efficiency driven by efficiency programs and policies?

In order to understand state performance and policy impacts on efficiency, a set of hypotheses was designed to be tested with the methods developed in this study. The main hypotheses are:

- *H1. Constituent pressure is related to policy innovation.*

  Literature on policy diffusion uses Internal Determinants model to explain policy adoption on the state level. Theory suggest that policy innovation is affected by multiple internal state characteristics including political, economic, and social factors, and constituent pressure (Berry & Berry, 2007).

- *H2. Three types of policy innovations increase state electricity productivity: regulation, financial incentives, and information programs.*

  Many policies are found to be able to generate great energy savings, including appliance standards, building energy codes, EERS, financial incentives, and green labeling (Cappers & Goldman, 2010; Chirarattananon, et al., 2010; Fayaz & Kari, 2009; Gillingham, Newell, & Palmer, 2006; Heinzle, 2012; Meier, 1997; Wang & Brown, 2014).

- *H3. The potential of electric end-use efficiency is achievable with financial, regulatory, and information policies.*

  The achievable potential of energy efficiency is driven by policy efforts where financial, regulatory and information instruments are used to change consumer behavior in energy efficiency adoption (Brown, et al., 2010; Brown et al., 2011). More specifically, this hypothesis can be tested in three hypotheses due to the differences in policy mechanisms.

  - *H3.1 financial incentives improve energy efficiency by providing financing support to reduce the cost of capital* (Hoicka, Parker, & Andrey, 2014);

- *H3.2 information programs improve energy efficiency by offering information/training to invoke awareness, educate consumers, and assist adoption* (Newell & Siikamäki, 2013);
- *H3.3 regulations improve energy efficiency by mandating efficiency requirements to accelerate market penetration* (Kelly, 2012)

The first hypothesis is related to the explanation of the differences in state strategies of adopting policies to promote energy efficiency. Internal Determinants models with fixed effects are used to examine the factors influencing the adoption of selected policies, including state socioeconomic characteristics, state fiscal capacity, ideology, problem seriousness, and the interactions among the policies. Problem seriousness is the measurement of constituent pressure on the general problems related to energy efficiency. Hypothesis 1 assumes that states choose to adopt different energy efficiency policies and programs because their governments put emphases on different constituent interests.

To test the second hypothesis, state level electricity productivity is evaluated against a selected set of energy efficiency policies by controlling for the activity and structure factors of the residential, commercial and industrial sectors. The impacts of the selected policies are examined with fixed-effect models which deal with the unobserved state fixed effects and time fixed effects. Hypothesis 2 will be rejected if none of the coefficients of the energy efficiency policies are significant in the state fixed effect models. Otherwise, the second hypothesis will be accepted and the policies do have significant impacts on improving energy efficiency. The models also provide estimations of the effect sizes and directions of the selected policies.

As for the third hypothesis, the assessment of achievable potential will be conducted using energy modeling. A portfolio of efficiency policies will be modeled with the National Energy Modeling Systems (NEMS) to estimate the long-term achievable potential. Three type of policies, financial, regulatory, and information policies, are modeled separately and test the three sub-hypotheses. Then, all selected policies are modeled in an integrated policy scenario to examine the policy dynamics and the combined effects on energy efficiency.

3.2 Theoretical Approach

According to the decomposition studies, the change in energy consumption (or efficiency) can be explained by activity effect, structure effect and intensity effect, while activity factors are usually affected by environmental factors. Based on the multiplicative Divisia index (Ang et al., 2010), energy consumption at a certain time *t* can be disaggregated into end-uses, or industrial subsector *j*:

$$E_t = F_{act}|_{F_{env}} \times S_t \times I_t = F_{act}|_{F_{env}} \times \sum_j s_{j,t} i_{j,t} \quad (1)$$

Where, F_{act} is the activity factor, such as population, number of households, number of buildings, building floor space, and industrial outputs (monetary or physical outputs);

F_{env} is the environmental factor, such as weather factor (e.g., number of heating degree-days and cooling degree-days), income, energy price, household demographics, economy development and other environmental factors not affect by energy policies;

S_t is the inert structural factor not affected by environmental factors at time *t*, such as building characteristics, housing type, age of infrastructure, industry mix, energy mix, etc;

I_t is the indicator of energy efficiency at time *t*; I_t is affected by energy efficiency policies.

And, $s_{j,t}$ is the normalized quantity of structural service demand for end-use j at time *t*; $i_{j,t}$ is energy intensity (energy per unit of service) for end-use j at time *t*.

For example, electricity consumption in residential buildings can be decomposed by population, structural service demand (m^2/capita), and intensity (kWh/m^2).

According to classic economic theory, individual consumption behavior is usually a function of income, price and preference. By expanding the defining factors to include energy efficiency policies, we have:

$$E = f\,(I, D, Price, Policy, X) \qquad (2)$$

Where, E is energy use; I is income; D is service demand; Price is electricity retail price; Policy is energy-related policy promoting energy efficiency; and X represents a set of other explanatory factors (see Table 2.1 for examples).

A fixed effect model can be easily derived based on Equation (2) to examine policy impacts on energy productivity. Energy productivity, an indicator of energy efficiency, is regressed with explanatory factors with panel data. The treatment group consists of states that have adopted new policies or updated their energy policies in the two years. The control group, on the other hand, is the group of states having no policy change during the two time periods. Energy productivity can be expressed by the following equation:

$$EP_{j,t} = \beta_1 X_{j,t} + \beta_2 P_{j,t} + s_j + y_t + \varepsilon_{j,t}, \quad t = 1, 2, \tag{3}$$

Where, $EP_{j,t}$ is electricity intensity indicator in state *j* and year *t*; $X_{j,t}$ is a vector of measured variables (e.g., energy prices, population, climate factors, household income, and other factors) affecting state-level electric end-use efficiencies; $P_{j,t}$ is a vector of selected energy efficiency policies in state *j* and year *t*.

The construction of the factor $P_{j,t}$ needs prudence since there are enormous policy options for energy efficiency due to variations in program design. The selection of energy efficiency policies should be simple for the sake of calculation, while representative enough to cover the most popular and long-lasting policies. One possible way of selection is the 'best practice' by looking at the policy choices in best performing states based on the electric efficiency indicators. To capture full policy impact, the policy vector should be weighted by state compliance effort and number of implementation years. Thus, the treatment group is the group of states that observe a change in the policy vector, while the control group exhibits no change in the policy vector.

The time-varying residual, also called idiosyncratic error, consists of three components:

- S_j is the unobserved variable that capture fixed differences in energy efficiency across states ("state fixed effect");
- y_t is the unobserved variable that capture year effect common to all states ("year fixed effect", or "common effect");

- $\varepsilon_{j,t}$ is the unobserved random disturbance.

By taking the difference between two years, we have:

For treatment group: $\Delta EP_j = \beta_1 \Delta X_j + \beta_2 \Delta P_j + \Delta y_t + \Delta\varepsilon_j$, (4)

Similarly, for control group: $\Delta EP_j = \beta_1 \Delta X_j + \Delta y_t + \Delta\varepsilon_j$, (5)

The year fixed effect can be estimated based on the control group data:

$$\Delta y_t = \overline{\Delta EP}_{control} - \hat{\beta}_1 \overline{\Delta X}_{control} \quad (6)$$

By plugging equation (6) to equation (4), we can easily get the estimate of policy effect $\hat{\beta}_2$ from the following regression result:

$$\widehat{\Delta EP} = \hat{\beta}_1 \Delta X_j + \hat{\beta}_2 \Delta P_j + \overline{\Delta EP}_{control} - \hat{\beta}_1 \overline{\Delta X}_{control} \quad (7)$$

The fixed effect model will provide unbiased estimation of the impacts of the selected policies by taking the "first difference" and explaining the within group variance using the policies, electricity price, and a set of activity and structure factors.

3.3 Conceptual framework

State-level data on electricity consumption, population, climate data, economic activities and other related data will be used to construct the panel data to measure state performance on electric end-use efficiency for the 50 states and Washington D.C, from 2005-2011. Fixed-effect model with Ordinary Least Squares (OLS) regressions will be used to analyze the policy impacts on state performance on electric end-use efficiency, by controlling for fixed state effects and common time-variant factors.

Policy innovation is defined as the behavior of adopting a policy which is previously new to a state. Policy innovation is different from policy invention which is the process of creating a new policy or program that is new to all states. Policy innovation only looks at the adoption of policies, while policy diffusion examines the diffusive behavior of policy adoption among states. This dissertation focuses on policy innovation, that is, the adoption of energy efficiency policies, and examines the impacts and factors of policy innovation.

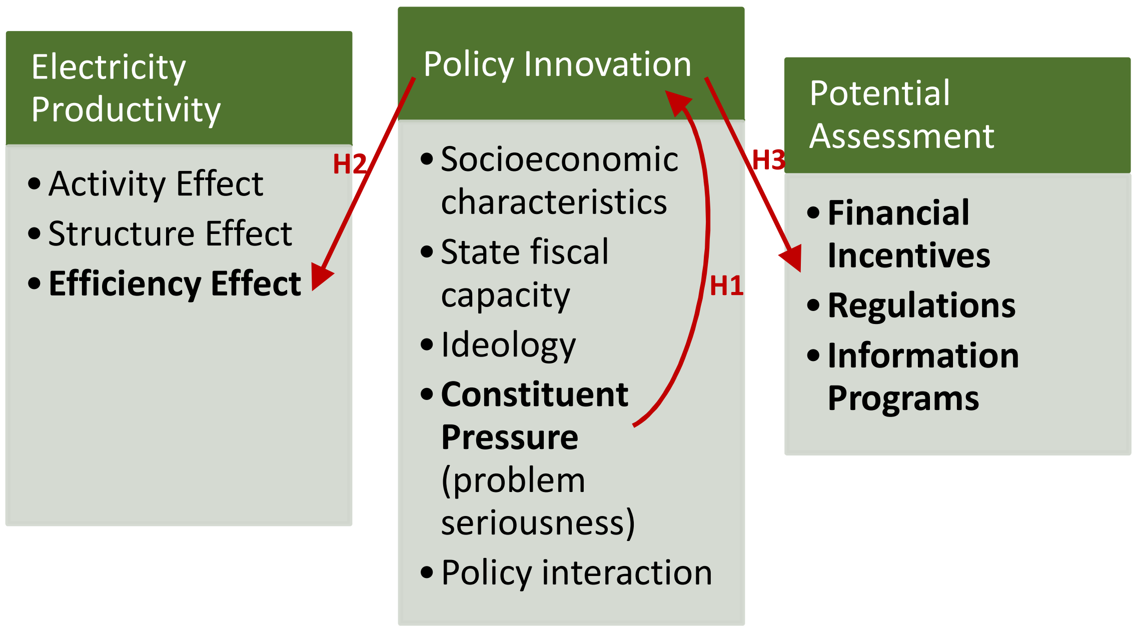

Figure 3. 1 Conceptual Framework for Analyzing the Relationship between Policy Innovation and Electricity Efficiency

Figure 3.1 illustrates the conceptual framework of the dissertation. State level data is used to construct the Internal Determinants models to explain the adoption of selected policies and test for the impact of the constituent pressure (Hypothesis 1). Retrospective analysis with state electricity productivity from 2005-2011 is used to study the impact of policy innovation on energy efficiency, where Hypothesis 2 is tested. *Ex ante* analysis was conducted with energy modeling to estimate the potential in energy efficiency that can be achieved with policies, while the third hypothesis is tested.

3.4 Data sources

The activity factors influencing electricity productivity include population, gross state product (GSP), and climate (heating degree days and cooling degree days). This data is available from the U.S. census survey, the Bureau of Economic Analysis (BEA), and the National Climate Data Center (NCDC). The structural factors in buildings and industries include household sizes, home age, the percent of electric heating equipment, the proportion of financial services, food and health services, and the proportion of electricity intensive industries. This data is available from the U.S. census survey, the Bureau of Economic Analysis (BEA), the American Housing Survey, and the State Energy Data System (SEDS).

The State Energy Data System (SEDS) is a very useful data set on state-level energy consumption. SEDS data provides detailed information about state energy consumption by sector and by source, with reliable data on electricity sales and prices, and energy intensity estimates.

Energy policies data on the federal, state, local and utility levels can be found in the Database of State Incentives for Renewables & Efficiency (DSIRE), which is available online. For some of the energy policies, measures of state compliance effort can be found in the state energy efficiency scorecard series of studies published annually by

ACEEE from 2006-2013 (Eldridge et al., 2008, 2009; Foster,et al., 2012; Molina et al., 2010;Eldridge, Prindle, & York, 2007; Sciortino et al., 2011).

ACEEE's scorecard studies evaluate state performance on energy efficiency by ranking their policies and programs, as well as their enforcement efforts. The overall state ranking is the combination of scores in six categories: utility and public benefits fund efficiency prorgams and policies, transportation, building energy code, combined heat and power, state government initiatives, and appliance efficiency standards. This series of studies not only focuses on the top-down effort on improving efficiency in buildings, but also the overall effort in all efficiency categories, which is a reflection of state attitude toward efficiency.

3.5 Selected Policies

Three major categories of policy instruments are available to promote energy efficiency in end-use sectors: regulatory, financial and information policies. A brief summary is provided for the financial, regulatory, and information policies and programs on energy efficiency.

3.5.1 Financial Policies

Financial incentive is the most popular policy instrument for energy efficiency. Currently, there are over 1,000 incentives offered by federal, state, and local governments and utilities, usually taking the form of rebates, loans, grants, personal tax, property tax, corporate tax, sales tax, etc. These financial incentives are usually offered for building envelope improvements (such as insulation, windows, etc.), efficient home appliances (such as heat pumps, lighting, solar water heaters, and so on), and combined heat and power (CHP) systems.

This dissertation looks at the state spending/ budget on energy efficiency programs. The ratepayer programs can be delivered either by utilities or by "public benefit" funds. From 2004 to 2012, the state investment in energy efficiency has grown more than four times, from around $1.4 Billion to $5.9 Billion (Downs et al., 2013; Eldridge et al., 2007).

3.5.2 Regulatory policies

Popular regulatory instruments promoting energy efficiency include appliance/equipment standards, building energy codes, energy efficiency resource standards, and energy standards for public buildings. The number of standards for appliances varies significantly by state, and it is extremely hard to quantify the impact of appliance standards. At the same time, when the standards on certain products get popular among states, the federal government will set up national rulings for them, which automatically overrules state appliance standards. Because of these reasons, appliance standard is excluded from this analysis.

Building Energy Codes generally impose efficiency requirements on building shell and HVAC and lighting equipment for new buildings. For residential buildings, states tend to adopt the International Energy Conservation Code (IECC), a prototypical code developed and updated periodically by the International Code Council. Most of the states have adopted the IECC 2003 codes (or equivalent) or more stringent codes, with only 9 of the states having no statewide code for residential buildings.

For commercial buildings, states tend to adopt the codes developed and updated periodically by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE). Most of the states have adopted the ASHRAE 90.1 (or equivalent) or more stringent codes, with the same 9 states having no statewide code for commercial buildings. Maryland is only state that has adopted the most recent codes for both residential and building buildings.

Energy Efficiency Resource Standards (EERS) and goals are state targets for electricity and natural gas savings (or, reductions in sales). The state goals or targets vary by state and vary by utility, with different efficiency requirements ranging from cumulative to annual savings and from base load to perk demand savings. Currently, 20 states have EERS and 7 states have goals. Out of the 27 state adopters, 12 of them have requirements and goals for both electricity and natural gas. The rest of them have efficiency goals only for end-use electricity (Figure 3.2).

The EERS targets include a large variety of forms. The energy saving requirements differ by annual percentage, annual quantity, or cumulative percent/quantity. The amount of energy savings is quantified and verified based on utility assessment, while the quantifying basis can be a fixed based year, or can be rolling period of multiple years. The EERS requirements may cover all utilities in the states, or cover only the investor-owned utilities. In this dissertation, only states with binding targets mandating savings in electricity sales are considered in the analysis. The EERS targets are normalized in annual savings requirements (Table 3.1).

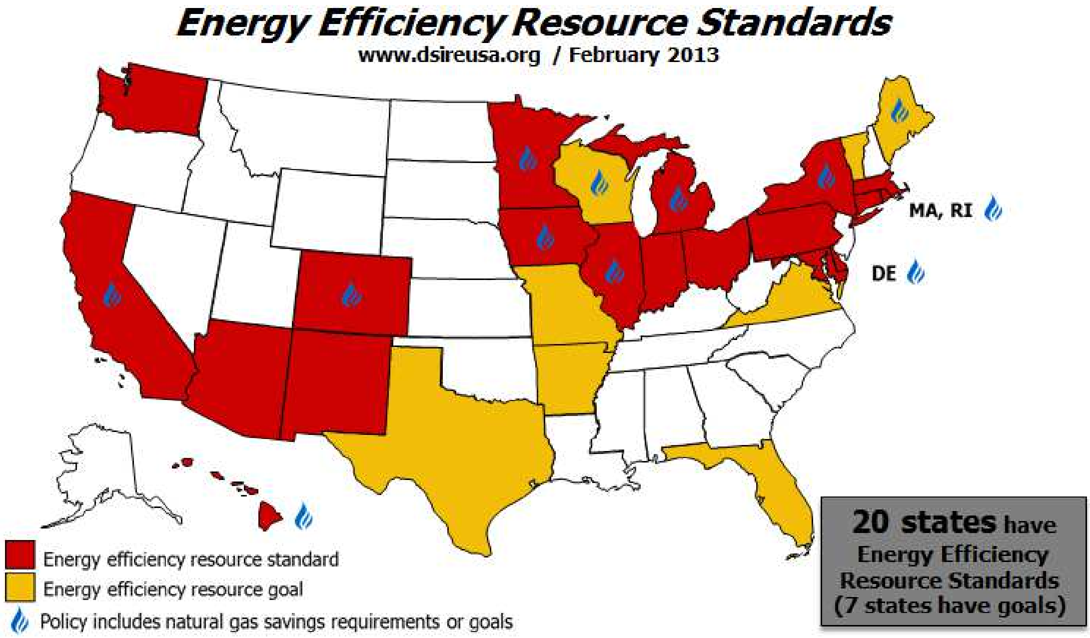

Figure 3.2 Adoption Status of Energy Efficiency Resource Standards as of February, 2013[2]

Table 3.1 Annualized EERS Target by State

State	2005	2006	2007	2008	2009	2010	2011
Alabama	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Alaska	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Arizona	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.25%
Arkansas	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.25%
California	0.80%	0.80%	0.80%	1.00%	0.90%	1.00%	1.00%
Colorado	0.00%	0.18%	0.18%	1.00%	1.00%	1.00%	0.80%
Connecticut	1.00%	1.00%	1.00%	1.00%	1.00%	0.00%	0.00%
Delaware	0.00%	0.00%	0.00%	0.00%	2.50%	0.00%	0.00%
District of Columbia	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Florida	0.00%	0.00%	0.00%	0.00%	0.35%	0.35%	0.35%
Georgia	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Hawaii	0.00%	0.00%	0.00%	0.00%	1.00%	1.00%	1.50%
Idaho	0.00%	0.00%	0.00%	1.50%	1.50%	1.50%	1.50%

[2] Data source: DSIRE, 2014

Table 3.1 Annualized EERS Target by State (Continued)

Illinois	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Indiana	0.00%	0.00%	0.00%	0.20%	0.40%	0.60%	0.80%
Iowa	0.00%	0.00%	0.00%	0.00%	0.00%	0.30%	0.50%
Kansas	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Kentucky	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Louisiana	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Maine	0.00%	0.00%	0.00%	0.00%	0.00%	1.00%	1.00%
Maryland	0.00%	0.00%	0.00%	1.80%	1.80%	1.80%	1.80%
Massachusetts	0.00%	0.00%	0.00%	0.00%	2.40%	1.40%	2.00%
Michigan	0.00%	0.00%	0.00%	0.00%	0.30%	0.50%	0.75%
Minnesota	0.00%	1.00%	1.50%	1.50%	1.50%	1.50%	1.50%
Mississippi	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Missouri	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Montana	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Nebraska	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Nevada	0.60%	0.60%	0.60%	0.60%	0.60%	0.60%	0.60%
New Hampshire	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
New Jersey	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
New Mexico	0.00%	0.00%	0.00%	0.70%	0.70%	0.70%	0.70%
New York	0.00%	0.00%	0.00%	1.90%	1.90%	1.90%	1.90%
North Carolina	0.00%	0.00%	0.25%	0.75%	0.75%	0.25%	0.25%
North Dakota	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Ohio	0.00%	0.00%	0.00%	0.00%	0.30%	0.50%	0.70%
Oklahoma	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Oregon	0.00%	0.00%	0.00%	0.00%	0.00%	0.80%	0.87%
Pennsylvania	0.00%	0.00%	0.00%	0.00%	0.00%	1.00%	1.00%
Rhode Island	0.00%	0.00%	0.00%	0.00%	1.00%	1.25%	1.50%
South Carolina	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
South Dakota	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tennessee	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Texas	0.10%	0.10%	0.10%	0.30%	0.30%	0.40%	0.40%
Utah	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Vermont	1.00%	1.00%	1.00%	1.80%	2.00%	2.25%	2.25%
Virginia	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Washington	0.00%	0.00%	0.00%	0.00%	1.00%	1.00%	1.00%
West Virginia	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Wisconsin	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Wyoming	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Decoupling is another significant regulatory instrument that enables utility companies to take an active part in energy efficiency improvement. The traditional business model for utilities ties profit with energy sales and revenue. In this case, utilities have disincentives to promote energy efficiency because they will lose profit due to reduced electricity and natural gas demand. States adopt decoupling mechanisms to remove the disincentives and encourage utility companies to play a role in efficiency improvement. The attributes of decoupling include three major parts (usually called the “three legged stool”) (York & Kushler, 2011):

- recovery of administrative and program cost;
- decoupling profit from sales and recovery of lost revenues
- performance incentives

The recovery of administrative and program costs is usually achieved through adjustments to rate cases and customer bills. The administrative and program costs can be authorized to be recovered within a year or in longer time periods. Decoupling mechanism separates profit from sales so that utilities are indifferent to any impacts on their revenue stream. The lost revenue can be recovered through adjustment mechanism and Straight Fixed Variable Rates (SFVR). The lost revenue is estimated through Evaluation, Monitoring and Verification (EM&V) so that it can be recovered through the adjustment to rate cases or fixed surcharge on costumer bill.

In addition to eliminating the disincentives through recovery mechanisms, incentives are created through various performance incentives. Some states allow utilities to share the net benefits with their customers. Some of the states provide rewards and bonus if the utilities achieve or exceeding the saving goals. Some states offer utilities an additional rate of return on the capitalized efficiency investment if they have achieved or exceeded the state target.

3.5.3 Information Policies

The **Lead by Example program** is the efficiency policies targeting energy usage in public buildings. Up to now, all states except for Alaska, Mississippi, New Mexico, North Dakota, and Vermont have adopted this policy. Many local governments also established their energy standards for public buildings (DSIRE, 2014).

In addition to the efficiency requirements, the Lead by Example also contains an informational component which requires the state owned facilities to conduct rating and benchmarking efforts. Some of the states require their public buildings be rated with the Energy Star or LEED program. Some states have benchmarking requirement using EPA's Portfolio Manager. This program aims at reducing energy consumption of public buildings, as well as providing information through the exemplary projects to encourage the participation of homeowners and commercial building owners.

CHAPTER 4

CONSTITUENT PRESSURE AND POLICY INNOVATION

States take varied approaches in improving energy efficiency (EE). Some states rely on the market to decide the natural rate of adoption for energy efficiency measures. Other states take proactive strategies of enforcing policy interventions to promote energy efficiency. Several policy instruments are available: regulations mandating adoption behavior and correcting market failures, financing incentives overcoming cost barriers, and information programs encouraging customer participation by offering information and technical support.

Each state is faced with specific needs for promoting energy efficiency, and the problems they face with promoting energy efficiency are embedded in a large variety of socioeconomic conditions. The decision of policy innovation always takes different forms and happens in different time scales. For instance, Texas and Vermont are the states making the first moves of setting up EERS targets to achieve electricity savings. In addition to the targets, Texas provides large amount of funding to run energy efficiency programs, while Vermont sets up decoupling mechanisms to enable utilities to play a significant role in improving energy efficiency. California, Connecticut and Nevada are among the early followers in adopting EERS targets. Other early adopters of regulatory approaches in EERS and decoupling include Vermont, Arizona, Indiana, New Hampshire, North Carolina, and Rhode Island.

Some states emphasize on providing financial incentives to promote energy efficiency, and have large budgets for their energy efficiency programs. New York, New Jersey, Oregon, Florida and Washington make significant amount of investment in energy efficiency. Idaho and Rhode Island are also leaders in efficiency investment with regard to the high portion of EE program budgets as percent of utility revenues. Massachusetts also pushes hard on the role of utilities by adopting decoupling mechanisms and providing a large budget for energy efficiency programs.

In contract to the approach of engaging utilities with regulations and incentives, some states focus on reducing electricity usage in buildings. These states adopt building energy codes for residential and commercial buildings, as well as efficiency requirements for state owned facilities. Some of the southern states, such as Florida, Georgia, Kansas, and Maryland, are among the early adopters of building codes, as well as Iowa and Montana. Maine, Michigan, Delaware, and Arkansas, on the other hand, made the first moves in reducing energy use in public owned buildings by requiring efficiency performances, rating and benchmarking.

California, Connecticut, Colorado, and Minnesota are the early leaders who adopted combined approaches of regulation, financial incentives and information programs to promote energy efficiency. Figure 4.1 illustrated the early state leaders taking regulatory, financial, information and combined approached for efficiency improvement. Massachusetts, New York, Oregon, Vermont, and Washington are the states making significant combined efforts recently.

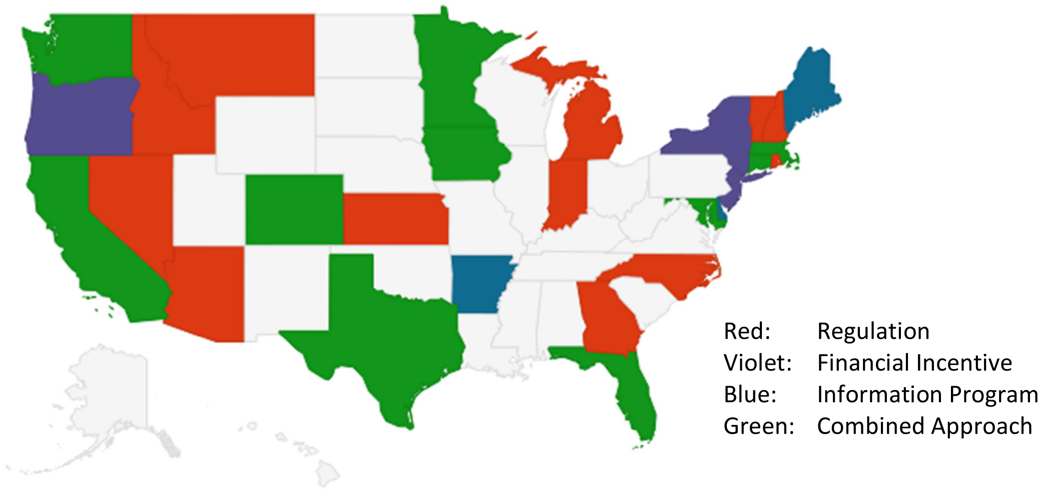

Figure 4.1 State Approaches in Energy Efficiency, 2005

An interesting policy question is why states take such different approaches to promote energy efficiency? Literature in policy diffusion suggests that the diffusion of policy innovation can be affected by inter-state behavioral factors, such as learning from the leaders and federal government, emulation from states within the same region, and competition with their neighbors. At the same time, state-specific socioeconomic characteristics also serve as important explanatory factors for policy innovation, such as population, GSP, and other economic, and political factors. This chapter argues that the differences in constituent pressure, measured by problem seriousness, can explain the differences in state strategies in improving energy efficiency.

4.1 Internal Determinants Model and Constituent Interest

Internal Determinants models explain policy innovation using internal characteristics of state development. The models postulate that internal factors are the key to policy decision of whether or not policy will be implemented and when a policy will be put in place. The internal factors causing a state to adopt a new policy or program are political, economic, social characteristics, as well as constituent pressure. States are considered to be unique and independent from outside forces.

L. Mohr (1969) proposed that the possibility of organizational innovation is inversely related to the obstacles to innovation, and is directly related to the motivations to innovate and the available resources to overcome the obstacles. With the internal determinants model, the motivations to innovate are related to the constituent pressure on policy innovation. This dissertation measures constituent pressure by problem seriousness, that is, how salient and urgent the problems are.

Policy rationales summarize the problems leading to the adoption of a certain energy policy. For instance, rationales for Energy Efficiency Resource Standards (EERS) are environmental benefits, reduced electricity usage, market failure correction in energy efficiency investment, economic development and green jobs, and energy security (Brennan & Palmer, 2013). Generally, the constituent interests relevant to energy efficiency programs and policies include environmental benefits, reduced fossil fuel consumption, economic development, and affordable and reliable energy supply. States adopt energy efficiency policies aiming at solving problems of environmental externalities, excessive electricity demand, economic development, and high electricity prices. Measurements of problem seriousness can be used to characterize the constituent pressure for policy innovation.

This Internal Determinants model is developed to explain the different factors influencing the three types of policy innovations: financial incentives, regulations, and information programs. It assumes that policy innovation is affected by internal state factors. Differences in constituent pressure are used to explain the differences in state strategies of policy innovation, by controlling for other internal factors.

Hypothesis 1. Constituent pressure is related to policy innovation.

The Internal Determinants model uses population, per capita income, and gross state product (GSP) to characterize the socio-economic factors of the states. It uses the state expenditure on natural resources, parks and recreation as the estimation of the state's fiscal capacity for policy innovation. The state expenditure is measured in total spending and percentage spending.

It measures state political ideology with SIERRA club membership. The Sierra Club is the nation's largest and most influential non-for-profit organization focusing on environmental issues. It has over 2.4 million members and supporters since 1892 when it was founded by John Muir. The club missions recently focus on reducing the use of fossil fuels toward a clean energy economy. Memberships of the Sierra Club can be used as an indicator of the environmental awareness of the states. In 2011, club membership of each state ranges from 556 to 35,793, with median of 5,198 memberships. California is the outlier having more than 145,000 memberships (Figure 4.2).

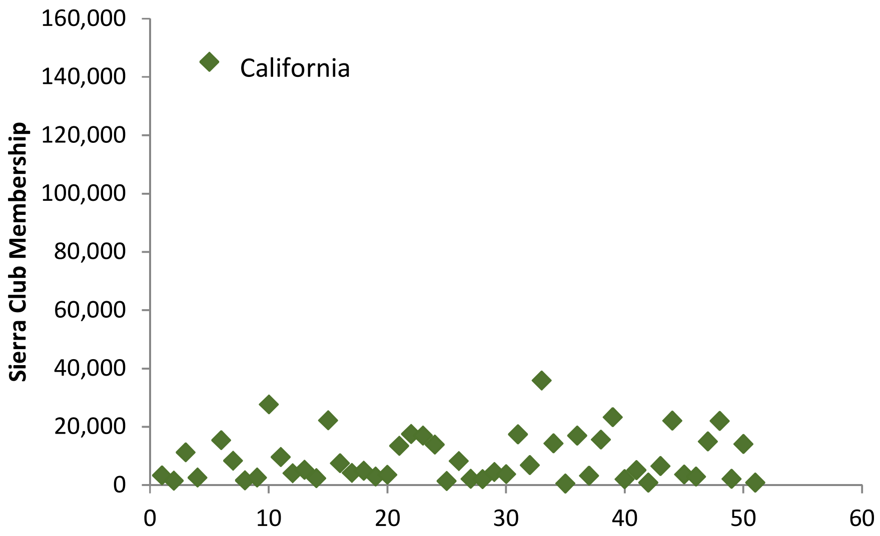

Figure 4.2 Total Sierra Club Memberships by State, 2011

The NOMINATE indicator of state government ideology developed by Berry et al. (2010) is the other measurement for state ideology. This indicator identifies state party ideology using “common-space” congressional ideology scores. A score of zero represents the most conservative position, and 100 representing the most liberal value. The nominate ideology indicator ranges from 0 to 91 in 2011, with median value of 55. The American states are extremely diversified in their government ideology (Figure 4.3).

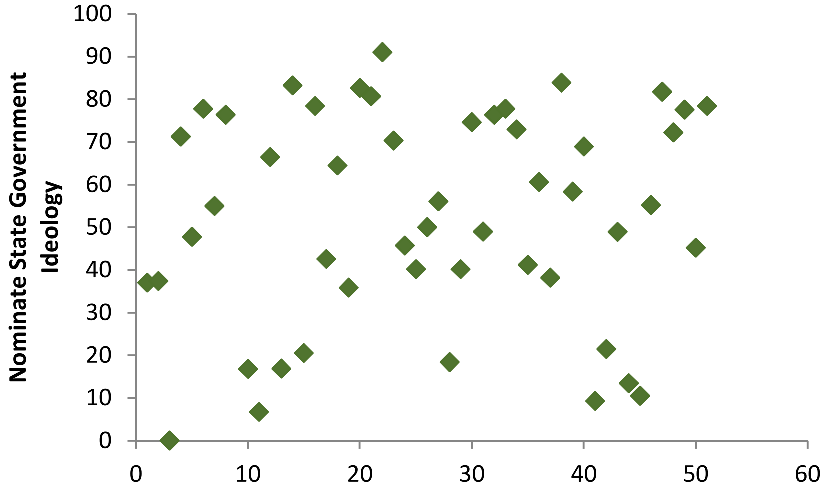

Figure 4.3 Nominate State Government Ideology, 2011

The dimension of constituent pressure is measured by problem seriousness in electricity price, electricity consumption, unemployment, and CO_2 emissions (Table 4.1). Electricity-related environmental benefits include avoided CO_2 emissions, avoided air pollution, and avoided water use for power production, and other environmental and public health benefits. The model chooses CO_2 emissions as the measurement of the environmental problem due to data availability[3]. Electricity price, grid reliability, peak demand and other factors influence grid stability. This model uses electricity price as the indicator of the security problem due to data limitations.

Two related models are developed for each energy efficiency policy: a restricted model and a full model. The restricted model tests the impacts of socioeconomic factors, state fiscal capacity, ideology, and problem seriousness. The adoption of other energy

[3] The non-energy benefits of energy efficiency include environmental and public health benefits from avoided CO_2 emissions and avoided air pollutions. However, the benefits of avoided air pollutions are hard to quantify. Even with quantification, they are usually much smaller than the benefit from reduced CO_2 emissions.

efficiency policies is also considered as an important political factor. The full model considers this political dimension, the impact of other energy efficiency policies, in addition to the factors in the restricted model.

Table 4.1 Constituent Interest and the Measurement of Problem Seriousness

Constituent Interest	Problem	Measurement of Problem Seriousness
Environmental benefits	Reducing environmental damages	CO_2 emissions per capita
Reducing energy consumption	Reducing electricity consumption	Electricity consumption
Economic development	Unemployment and creating green jobs	Unemployment rate
Grid security	Affordable and reliable electricity supply	Electricity price

The matrix of energy efficiency policies being considered are (1) financial incentives: the total budget of energy efficiency programs, and program budget as percent of utility revenue; (2) regulations: EERS, decoupling mechanisms, and building energy codes; (3) information programs: the Lead by Example program. The data of state investment in energy efficiency programs, the total budget/spending and the budget as % of utility revenue, can be found in Appendix A, Table A.1 &A.2.

EERS is an energy savings target that state imposes on utility companies, aiming at promoting energy efficiency by involving the most significant player of the energy market. State EERS targets vary greatly in design and duration. For instance, the energy savings targets can be annual percentage, annual quantity, or cumulative percent/quantity. The basis of quantifying the amount of energy savings can be a fixed based year, or can be rolling period of multiple years. The EERS requirements may cover all utilities in the states, or cover only the investor-owned utilities. Based on the analysis of state EERS, the efficiency requirements are normalized in annualized saving goal which takes into account both the total saving requirements and time length of the binding targets. Only states with binding targets mandating savings in electricity sales are considered in the analysis. Information about the annualized energy saving targets for EERS can be found in Appendix A, Table A.3.

States adopting decoupling policies aim to remove the disincentives of utility companies from implementing energy efficiency programs. State policies help decouple utility profits from sales. Decoupling mechanism comprises three parts: cost recovery which allows utilities to recover direct program costs, decoupling policy and lost revenue recovery which allows utilities to recover their fixed costs, and performance incentives which reward utilities in achieving efficiency gains. State decoupling policies are quantified by scoring the three components of decoupling mechanisms. The details of state scores on Decoupling can be found in Appendix A, Table A.4.

Building energy codes impose performance requirement on building envelope, and the heating, ventilation, and air-conditioning (HVAC) systems for new buildings, and for some states, retrofitted buildings. Many states choose to adopt model codes developed by third party organizations, for instance, the International Energy Conservation Code (IECC) for residential buildings, and the ASHREA codes for commercial buildings. Some states choose to develop and update periodically their own building energy codes.

The adoption of building energy codes concentrated in 2009 when the American Recovery and Reinvestment Act required states to adopt building energy codes to get funding from DOE’s State Energy Program. The measurement of building codes is scoring based on code stringency (Table 4.2). Scores of code stringency of residential buildings are summed up with the scores of commercial buildings. State scores range from 1-12, and the Building Codes policy is treated as ordinal variable in the model. The state scores on the stringency of building codes is illustrated in Appendix A, Table A.5.

Table 4.2 Scoring Method for Building Energy Codes

Residential Buildings		Commercial Buildings	
Score	Level of Stringency	Score	Level of Stringency
0	No mandatory state energy code	0	No mandatory state energy code
1	Precedes 1998 MEC/ICEE code	1	Precedes ASHREA 90.1-1999 code
2	1998-2001 IECC code	2	ASHREA 90.1-1999 code or equivalent
3	Meets 2003 IECC or equivalent	3	Meets ASHREA 90.1 2001 or equivalent
4	Meets 2006 IECC or equivalent	4	Meets ASHREA 90.1 2004 or equivalent
5	Meets 2009 IECC or equivalent	5	Meets ASHREA 90.1 2007 or equivalent
6	Exceeds 2009 IECC	6	Exceeds ASHREA 90.1 2007

State energy efficiency programs are administrated and delivered through two types of ratepayer-funded programs: utility programs and "public benefits" energy programs. State spending or budget of these programs is used to quantify the financial incentives on energy efficiency. From 2004 – 2012, the U.S. investment in energy efficiency programs has grown by more than four times: the total state spending/budget has increased from around $1.4 Billion to $5.9 Billion (Downs et al., 2013; Eldridge et al., 2007).

In 2011, California, New York, Massachusetts, Washington, New Jersey, Pennsylvania, Minnesota, Florida, Oregon, and Maryland were the top ten states having efficiency program budgets over $150 Million. In terms of energy efficiency program budget as a percent of utility revenues, Massachusetts, Vermont, Rhode Island, New York, Oregon, Washington, California, Minnesota, Utah, Connecticut were the 2011 top states having efficiency program budgets over 2.8% of utility revenues. See appendix (Table A4.1 and Table A4.2) for more information on the actual spending and budgets of state efficiency programs.

State governments take opportunities to be leaders in energy efficiency by incorporating performance requirements and targets into their own facilities and operations. State Lead by Example programs set up efficiency requirement and/or targets of energy savings, and label and benchmark building performance data of state owned buildings. The Lead by Example program is taken as a representation of information policies which promote energy efficiency. The measurement of policy innovation is 0-2 scale scores based on whether or not states have energy efficiency requirements for state buildings, and whether or not states have taken benchmarking efforts for state buildings. Details of state scores is shown in Appendix A, Table A.6.

The decoupling policy, building codes and the Lead by Example program are coded as ordinal variables. Extra scrutiny is need when Internal Determinant models are used to explain the adoption of these three policies because they are not interval level dependent variables. Usually, recoding the ordinal variable into binary variable is necessary and logit fixed effect model is need to deal with this type of dependent variables. However, a simplified fixed effect model is used to deal with decoupling, building codes and Lead by Example in this dissertation.

Riedl and Geishecker (2012) uses Monte Carlo simulation to compare the effectiveness of several sophisticated models dealing with ordinal dependent variables. The findings suggest that simple binary recoding schemes can deliver unbiased and efficient estimates of the parameters. And the simple linear fixed effect model can provide the relative effect size of the variables. Given the information, this chapter applies linear fixed effect model to explain policy innovation in decoupling, building codes and the Lead by Example program, and discusses only the relative effect sizes.

Table 4.3 summarizes the variables used in the Internal Determinants models in this chapter. The correlation among the dependent variable, the policy variables, and the control variable can be found in Appendix A, Table A.7.

Table 4.3 Summary of the Policy Variables and Internal Determinants

Variable	Observations	Mean	Standard Deviation	Min	Max
Total EE Program Budget	357	61.2	144.4	0	1162.5
%EE Budget of Utility Revenue	357	0.90%	1.05%	0	5.77%
Lead by Example Program	357	0.93	0.70	0	2
EERS	357	0.28%	0.54%	0	2.50%
Decoupling	357	1.39	1.24	0	3
Building Codes	357	5.73	3.09	0	12
Population	357	5,957,746	6,652,279	514,157	37,700,000
Per capita Income ($)	357	38,526.4	7,048.9	26,442.6	73,783.4
GSP (Million $)	357	272,240.9	327,877.0	22,743	1,958,904
Total State Expenditure on Natural Resources, Park and Recreation($)	350	544,654.1	696,907.3	46,960	5,368,779
% State Expenditure Natural Resources, Park and Recreation($)	350	1.98%	1.15%	0.56%	7.75%
Sierra Club Membership per capita	357	0.0034	0.0069	0.0002	0.0545
State Government Ideology	300	51.1	23.7	0	91
Electricity Price ($/MBtu)	357	27.93	10.50	14.43	92.78
Electricity Consumption (GWh)	357	72,632.0	68,279.1	5,497	376,065
Unemployment Rate (%)	357	7.6	2.4	3.1	15.1
CO_2 Emission per capita (tonne/capita)	306	24.5	19.5	5.4	123.7

4.2 Constituent Pressure and Financial Incentives

The Internal Determinants model was used to test whether constituent pressure has impact on state investment in energy efficiency programs. The restricted model controls for state socioeconomic characteristics, state fiscal capacity and ideology. The full model also looks into the impacts of other energy efficiency programs and policies. Table 4.4 illustrates how the state budgets on energy efficiency programs are affected by the internal state characteristics.

Table 4.4 Internal Determinants for Energy Efficiency Program Budget

Dimensions	Variables	Restricted Model	Full Model
Socioeconomic characteristics	Population	5.86E-05 (1.02E-04)	6.86E-05 (1.04E-04)
	Per Capita Income	-7.06E-04 (1.91E-03)	-1.28E-03 (1.91E-03)
	GSP	0.0012** (0.0005)	0.0011** (0.0005)
State Fiscal Capacity	State Expenditure on Natural Resources, Parks & Recreation		
	Total Expenditure	7.59E-05 (7.47E-05)	8.37E-05 (8.19E-05)
	% Expenditure	-639.8 (1335.7)	-687.7 (1532.3)
Ideology	SIERRA Club Membership per capita	-2831.2 (2967.4)	-2682.5 (3140.9)
	State Government Ideology	-0.0995 (0.1492)	-0.1306 (0.1342)
Problem Seriousness	Electricity Price	-1.4844 (1.2165)	-1.2555 (1.1258)
	Electricity Consumption	-0.0058* (0.0031)	-0.0054* (0.0030)
	Unemployment Rate	8.0004** (3.1859)	7.3193** (2.7723)
	CO_2 Emissions per capita	4.3781 (3.2135)	4.3709 (3.2599)
Other Energy Policies	EERS		43.2 (1017.9)
	Decoupling		-1.6873 (3.1575)
	Building Codes		3.8596** (1.9233)
	Lead by Example		-7.3577 (4.5571)
Number of observations		300	300
R^2-within R^2-between R^2-overall		0.4705 0.8121 0.7054	0.4822 0.7904 0.6845

[a]Robust standard error presented in parentheses.
*p<0.10 **p<0.05 ***p<0.01

A joint test of the year dummies suggests that no time fixed effect is needed. The restricted model and the full model are both one-way fixed effect models, which can explain 47-48% of the within group variance. Both models suggest GSP, electricity consumption and unemployment rate have significant impacts on state budgets for energy efficiency programs. Other internal state characteristics, such state fiscal capacity and ideology, are not significantly correlated with the investment in EE programs. The full model also predicts significant positive correlation between state investment in EE programs and building energy codes.

In both models, problem seriousness in electricity consumption is negatively related with EE program budget. It is possible that states are more interested in investing in energy efficiency when they are faced with the need of meeting excessive electricity demand. Meanwhile, unemployment rate is positively related with EE program budget. The higher the unemployment rate, the higher the portion of investment in energy efficiency. Scholars suggest the rationale is that states tend to invest more in energy efficiency with the purpose of creating green jobs, when constituent pressure on economic development is high. However, it is also possible the causality is on the opposite direction, that more investment in energy efficiency leading to higher unemployment rate.

The measurement of EE program budget as a percent of utility revenue reveals the financial efforts of state utilities take to improve energy efficiency. Table 4.5 demonstrates the results from the internal determinant model for this measure. Similar to the total EE program budget, the budget as percent of utility revenue is also positively correlated with unemployment rate.

Table 4.5 Internal Determinants for Energy Efficiency Program Budget as a Percent of Utility Revenue[a]

Dimensions	Variables	Restricted Model	Full Model
Socioeconomic characteristics	Population	-1.56E-10 (4.54E-09)	-1.96E-10 (4.41E-09)
	Per Capita Income	1.33E-07 (3.93E-07)	6.68E-08 (3.57E-07)
	GSP	3.41E-08 (3.03E-08)	3.33E-08 (2.78E-08)
State Fiscal Capacity	State Expenditure on Natural Resources, Parks & Recreation		
	Total Expenditure	3.20E-09 (3.24E-09)	3.11E-09 (3.18E-09)
	% Expenditure	-0.1236 (0.1321)	-0.1206 (0.1218)
Ideology	SIERRA Club Membership per capita	-0.2278 (0.1493)	-0.1369 (0.1397)
	State Government Ideology	1.44E-05 (2.11E-05)	-2.21E-06 (1.69E-05)
Problem Seriousness	Electricity Price	-1.23E-04 (1.16E-04)	-1.18E-04 (1.13E-04)
	Electricity Consumption	-1.75E-07 (1.35E-07)	-1.73E-07 (1.33E-07)
	Unemployment Rate	7.16E-04** (3.44E-04)	6.61E-04* (3.36E-04)
	CO_2 Emissions per capita	1.04E-04 (1.15E-04)	7.79E-05 (1.12E-04)
Other Energy Policies	EERS		0.1877** (0.0780)
	Decoupling		-7.59E-05 (3.11E-04)
	Building Codes		-1.10E-04 (1.33E-04)
	Lead by Example		-5.87E-04 (5.06E-04)
Number of observations		300	300
R^2-winthin		0.4911	0.5221
R^2-between		0.0975	0.1367
R^2-overall		0.1324	0.1762

[a]Robust standard error presented in parentheses.
*p<0.10 **p<0.05 ***p<0.01

The difference of using the percentage budget as the dependent variables is that GSP and electricity consumption are not significantly affecting the portion of state utilities spending in energy efficiency program. However, this percentage EE budget is positively related with the annualized EERS target, as demonstrated by the full model. A high annualized EERS target within a state leads to a high portion of investment on energy efficiency program. It is understandable that when states set up energy saving goals for utilities, the pressure of achieving the targets drives up the portion of utility investment in EE programs.

Overall, the constituent interests in electricity consumption and economic development are related with state decision of investing in energy efficiency. The total EE program budget is related with the stringency of building codes, while the budget as percent of utility revenue is related with EERS targets of the states.

4.3 Constituent Pressure and Regulations

State decisions to adopt EERS targets are explained by internal determinants. Note that EERS targets are in a variety of different forms. When state energy savings targets are normalized in annual electricity saving percentages, the measurement loses track of some of the effects associated with the specific forms of the EERS targets. However, the models have the power of explaining the state decisions in setting the requirements of percent energy savings when the policy variable is quantified with annualized targets. The full Internal Determinant model can explain 41% of the within group variance (Table 4.6).

Table 4.6 Internal Determinants for EERS [a]

Dimensions	Variables	Restricted Model	Full Model
Socioeconomic characteristics	Population	-1.62E-09 (2.27E-09)	6.70E-10 (1.66E-09)
	Per Capita Income	8.06E-08 (3.44E-07)	1.62E-08 (3.14E-07)
	GSP	2.61E-08 (2.36E-08)	1.24E-08 (1.56E-08)
State Fiscal Capacity	State Expenditure on Natural Resources, Parks & Recreation		
	Total Expenditure	2.56E-09 (3.03E-09)	2.34E-09 (2.44E-09)
	% Expenditure	-0.1436 (0.1054)	-0.0680 (0.1041)
Ideology	SIERRA Club Membership per capita	-0.3256** (0.1520)	-0.2693** (0.1100)
	State Government Ideology	9.50E-05 (3.13E-05)	7.52E-05*** (2.72E-05)
Problem Seriousness	Electricity Price	3.27E-06 (1.22E-04)	6.82E-05 (1.22E-04)
	Electricity Consumption	-7.34E-08 (1.35E-07)	4.16E-09 (1.39E-07)
	Unemployment Rate	2.32E-04 (3.35E-04)	-1.12E-04 (2.93E-04)
	CO_2 Emissions per capita	1.31E-04 (1.33E-04)	1.55E-04 (1.10E-04)
Other Energy Policies	EE Program Budget		-7.08E-06 (6.38E-06)
	EE Percentage Budget		0.3054*** (0.0988)
	Decoupling		5.49E-04 (3.89E-04)
	Building Codes		7.22E-04*** (2.56E-04)
	Lead by Example		-9.83E-04** (5.19E-04)
Number of observations		300	300
R^2-winthin R^2-between R^2-overall		0.2975 0.0076 0.0018	0.4111 0.1461 0.1302

[a]Robust standard error presented in parentheses.
*p<0.10 **p<0.05 ***p<0.01

The restricted model and the full model are both two-way fixed effect models because the time fixed effect is need according to the joint test of the year dummies. Results from the models reveal the insignificance of constituent pressure, while Sierra club membership per capita is negatively related with EERS target in both models. The full model also suggests state government ideology have positive impact on the annualized EERS targets.

The within group variance being explained increases by 11% when other EE programs and policies are included in the full model, indicating significant impacts of other policies on the adoption of EERS targets. States spending high portion of utility revenues on energy efficiency programs have probabilities to adopt high annualized EERS targets. Similarly, states with stringent building codes are more likely to adopt high annualized EERS targets. However, the Lead by Example program is negatively related with EERS.

Generally speaking, the dynamics of EERS with other energy efficiency policies have impacts on the adoption of high EERS targets, while constituent pressure has no significant impact on EERS.

Decoupling is the regulation closely related to EERS target and state energy efficiency programs. Decoupling policy removes the disincentive of utilities for not investing in energy efficiency because their profit is tied with revenue and sales. Decoupling mechanisms may also include performance incentives enabling utilities to be rewarded by being progressive in energy efficiency. The Internal Determinants model reveals the significant internal factors affecting state decisions in setting up decoupling mechanisms for utilities (Table 4.7).

Table 4.7 Internal Determinants for Decoupling [a]

Dimensions	Variables	Restricted Model	Full Model
Socioeconomic characteristics	Population	2.14E-07 (5.02E-07)	3.08E-07 (5.49E-07)
	Per Capita Income	-6.51E-05 (6.75E-05)	-5.85E-05 (6.66E-05)
	GSP	-4.83E-06 (6.11E-06)	-5.98E-06 (5.63E-06)
State Fiscal Capacity	State Expenditure on Natural Resources, Parks & Recreation		
	Total Expenditure	1.12E-06** (4.81E-07)	1.02E-06* (5.21E-07)
	% Expenditure	-43.91** (21.16)	-37.51* (22.13)
Ideology	SIERRA Club Membership per capita	5.24 (26.54)	7.54 (31.03)
	State Government Ideology	0.0132** (0.0050)	0.0108** (0.0050)
Problem Seriousness	Electricity Price	0.0066 (0.0215)	0.0050 (0.0224)
	Electricity Consumption	2.03E-05 (2.58E-05)	2.29E-05 (2.45E-05)
	Unemployment Rate	0.0427 (0.1115)	0.0436 (0.1090)
	CO_2 Emissions per capita	-0.0128 (0.0449)	-0.0156 (0.0444)
Other Energy Policies	EE Budget		-2.70E-05 (9.90E-04)
	EE Percentage Budget		-4.65 (22.46)
	EERS		25.77 (17.47)
	Building Codes		0.0149 (0.0571)
	Lead by Example		0.1010 (0.1166)
Number of observations		300	300
R^2-winthin R^2-between R^2-overall		0.4632 0.0150 0.0417	0.4741 0.0200 0.0411

[a]Robust standard error presented in parentheses.
*p<0.10 **p<0.05 ***p<0.01

Similar to the EERS models, the models for Decoupling are two-way fixed effect models due to the significance of time fixed effects. The model can explain more than 40% of the within group variation. The results suggest that state fiscal capacity and state government ideology are significant internal characteristics influencing the adoption of decoupling mechanisms. More liberal state governments are more likely to adopt decoupling mechanisms.

Interestingly, the two measurements of state fiscal capacity affect Decoupling in different directions. The total state expenditure on natural resources, parks and recreation is positively related with decoupling mechanism. However, the % expenditure is negatively related with Decoupling. If two states spend the same portion of expenditure on natural resources, parks and recreation, the higher the total expenditure, the more likely to adopt decoupling mechanisms. If states have the same total expenditure on natural resources, parks and recreation, the higher portion of this expenditure, the less likely to adopt Decoupling. Given the fact that the % expenditure is coded in decimals and its effect size is larger than the effect of total expenditure, the % expenditure has more significant impact than the total expenditure.

Moreover, both the restricted model and the full model suggest no constituent interest is significantly correlated with Decoupling. The full model also indicates that the decoupling policy is not correlated with other energy efficiency policies.

Unlike EERS and decoupling policies aiming at encouraging participation of utility companies, building energy codes are regulations states can adopt to impose performance requirements for energy usage in buildings. Table 4.8 illustrates the results from the Internal Determinants models for building energy codes.

Table 4.8 Internal Determinants for Building Energy Codes [a]

Dimensions	Variables	Restricted Model	Full Model
Socioeconomic characteristics	Population	-2.63E-06*** (9.03E-07)	-2.82E-06*** (8.62E-07)
	Per Capita Income	-6.08E-06 (1.30E-04)	-7.04E-06 (1.23E-04)
	GSP	2.28E-05*** (7.67E-06)	1.68E-05** (7.24E-06)
State Fiscal Capacity	State Expenditure on Natural Resources, Parks & Recreation		
	Total Expenditure	-1.24E-07 (8.07E-07)	-8.29E-07 (8.01E-07)
	% Expenditure	-61.64* (36.00)	-42.45 (38.66)
Ideology	SIERRA Club Membership per capita	35.23 (70.87)	75.94 (62.37)
	State Government Ideology	0.0095 (0.0177)	-0.0018 (0.0178)
Problem Seriousness	Electricity Price	-0.0385 (0.0398)	-0.0401 (0.0389)
	Electricity Consumption	-1.21E-04*** (4.36E-05)	-8.91E-05* (4.93E-05)
	Unemployment Rate	0.1715 (0.1983)	0.1360 (0.1790)
	CO_2 Emissions per capita	-0.0337 (0.0677)	-0.0560 (0.0646)
Other Energy Policies	EE Budget		0.0046*** (0.0013)
	EE Percentage Budget		-57.58* (31.06)
	EERS		120.77*** (31.53)
	Decoupling		0.0529 (0.2045)
	Lead by Example		0.0739 (0.1872)
Number of observations		300	300
R^2-winthin		0.4143	0.4746
R^2-between		0.0525	0.0575
R^2-overall		0.0291	0.0317

[a]Robust standard error presented in parentheses.
*p<0.10 **p<0.05 ***p<0.01

Two-way fixed effect models were applied to account for the significant time fixed effect in the Internal Determinants models for building codes. The models can explain over 40% of the within group variable (Table 4.8).

Electricity usage in buildings is closely related to the building stock and occupancy. Both the restricted model and full model suggest significant impacts of population and GSP, while state fiscal capacity measured by the portion of state expenditure on natural resources, parks and recreation is also predicted to be significant in the restricted model. Large population leads to low building code stringency, while high GSP leads to stringent building codes. On the other hand, higher portion of state spending on natural resources, parks and recreation leads to lower level of building codes. However, the coefficient of this % expenditure becomes insignificant when other energy efficiency policies are included in the full model.

Interestingly, the constituent pressure in electricity consumption is negatively related with the stringency of building codes, as predicted by both the restricted model and the full model. A possible explanation is that, in states with low constituent pressure in reducing electricity consumption, state governments are less likely to adopt stringent building codes.

Moreover, the full model suggests that the adoption of building codes is related to state investment in EE programs and the adoption of EERS. If state utilities spend the same portion of revenue on EE program, the higher the total budget, the more likely to adopt stringent building codes. If states have the same investment in EE programs, the higher the percent of utility revenue, the less likely to adopt building codes. The adoption of EERS and building codes are positively related, controlling for all other variables.

4.4 Constituent Pressure and Information Programs

Some states have efficiency requirements, and rating and/or benchmarking requirements for state-owned facilities when states run Lead by Example programs. The Lead by Example program does not just aim at reducing energy consumption of public buildings, but also aims at providing information through the exemplary projects to reduce energy usage of private buildings. The Lead by Example program has two components: the efficiency requirement of energy performance, and the rating/benchmarking systems. Table 4.9 illustrates the results from the Internal Determinants model for the Lead by Example program.

The restricted model and the full model both suggest state wealth (measure by per capita income and GSP), and environmental awareness (Sierra club membership per capita) can significantly influence the adoption of Lead by Example programs. High per capita income lead to low probability of policy innovation, but high GSP lead to high probability of adopting the Lead by Example program. If states have high per capita Sierra club membership, they are more likely to adopt the Lead by Example program.

State fiscal capacity has mixed effect on the Lead by Example program. If state have the same percentage expenditure on natural resources, parks and recreation, states spending large amount of money tend to have high probabilities of policy innovation. But the % of state expenditure has the opposite effect. This indicates both scale (total expenditure) and portion (% expenditure) matter to policy innovation. When state spend same amount of money, states with high portions of expenditures are less likely to invest their capacity in the Lead by Example program, indicating states take the Lead by Example programs as substitutes to financial incentives.

Table 4.9 Internal Determinants for Lead by Example [a]

Dimensions	Variables	Restricted Model	Full Model
Socioeconomic characteristics	Population	-1.21E-07 (1.68E-07)	-1.35E-07 (1.74E-07)
	Per Capita Income	-7.77E-05** (3.76E-05)	-7.27E-05* (3.67E-05)
	GSP	3.25E-06** (1.57E-06)	4.06E-06*** (1.51E-06)
State Fiscal Capacity	State Expenditure on Natural Resources, Parks & Recreation		
	Total Expenditure	5.50E-07** (2.34E-07)	5.91E-07*** (2.20E-07)
	% Expenditure	-23.64* (11.94)	-25.43** (11.52)
Ideology	SIERRA Club Membership per capita	43.51** (9.90)	35.49*** (9.90)
	State Government Ideology	-0.0014 (0.0038)	-0.0003 (0.0040)
Problem Seriousness	Electricity Price	0.0148 (0.0105)	0.0135 (0.0087)
	Electricity Consumption	2.17E-07 (1.50E-05)	-2.89E-06 (1.59E-05)
	Unemployment Rate	-0.0571 (0.0496)	-0.0475 (0.0504)
	CO_2 Emissions per capita	0.0050 (0.0141)	0.0089 (0.0136)
Other Energy Policies	EE Budget		-6.83E-06 (4.38E-04)
	EE Percentage Budget		-12.04 (12.44)
	EERS		-14.90** (7.26)
	Decoupling		0.0326 (0.0384)
	Building Codes		0.0067 (0.0175)
Number of observations		300	300
R^2-winthin		0.4075	0.4250
R^2-between		0.2356	0.1626
R^2-overall		0.2307	0.1835

[a]Robust standard error presented in parentheses.
*p<0.10 **p<0.05 ***p<0.01

Interestingly, states with high annualized EERS targets are less likely to adopt the Lead by Example programs, which also indicates a substitution relationship of the two policies. This suggest that states putting more emphasis on regulations like EERS won't take significant effort on developing information programs to promote energy efficiency

The restricted model and the full model both indicate no significant impact of constituent pressure on the state level policy decisions of adopting Lead by Example programs.

The goodness of fit was checked for every Internal Determinants model. All models report the robust standard errors to control for heterskedasticity. Hausman tests were conducted to test whether random effect models would be better fits than fixed effect model for the panels. Results from the Hausman tests reject the null hypothesis at the 0.1 significance level suggesting that fixed effect models are a good fit.

The panel used in the Internal Determinants models is micro panel containing 51 groups and 7 years. Autocorrelation is generally not a problem for this type of panels. A Lagram-Multiplier test, the Drukker test, can be used to test for the serial correlation. However, results from the Drukker tests suggest strong autocorrelations for all fixed effect models, indicating the existence of biases due to serial correlations. It the quite possible that the standard errors are under-estimated and the R-squared is over-estimated in the models.

4.5 Summary

The Internal Determinants models suggest that constituent pressure is relevant to the adoption of all selected energy efficiency programs and policies (Table 4.10). Financial incentives offered by state EE programs are related to electricity consumption and unemployment rate. State unemployment rate is positively related to the investment in energy efficiency programs. The adoption decision of building codes is also negatively related to electricity consumption. The impact of constituent interests in electricity consumption is negative on state investment in EE programs and the stringency of building codes. This indicates that states with less constituent pressure in the reduction of electricity consumption tend to invest less in energy efficiency and be slow in building code adoption.

Constituent pressure in electricity price and CO_2 emission has no significant impact on policy innovation. Also, the adoption of EERS, Decoupling, and the Lead by Example program, has no significant correlation with any of the constituent pressure, as measured by problem seriousness in the Internal Determinants models. However, other state characteristics, such as GSP, state fiscal capacity, environmental awareness (measured by Sierra club membership per capita), and state government ideology have some impacts on policy innovation.

Logarithm transformations of the independent variables were applied to the Internal Determinant models to deal with the outliers and simplify the estimation of coefficients. Table 4.11 illustrates the summary of results from the Internal Determinant models with explanatory variables in their log forms. Similar to the models in Table 4.10, the models with log forms are also two-way fixed effect models.

Table 4.10 Summary of State Internal Determinants

Dimensions	Variables	EE Program Budget	EERS	Decoupling	Building Codes	Lead by Example
Socioeconomic Characteristics	Population				-	
	Per Capita Income					-
	GSP	+			+	+
State Fiscal Capacity	State Expenditure on Natural Resources, Parks & Recreation					
	Total Expenditure			+		+
	% Expenditure			-		-
Ideology	SIERRA Club Membership per capita		-			+
	State Government Ideology		+	+		
Problem Seriousness	Electricity Price					
	Electricity Consumption	-			-	
	Unemployment Rate	+				
	CO_2 Emissions per capita					
_Iyear	Significant year dummies	N/A		2007	2008	2006 2007 2008 2009 2010

The comparison of Table 4.11 with Table 4.11 reveals that many of the internal determinants lose significance after the logarithm transformation in explaining policy innovation. For the EE program budget as percent of utility revenue, the log of unemployment rate is correlated with state investment in EE programs. All other factors, except for the adoption of EERS and the time fixed effect in 2008, have no significant correlation with the dependent variable.

The adoption of EERS is correlated with the state investment in EE programs and the adoption of building codes and the Lead by Example program. The log forms of all other internal determinants and time fixed effect are not relevant to the annualized EERS targets. Similarly, the adoption of the Lead by Example program is not correlated with any of the log forms of the internal determinants or other policies. However, time fixed effects (i.e., the year dummies) are significant factors affecting the adoption of this program.

Table 4.11 Summary of State Internal Determinants with Logarithm Transformation

Dimensions	Variables	EE Program Budget	EERS	Decoupling	Building Codes	Lead by Example
Socioeconomic Characteristics	Log_Population					
	Log_Per Capita Income				+	
	Log_GSP					
State Fiscal Capacity	State Expenditure on Natural Resources, Parks & Recreation					
	Log_Total Expenditure			+	-	
	Log_% Expenditure			-		
Ideology	Log_SIERRA Club Membership per capita					
	Log_State Government Ideology			+		
Problem Seriousness	Log_Electricity Price				-	
	Log_Electricity Consumption				-	
	Log_Unemployment Rate	+				
	Log_CO2 Emissions per capita				-	
_Iyear	Significant year dummies	2008		2007	2007 2008 2009 2010	2006 2007 2008 2009 2010

The adoption of decoupling mechanisms and building energy codes are correlated with the logs of some of the internal determinants. The logarithm of state total expenditure on natural resources, parks and recreation is positively related with decoupling, while the log of state percentage expenditure has negative coefficient.

For the adoption of building energy codes, the log of per capita income is positively correlated with code stringency. The log of state total expenditure is negatively correlated with code stringency, while the log of percentage expenditure is significant. The logs of electricity price, electricity consumption and CO_2 emission per capita are all negatively correlated with the stringency of building codes.

Meanwhile, policy innovation affects each other. Table 4.12 summarizes the significant impacts of energy efficiency policies on the adoption of each individual policy. State investment in EE programs is positively related with both EERS and Building Codes. States with high annualized EERS targets have high probabilities of adopting building energy codes. However, the correlation between EERS and the Lead by Example program is significantly negative, indicating a substitution relationship between these two policies. States adopted high annualized EERS targets may choose not to run Lead by Example programs, vice versa. This indicates that state tend to choose only one policy from EERS targets and the Lead by Example program, rather than adopting a combination of both, to promote energy efficiency.

Table 4.12 Interaction of Energy Efficiency Policies

	EE Program Budget	EERS	Decoupling	Building Codes	Lead by Example
EE Program % Budget					
EERS	+				
Decoupling					
Building Codes	+	+			
Lead by Example		-			

In addition, the adoption of decoupling mechanisms is not affected by the adoption of other energy efficiency policies. Rather, it is influenced by some of internal state factors as demonstrated in Table 4.10.

In general, the differences in constituent interests, as measured by problem seriousness, can help in explaining why states take district strategies in improving energy efficiency. States faced with high electricity prices are more likely to adopt information programs such as the Lead by Example program. States with significant CO_2 emissions are less likely to adopt regulations such as EERS and building energy codes. States facing high unemployment rates are more likely to take a combined approach of financial incentives, regulations and information programs, because all these policies are considered to have the ability of generating green jobs.

The fixed effect models explaining policy innovation with internal state characteristics are good fits for the panels. However, the data suffers from the problems of heteroskedasticity and autocorrelation. Biases exist in the estimations of coefficients and standard errors. Some of the models have dependent variables in ordinal format, and linear fixed effect models are quite limited in dealing with this type of dependent variables. It is appropriate to just discuss the significance and direction of the effects and avoid the actual effect sizes because of the biases and model limitations.

CHAPTER 5

POLICY INNOVATION AND ENERGY EFFICIENCY

Sustainability is a salient long-term goal for most of the city planners in U.S. metropolitan areas. An important aspect of sustainable development is to maintain a resilient energy-economic system, providing reliable and sustainable energy supply for the economy. Our electricity market is faced with many urgent challenges in sustainability, such as clean energy deployment, demand-side management, grid reliability, environmental protection and energy security. The challenges are escalated with population growth and extreme weather.

State and local governments undertake a variety of approaches to promote energy efficiency, aiming at constraining energy consumption while maintaining economic growth. Regulations are issued to mandate improvement in energy efficiency. Financial supports are provided to incentive market penetration and consumer adoption of high efficiency products. Information programs are designed to encourage participation in the energy efficiency market.

Policy innovation, defined as the adoption of a new policy by a certain state, is the behavior accounting for state efforts in the public policy to solve their energy issues and problems. The heterogeneity in state socioeconomic conditions and political contexts drives states to take different approaches to improve energy efficiency. In fact, the 50 American states, and Washington D.C, are often seen as the natural laboratory of policy experiments for salient large-scale problems. In the case of improving energy efficiency, it is also true that states undertake various policy interventions to accelerate the adoption of highly efficient products and clean energy technologies.

From 2005 to 2011, the U.S. has successfully reduced its overall energy intensity by 15%, while reducing its per capita energy usage by 7%. The achievement is as prominent in electricity productivity as in energy efficiency (Fig 5.1). Average states, like Maryland, Oregon and Virginia, keep steady paces in increasing their electricity productivity. Leading states, such as Washington D.C., New York, California and Massachusetts, are generally more productive in terms of gross state product (GSP) per electricity consumption. These states also tend to have faster paces of improving their electricity productivities. Other states, like Wyoming and Kentucky, have relatively low electricity productivities with slow improvements. The general trend is that the American states have been improving their electricity productivity over the past few years.

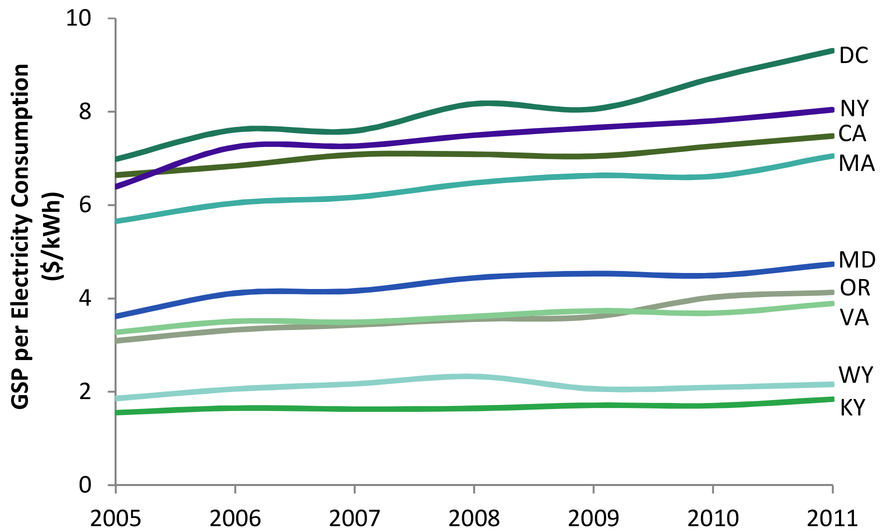

Figure 5.1 Electricity Productivity, Selected States for Illustration

Despite the national trend of productivity enhancement, states went through different trajectories in improving energy efficiency. Many states keep quite steady speeds, while some state experienced fluctuations during the 2007-2009 period of economic recess. States like Wyoming slowed down in efficiency improvement after 2009, while states like Oregon move faster in enhancing their electricity productivities.

There exist several different theories trying to explain the increased efficiency and inter-state differences. A large body of literature tests the relevance of state policies through two distinct approaches: (1) ex post analysis evaluating the effects and impacts of regulations and EE programs (Geller, 1997; Vine, du Pont, & Waide, 2001); and, (2) ex ante studies modeling energy policies and predict potential savings (Gellings et al., 2006; Wang & Brown, 2014; Worrell & Price, 2001). At the same time, scholars apply neoclassical economic theories of market failure and barriers to explain the rationale of policy intervention for energy efficiency improvement (Gillingham, Newell, & Palmer, 2009).

On the other hand, economists question the rigor of empirical studies in estimating the impacts of energy efficiency programs. Allcott and Greenstone (2012) urge researchers to utilize randomized controls and quasi-experimental techniques to produce generalizable conclusion of the effectiveness of energy efficiency programs. Levinson (2014) questions the relevance of policy in California's energy efficiency gains. Rather than crediting standards, Levinson attributes California's achievement to population migration, California's climate conditions and demographics.

However, both advocates and skeptics have ignored the fact that energy efficiency cannot be simply measure by a single metric, such as energy intensity or electricity consumption per capita. In fact, improvements on these metrics are caused by the underlining efficiency/intensity effect, as well the activity and structural effects. It is important to estimate the relevance and impact of policies based on the true underpinning efficiency effect rather than a simple energy efficiency indicator.

5.1 Decomposition of Electricity Productivity

Similar to the decomposition of energy efficiency indicators, electricity productivity, measured by gross state product (GSP) per electricity consumption, can also be decomposed into three factors: activity, structure, and efficiency effects. The activity effect measures the economic and social/physical activities which influence the demand for energy services. The activity effect is affected by various socioeconomic factors: population, climate, state demographics, and GSP. The structure effect is the embedded home, business, and industry structure which influence the demand for energy services. For residential buildings, the structure effect is considered to be affected by occupancy characteristics, building age, and the consumer choice of heating equipment. Bernstein et al. (2003) found that energy consumption in the commercial sector is affected by the business mix-up of financing services and other services. This dissertation uses the % GSP of financing services, % GSP of energy intensive businesses, and % GSP of electricity intensive manufacturing industries to characterize the structural effect of businesses and industries.

Energy consumption in commercial buildings depends on occupancy pattern, that is, the types of businesses running in buildings (Table 5.1). Food sales and service, hospitals and other inpatient health care facilities are highly energy intensive in terms of energy consumption per floor space. On the other hand, buildings providing financing services are low in energy consumption. The structure effect which influence commercial building energy efficiency should account for the energy-intensive and capital-intensive businesses. The percentages of GSP generated by food and health services, and financial services can be used to control for the structure effect of the commercial sector.

Table 5.1 Commercial Sector Energy Consumption by Building Type [4]

Building Type	Consumption (thousand Btu/SF)	% of Total Consumption
Health Care		
Inpatient	438.8	6%
Outpatient	205.9	2%
Food Sales	535.5	5%
Lodging	193.1	7%
Office	211.7	19%
Mercantile		
Retail (Non-Malls)	172.6	5%
Enclosed & Strip		
Malls	255.6	13%
Education	159.0	11%
Service	151.6	4%
Food Service	522.4	6%
Religious Worship	77.0	2%
Public Order and Safety	221.1	2%
Warehouse and Storage	94.3	7%
Public Assembly	180.0	5%
Vacant	33.1	1%
Other	318.8	4%

The industry sector is a complex mix of various manufacturing process and fuel demand. Electricity consumption of manufacturing industries varies from each other significantly. Table 5.2 illustrates the total electricity consumption and electricity

[4] Data taken from the 2012 Building Energy Databook, based on the 2003 Commercial Building Energy Consumption Survey (CBECS). All numbers are national average consumption of all fuels combined. The second column is the total energy consumption per floor space by building type. The third column is the percentage of total national energy consumption.

intensity, measured by electricity usage per dollar of value added, by industry in 2011. Primary metals, textile, paper, wood products, nonmetallic mineral products, plastics and rubber products, and chemicals, are highly electricity intensive industries. These electricity-intensive industries consume 61% of total electricity in the industrial sector, while generating only 31% of industrial GDP. The industrial structure effect can be characterized by the share of electricity intensive industries of each state.

Table 5.2 Electricity Intensity for Manufacturing Industries

NAICS	Industry	Electricity Consumption (TBtu)	Electricity Intensity (kBtu/$)
331	Primary Metals	458	7.57
313	Textile Mills & 314 Textile Product Mills	86	5.48
322	Paper	247	4.63
321	Wood Products	91	4.12
327	Nonmetallic Mineral Products	147	4.02
326	Plastics and Rubber Products	182	2.76
325	Chemicals	517	1.52
337	Furniture and Related Products	32	1.40
311	Food & 312 Beverage and Tobacco Products	281	1.28
323	Printing and Related Support	45	1.15
332	Fabricated Metal Products	143	1.14
335	Electrical Equipment, Appliances, and Components	44	0.88
336	Transportation Equipment	195	0.87
333	Machinery	111	0.81
324	Petroleum and Coal Products	137	0.79
315	Apparel & 316 Leather and Allied Products	8	0.77
339	Miscellaneous	33	0.40
334	Computer and Electronic Products	94	0.38

In addition to the activity and structure effects, the efficiency effect is the factor influencing electricity productivity by using less electricity to provide the same energy service. The efficiency factor is generally affected by consumer choice of high-efficient products and technologies. The adoption of energy efficiency measures is the true underpinning effect that drives up state electricity productivity when the activity and structure effects get separated.

Table 5.3 lists the factors that influence the activity, structure and efficiency components of electricity productivity. The climate factor is measured by heating degree days and cooling degree days; household sizes of owner and renter homes are the portraits of residential building occupancy; building age is characterized by the percent of houses built after 2000; and electric heating is measured by the percent of homes using electric heating equipment.

Table 5.3 Activity, Structure and Efficiency Effects of Electricity Productivity

<table>
<tr><th>Sector</th><th>Activity Effect</th><th>Structure Effect</th><th>Efficiency Effect</th></tr>
<tr><td>Residential</td><td>Population;
Climate;
Per capita Income</td><td>% Electric Heating;
Occupancy:
Units Built after 2000</td><td rowspan="3">Electricity Price;
Regulations:
• EERS,
• Decoupling
• Building energy codes
Financial incentives:
• Utility EE program budget;
• EE budget as % of revenue
Information programs:
• State Lead by Example program</td></tr>
<tr><td>Commercial</td><td>Value added (GSP)</td><td>% Financing;
% Food Service and Inpatient Health Care</td></tr>
<tr><td>Industry</td><td>Value added (GSP)</td><td>% Electricity Intensive Industries</td></tr>
</table>

In the fixed effect models, electricity productivity is the dependent variable, while the activity and structural factors serving as the control variables. Table 5.4 summarizes the dependent variable, electricity price, and the control variables. The policy variables are the same as in the Internal Determinants models in Chapter 4. A summary of the policy variables can be found in Table 4.3.

Table 5.4 Summary of the Non-policy Variables in the Fixed Effect Models

Variable	Observations	Mean	Standard Deviation	Min	Max
Electricity Productivity	357	3.82	1.65	1.55	9.31
Electricity Price	357	27.93	10.50	14.43	92.78
Population	357	5,957,746	6,652,279	514,157	37,700,000
HDD	357	5208.1	2250.7	0	10984
CDD	357	1192.2	964.4	0	4965
Per capita Income	357	38,526.4	7,048.9	26,442.6	73,783.4
% Electric Heating	357	30.2%	19.3%	3.6%	92.7%
% Post2000 Homes	357	12.3%	5.2%	2.7%	32.7%
Household Size –Owner Homes	357	2.7	0.2	2.2	3.29
Household Size –Renter Homes	357	2.4	0.2	1.81	2.91
% Financing	357	7.7%	5.1%	2.0%	36.8%
% Food and Health	357	5.3%	1.1%	2.3%	8.8%
% Electricity-intensive Industries	357	3.4%	2.2%	0.1%	11.6%

5.2 Measurement of Policy Innovation

This dissertation assumes that the efficiency component of electricity productivity is affected by three types of energy policies: regulation, financial incentives, and information programs.

Hypothesis 2: Three types of policy innovations increase state electricity productivity: regulation, financial incentives, and information programs.

Testing this hypothesis faces two challenges: a) isolating the efficiency component from the activity and structure effects; and, b) quantifying policy innovation. The first challenge can be solved by running controls of the activity and structure factors listed in Table 5.3. Secondly, policy innovation is defined as the state behavior of adopting a policy that is new to the individual state. Focusing on the state level, policy innovation characterizes the adoption behavior, which is different from policy invention and diffusion. Policy invention refers to the design and creation of a new policy/program that no other state has taken similar actions before. Policy diffusion focuses on the inter-state behavior of policy adoption. The Hypothesis 2 assumes state policy innovation has an impact on electricity productivity.

The policies selected to test Hypothesis 2 are listed in the last column of Table 5.3. Three independent regulations are modeled: Energy Efficiency Resource Standard (EERS), state decoupling mechanisms, and building energy codes.

5.3 Explanatory Models for State Electricity Productivity

Explanatory models were developed to test Hypothesis 1, in which state performance on electricity productivity is regressed on policy innovations by controlling for the activity and structure factors. Fixed-effect models are used to eliminate the impact of the unobserved factors.

$$EP_{i,t} = \alpha X^{a}_{i,t} + \beta X^{s}_{i,t} + \gamma ElecPrice_{i,t} + \delta Policy_{i,t} + \mu_i + \varepsilon_{i,t}$$

Where, $EP_{i,t}$ is the electricity productivity of state i at time t;

$X^{a}_{i,t}$ is the vector of activity factors of state i at time t;

$X^{s}_{i,t}$ is the vector of structure factors of state i at time t;

μ_i is the time invariant state fixed effect. This is the unobserved effect that is specific to individual states and does not vary by time;

$\varepsilon_{i,t}$ is the idiosyncratic error term. $\varepsilon_{i,t}$ is iid $(0,\sigma^2_{\varepsilon})$.

In fixed-effect model, the unobserved factors are represented by the fixed parameter μ_i. It is also assumed that the explanatory variables are independent of the idiosyncratic error $\varepsilon_{i,t}$, but not independent of the state fixed effect.

Taking the difference between the observations and the group average, we have:

$$\mathrm{EP}_{i,t} - \overline{\mathrm{EP}_i} = \alpha(X^a_{i,t} - \overline{X}^a_i) + \beta(X^s_{i,t} - \overline{X}^s_i) + \gamma(\mathrm{ElecPrice}_{i,t} - \overline{\mathrm{ElecPrice}_i}) + \delta(\mathrm{Policy}_{i,t} - \overline{\mathrm{Policy}_i}) + (\varepsilon_{i,t} - \bar{\varepsilon}_i)$$

This “within transformation” helps to eliminate the unobserved state fixed effects, and provides estimations of the effect size and direction of the explanatory variables based on “first difference”.

To evaluate state electricity productivity, four different models were developed to test the relevance and impact of policy innovations. Each explanatory model controls for electricity price, the activity and structure factors (i.e., population, HDD, CDD, per capita income, % electric heating, household size of owner and renter homes, % post-2000 units; % financing, % food and healthcare, and % electricity intensive industries.)

More specifically, Model 1 is a fixed-effect model testing the impact of the individual policies. Model 2 is a fixed-effect model to test the differences in impacts of three policy types with a combined regulation index replacing individual regulations.

Model 3 is a fixed-effect model testing the lagged effects of policy innovations. Model 1-3 provide estimations of robust standard errors. And lastly, Model 4 is a feasible generalized least squares (FGLS) model accounting for both heteroskedasticity and serial correlation. Table 5.5 illustrates the results from the four explanatory models.

The fixed-effect models can explain about 80% of the within group variance. All control variables, except for the % post-2000 homes, household size of renter homes, and % electricity-intensive industries, have significant impacts on electricity productivity. The directions of effects for the control variables are highly consistent from Model 1-4. Higher electricity prices, more population, and higher per capita incomes lead to higher productivity. Moderate climate correlate with high electricity productivity and more degree days lead to low efficiency. If a state has more electric heated homes, the electricity productivity will be low. The bigger the household size for owner homes, the lower the productivity. The higher portion of business providing financing, and food and health services, the higher the efficiency.

Model 1 explores the impact of policy innovation of individual policies. Financial incentives, represented by the energy efficiency program spending/budget, have significant impacts on electricity productivity. By controlling for the activity and structure effect, the state energy efficiency improves when the total budget on energy efficiency program grows. But it is irrelevant whether the utilities spend high portions of their revenues on efficiency programs. The Lead by Example program, an example of state information programs, also has significant and positive impact on electricity productivity.

Table 5.5 Regression Results from Explanatory Models

Coefficient [a]	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Total EE Budget	0.0003** (0.0002)	0.0004** (0.0002)	0.0002* (0.0001)	0.0005*** (0.0001)
EE Budget as % Revenue	1.89 (2.96)	2.76 (2.92)	2.1156 (2.4837)	8.3497*** (1.8796)
Lead By Example	0.045* (0.023)	0.04* (0.02)	0.0299 (0.0204)	0.0362** (0.0158)
EERS	2.14 (3.34)		0.7033 (2.7875)	-2.6519 (2.1287)
Decoupling	0.009 (0.010)		-0.0055 (0.0084)	0.0130 (0.0084)
Building Codes	0.004 (0.004)		0.0087* (0.0049)	0.0111** (0.0047)
Combined Regulation Index		0.00007 (0.02272)		
EERS 1-year-lag			-1.5483 (2.6386)	-5.0483** (2.1925)
Decoupling 1-year-lag			0.0023 (0.0132)	0.0006 (0.0090)
Building Codes 1-year-lag			0.0111 (0.0076)	0.0138** (0.0054)
Constant	3.44*** (0.81)	3.34*** (0.82)	3.19*** (0.87)	-3.09*** (0.40)
Electricity Price	+***	+***	+***	+***
Population	+*	+*	+	+***
HDD	-***	-***	-***	-***
CDD	-***	-***	-***	-***
Per Capita Income	+***	+***	+***	+***
% Electric Heating	-**	-***	-**	-***
% Post2000 Homes	+	+	+	-***
Household Size-Owner	-**	-***	-***	+***
Household Size-Renter	-	-	-	+
% Financing	+**	+**	+*	+***
% Food and Health	+***	+***	+***	+***
% Electricity-intensive Industries	-	-	-	-***
Number of observations	357	357	306	306
R^2-within	0.8394	0.8375	0.7841	Wald $chi^2(21)$ = 8397.06
R^2-between	0.6676	0.6675	0.6382	
R^2-overall	0.6715	0.6714	0.6403	

[a]For Models 1-3, robust standard error presented in parentheses.
*p<0.10 **p<0.05 ***p<0.01

Regulations, on the other hand, do not have significant impact on state energy efficiency. A correlation test suggests that regulations are neither correlated with each other, nor correlated with other policy or control factors in the model. See Appendix A, Table A.7 for the correlation table of the variables. Thus, the insignificant coefficient is not caused by strong correlations of the policy matrix.

A new single combined index for regulations is developed to further test the impact of adopting regulatory policies in Model 2. The combined index is the sum of the normalized percentage scores on the three regulation variables: EERS, decoupling and building energy code. Model 2 presents the fixed-effect regression using this combined regulation index. Similar to Model 1, total energy efficiency program budget and Lead by Example program have significant positive impacts, while regulation is still not directly relevant to electricity productivity.

Although both models return insignificant coefficients for regulations, it is still possible that regulations have time-lagged impacts on electricity productivity. Information criterion procedure was used to select the lag length for the time-lagged effects of the regulatory and information policies. The Akaike's information criterion (AIC) suggests that 1-year time lag is the most appropriate lag length. Model 3 tests for the 1-year lagged effects of EERS, decoupling and building energy codes. Results from Model 3 suggest that time-lagged effects of regulations have no significant impacts on energy efficiency.

Also note that building energy codes are very different from the other two regulatory policy instruments. Building codes focus on buildings by requiring efficiency performances of the building envelope and HVAC systems. EERS is energy savings targets imposed on utilities, while decoupling is an enabling policy encouraging utility companies to take action in promoting efficiency. Both EERS and decoupling are related to the behavior of utility companies, and they are closely relevant to the investment in state energy efficiency programs. The coefficients of EERS and decoupling are possibly underestimated when EE program budgets also present in the models. It is possible that the coefficients of EERS and decoupling only represent the residual effects of utility behavior, because the main effect is captured by their investments in energy efficiency programs.

In general, financial incentives and information programs have positive impacts on energy efficiency. The estimations of effect size are quite consistent across models: approximately 0.0004 for EE program budget and 0.04 for Lead by Example program. However, policy innovation of regulations does not have immediate and significant impacts, but it may lead to positive influences several years after the adoption of the regulatory approach.

5.4 Goodness of Fit and the Feasible Generalized Least Squares Model

A Hausman test was used to decide whether the random-effect model will be more appropriate than the fixed-effect model in dealing with this panel data. The null hypothesis of the Hausman test is that error terms are not correlated with the regressors. If the test result fails to reject the null, the random-effect model will be preferred over the fixed effect model. With this panel data, the Hausman test returns chi2(17) = 85.73, with probability equals to 0.0000. This means that we reject the null hypothesis and fixed-effect model is preferred over random-effect model to explain state electricity productivity based on the panel data from 2005-2011.

Models 1-3 apply one-way fixed-effect model which assume the time invariant fixed effect of the states. Possibilities exist that time-fixed effect should also be taken into account for the panel data. Figure 5.2 illustrates the heterogeneity in electricity productivity across years. Time fixed parameter represents the effect that is same to all states but varies by time. The economic recession from 2007-2010 is a good example of time fixed effect.

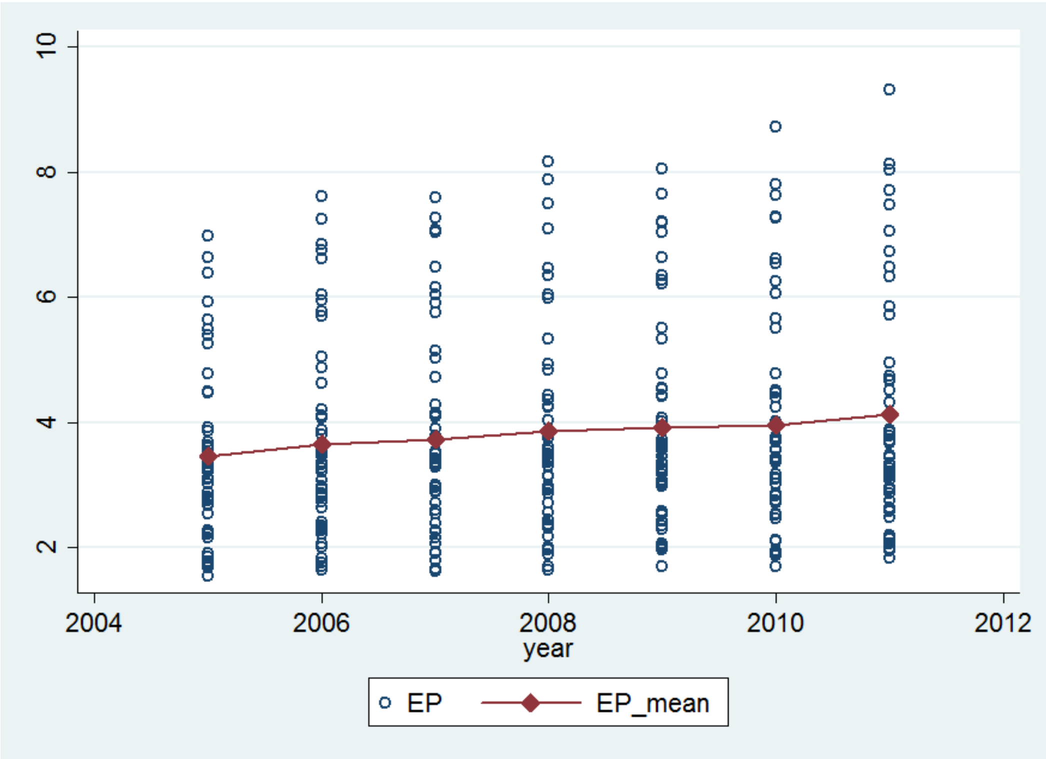

Figure 5.2 Heterogeneity in Electricity Productivity

To test whether time fixed effect is needed, a joint test of all year dummies was performed against the null hypothesis that their coefficients are 0. The result suggests

F(5,50)=3.48 with probability equals to 0.0089, indicating that we reject the null hypothesis at the 0.05 level. This test suggests the relevance of the time fixed effect.

A two-way fixed effect model was applied to this panel data, demonstrating similar results to the one-way fixed effect model (Table 5.6). Coefficient estimations from the two-way fixed effect model are close to the estimations from the one-way fixed effect models. Again, total energy efficiency program budget and building codes have positive impacts on electricity productivity, while time lagged effect of regulations have no significant correlations with the dependent variable.

To simplify the model in estimating the impacts of policy innovations on electricity productivity, logarithm transformations of the dependent variable and some of the explanatory variables are used in the two-way fixed effect model. Table 5.7 illustrates the results from the fixed effect model with logarithm transform. Table 5.7 reports the coefficients of the policies and their 1-year lags, using the logarithm of electricity productivity as the dependent variable.

Some of the control variables, the activity and structure factors and electricity price, are transformed into logarithms. Population, per capita income, and electricity price have large scales and their logged forms are used in the model. The policy variables contain many zero values. Transforming policy variables into logarithms will create large portions of missing values. The model in Table 5.7 does not have logarithms of the policy variables, except for the total budget of energy efficiency programs. The log form of this variable creates 27 missing values. Because of the missing values, the fixed effect model with logarithm transformation loses some of the variance in the independent variables

Table 5.6 Regression Result from the Two Way fixed-Effect Model

Coefficient [a]	**Electricity Productivity**
Total EE Budget	0.0003* (0.0001)
EE Budget as % Revenue	1.1222 (2.6586)
Lead By Example	0.0238 (0.0209)
EERS	-0.2889 (2.6533)
Decoupling	-0.0143 (0.0092)
Building Codes	0.0102** (0.0047)
EERS 1-year-lag	-0.6622 (2.3941)
Decoupling 1-year-lag	0.0101 (0.0139)
Building Codes 1-year-lag	0.0042 (0.0077)
Constant	4.8258*** (1.2596)
Electricity Price	+***
Population	+
HDD	-***
CDD	-
Per Capita Income	+***
% Electric Heating	-***
% Post2000 Homes	+
Household Size-Owner	-***
Household Size-Renter	-*
% Financing	+
% Food and Health	+
% Electricity-intensive Industries	-
Significant year dummies	_Iyear2010
Number of observations	306
R^2 within	0.8011
R^2-between	0.5816
R^2-overall	0.5848

[a] Robust standard error presented in parentheses.
*p<0.10 **p<0.05 ***p<0.01

Table 5.7 Regression Results from Fixed Effect Model with Logarithm Transformation

Coefficient [a]	Log_Electricity Productivity
Log_Total EE Budget	-0.0013 (0.0024)
EE Budget as % Revenue	0.2628 (0.3691)
Lead By Example	0.0052 (0.0053)
EERS	-0.0575 (0. 5249)
Decoupling	-0.0028 (0.0023)
Building Codes	0.0030*** (0.0011)
EERS 1-year-lag	0.1720 (0.4174)
Decoupling 1-year-lag	-0.0006 (0.0024)
Building Codes 1-year-lag	-0.0004 (0.0020)
Constant	-4.2713 (5.7329)
Log_Electricity Price	+**
Log_Population	-
HDD	-***
CDD	-**
Log_Per Capita Income	+***
% Electric Heating	-*
% Post2000 Homes	-
Household Size-Owner	-
Household Size-Renter	-**
% Financing	+***
% Food and Health	-
% Electricity-intensive Industries	+
Significant year dummies	2006, 2007, 2008, 2010
Number of observations	274
R^2 within	0.8197
R^2-between	0.4862
R^2-overall	0.5015

[a] Robust standard error presented in parentheses.
*p<0.10 **p<0.05 ***p<0.01

There are some differences in the estimation of the coefficients of the policy variables after the logarithm transformation. A comparison of Table 5.6 and 5.7 reveals that the financing and information policies are not significantly correlated with the log form of electricity productivity. However, building energy codes remain significantly and positively correlated with the log of electricity productivity. None of the time lags of the policies have significant correlation with the log of electricity productivity.

Some of the activity and structure factors lose their significance after the logarithm transformation. For example, the logs of % GSP of electricity-intensive industries are not significantly correlated with the log of electricity productivity. The log of household size of owner homes is not significant, while the log of household size of renter homes remains significant. All other activity and structure factors have the same impacts on electricity productivity.

Generally speaking, the change in activity and structure factors is not significant after logarithm transformation. The correlations have changed a lot between the log of electricity productivity and the policy variables. The financing and information policies are irrelevant to the change in electricity productivity. Building codes are positively related with the log of electricity productivity, while other regulations and their time lags are not significantly correlated with the dependent variable.

Overall, this panel data belongs to micro panel because it does not have very long time serials with 51 groups and 7 years of observations of each group. A test of cross-sectional independence suggests that this panel to some extent has the problem of residuals being correlated across states. A Pasaran CD test was used to test for cross-sectional independence for Model 1. The p-value of 0.0349 rejects the null hypothesis of no cross-sectional dependence at the 0.05 level, indicating week contemporaneous correlation. Model 2 has stronger contemporaneous correlation with p-value of 0.0089. Model 3 is strongly unbalanced and Pasaran CD test is not applicable. Because the incorporation of time-lagged effect leads to missing data of some of the years, making the panel unbalanced.

The issue of heteroskedasticity is also tested. Although Models 1-3 uses the option "robust" to control for heteroskedasticity, modified Wald tests still suggest strong heteroskedasticity of the models. At the same time, serial correlation tests were also performed on this micro panel. In general, autocorrelation is not a problem for micro panels. However, the Drukker tests suggest strong autocorrelations for Models 1-3. Serial correlation biases the standard errors of the coefficients to be smaller and higher R-squared. The standard errors from Models 1-3 are underestimated and the R-squares are overestimated due to the autocorrelation issues.

To account for the heteroskedasticity and autocorrelation of the panel data, a feasible generalized least squares (FGLS) model was used to test all explanatory factors. The advantage of using FGLS model is that GLS models allow flexible variance-covariance structures of panel data. GLS model can deal with heteroskedasticity across panels, correlation across panels and autocorrelation within panels. Model 4 in Table 5.5 shows the results from the FGLS regression. All significant factors in Model 3 remain significant, while the energy efficiency budget as percent of utility revenue became statistically significant in Model 4. More interestingly, the decoupling and building energy codes also have significant coefficients. The GLS model indicates positive impact on energy efficiency when states adopt decoupling mechanisms, adopt building energy codes or increase their code stringency.

The coefficient of EERS remains insignificant statistically as suggested by the GLS regression of the state data from 2005-2011. However, the time-lagged effects of EERS have significantly negative impacts on electricity productivity. This finding is counter-intuitive because the policy rationale for EERS is to urge utilities to become more energy-efficient when they are required to follow the energy saving target. Again, the coefficient of EERS and its lagged effects may reflect merely the residual effects of utility efforts, because the major positive impacts are captured by the coefficients of energy efficiency program budget and the decoupling policy. Moreover, the time-lagged variables may only be indicators of the unobserved factors that are not specified in the model (Mckinnish, 2002).

In general, results from the GLS model confirm the significance and directions of the policy variables estimated with the fixed effect models. Financial incentives and information programs are estimated to increase efficiency, while regulations generally have time-lagged effects.

5.5 The Relevance of Policy Innovation

The efficiency-gains story in California may lead to questioning the credibility of appliance standard (Levinson, In Press). However, generally speaking, policy innovation is relevant in promoting electric end-use efficiency. State data on electricity productivity from 2005-2011 was used to test the relevance of policy innovation in regulation, financing, and information programs. Fixed effect models were developed to explore the impact of policy innovation on energy efficiency by controlling for the activity and structure factors in electricity productivity.

The models illustrate significant positive impacts of financial incentives and information programs. However, regulations are estimated to have mixed impacts on electricity productivity. The models suggest significant time-lagged impacts of regulations, but the direction of the effect can be either positive or negative. Two-way fixed effect model and generalized least squares model demonstrate similar estimations of the financial and information programs. They also estimate more significant positive impacts of decoupling and building energy code, while indicating negative time-lagged impact of EERS.

The caveat is that the models are subject to the issues of heteroskedasticity, cross-sectional dependence, and autocorrelation. The problem can be controlled with robust standard errors and the FGLS model. But in general, these biases make the fixed effect model underestimate the standard error and overestimate the R-squares.

CHAPTER 6

ASSESSMENT OF THE ACHIEVABLE POTENTIAL[5]

The potential for electric end-use efficiency has invoked great interest over the past several decades because the cheapest megawatt hour of electricity is often the one that is not produced (Croucher, 2011). Advocates of energy efficiency claim that huge potentials for future efficiency improvements are yet to be exploited. There is a large body of literature assessing the potential in energy efficiency. Comprehensive and integrated resource planning also considers the potential for increases in energy efficiency to reduce the requirements for new generation and transmission investments.

Although energy efficiency improvement has been very helpful in reducing energy intensity in the past, the future of energy efficiency still remains uncertain (Figure 6.1). Some of the economists question the potential in energy efficiency improvements. Allcott and Greenstone (2012) argues that energy efficiency programs are not making actual impacts because the estimated savings are too small to be noticeable. Borenstein (2014) argues that energy efficiency potential is not big because the market barriers are so significant.

What is the future of energy efficiency? Will the efficiency improvement sustain in our future, or it is "tapped out"? The policy question is whether energy efficiency policies can continue providing driving forces to improve the energy efficiency of our economy.

[5] The method and findings of this chapter draws on the published paper by Wang & Brown (2014).

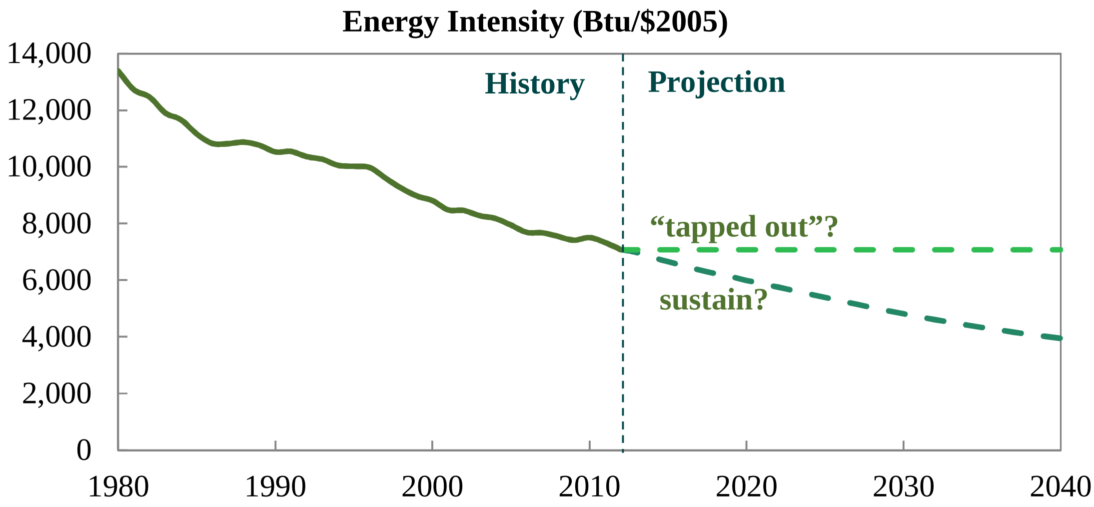

Figure 6.1 Energy Intensity of the U.S.

Clearly, critical questions still need to be answered for both practical and theoretical reasons: what is the magnitude of energy-savings potential that can be achieved by deploying energy-efficiency measures? And, what are the cost-effective policy instruments available for tapping this potential? A careful examination of the policy options for energy efficiency would contribute valuable information to facilitate environment protection and climate mitigation by utilities, government agencies, and non-governmental organizations. This estimation of the economically achievable potential attempts to update and extend the current literature on energy-efficiency, demonstrating a novel analytical approach for presenting policy measures in terms of relative impact and cost-effectiveness -the policy supply curve.

Numerous obstacles – including market failures and barriers – contribute to the energy efficiency gap (Figure 6.2). Market failures related to the deployment of energy efficiency measures include (1) misplaced incentives; (2) distortionary fiscal and regulatory policies; (3) unpriced externalities; and (4) information asymmetry. Recent literature focuses on information-based market failures including a general lack of information, information asymmetries, and price signaling (Brown & Chandler, 2008).

"Market barriers" include other obstacles that contribute to the slow diffusion and adoption of energy-efficient innovations (Hirst & Brown, 1990; Jaffe & Stavins, 1994; Levine, et al., 1995). It is important to understand the full range of obstacles to energy-efficient technologies. These barriers include: (1) high upfront cost of the clean energy technologies, (2) behavioral barriers, such as the lack of interest, inattention, and the low priority of energy issues among consumers, (3) capital market imperfections, (4) incomplete markets for energy-efficient features and products, and (5) prolonged infrastructure longevity rooted in the behavioral economics of sunken costs.

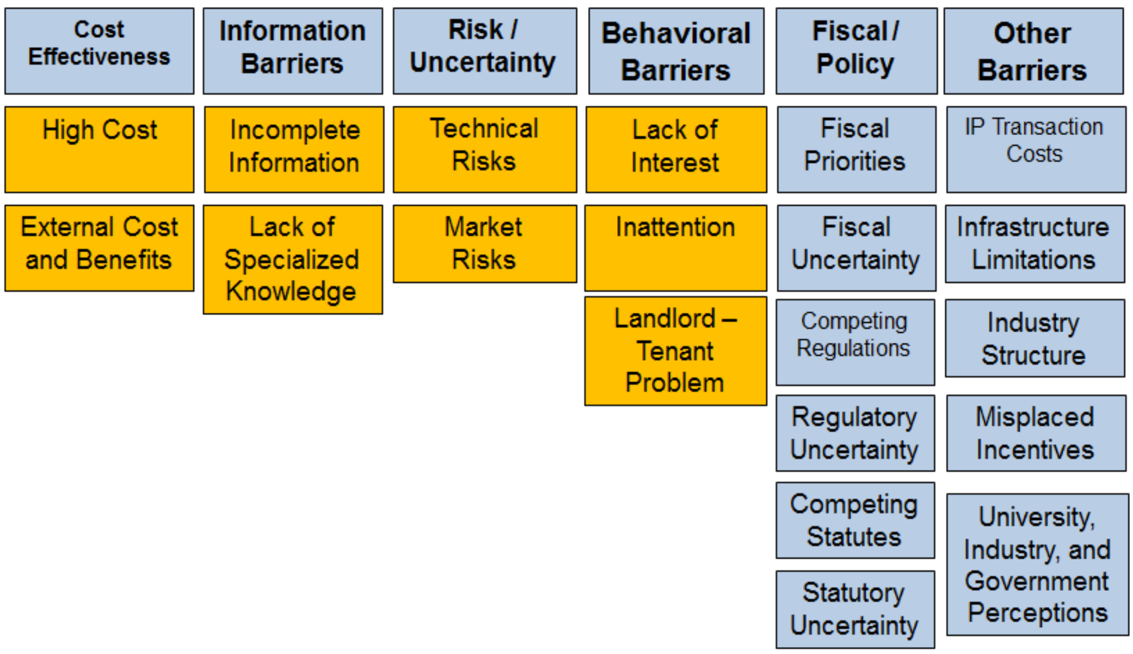

Figure 6.2 Barriers Hindering Energy Efficiency Improvement

States apply policy interventions to address the market failures and barriers and to leverage drivers for energy efficiency (Brown & Sovacool, 2011; Geller, 2002). One succinct typology of policies identifies three ways of exploiting the achievable potential for energy efficiency: (1) financial assistance, including subsidies, bulk procurements, and loan guarantees; (2) regulatory requirements, such as codes, standards, and cap and trade programs; and (3) information programs including labeling, education, R&D support, and workforce training (Brown et al., 2011).

This leads to the critical question whether the energy efficiency policies and programs can continue providing energy efficiency gains in the future. To answer this question, this chapter examines the hypothesis that energy efficiency policies will continue providing motives to improve energy efficiency and there is potential in energy savings in the future due to the implementation of energy policies.

H3. The potential of electric end-use efficiency is achievable with financial, regulatory, and information policies.

The mechanisms for improving energy efficiency vary by policy type because financial, regulatory and information instruments exercise different leverages to change consumer behavior in energy efficiency adoption. The Hypothesis 3 can be divided into three hypotheses based on the three distinct policy mechanisms. More specifically:

- *H3.1 financial incentives improve energy efficiency by providing financing support to reduce the cost of capital* (Hoicka, Parker & Andrey, 2014);

- *H3.2 information programs improve energy efficiency by offering information/training to invoke awareness, educate consumers, and assist adoption* (Newell & Siikamäki, 2013);
- *H3.3 regulations improve energy efficiency by mandating efficiency requirements to accelerate market penetration* (Kelly, 2012)

Hypothesis 3 is tested by modeling a selected array of energy efficiency policies and estimating the potential electricity savings due to the implementation of these policies. The chapter focuses on the economically achievable potential for improving the energy-efficiency of homes, commercial buildings, and industrial plants from a specific set of policies. The approach involves identifying a series of energy-efficiency policies and examining their impacts and cost-effectiveness. The levelized cost of policy-driven electricity savings are estimated to ensure the effectiveness of the policies. A policy supply curve was constructed to characterize policies as opportunities to promote energy efficiency from the societal perspective. The impacts of the selected policies were studied on electricity rates and the power sector, CO_2 emissions and the whole economy.

The potential energy savings from each type of policies are assessed with the energy modeling approach and the levelized cost of electricity (LCOE) was calculated by policy type. The modeling of policies is strictly based on the policy mechanisms so that the model levers are the reflections of the policy assumptions on behavioral changes. In doing this estimation, Hypotheses 3.1 -3.3 are tested for the effectiveness of the policy mechanisms. If the model predicts no significant electricity savings from policy implementation, the hypotheses will be rejected because the policy mechanisms are not effective. If the levelized costs of the policies are too high, the hypotheses will also be rejected because they are not feasible.

This dissertation focuses on the achievable potential of energy efficiency in the U.S., defined as the portion of the energy-efficiency gap that can be narrowed by the implementation of policies and programs. The achievable potential is distinguished from technical and economic potentials by considering policy efforts in promoting the adoption of energy efficiency measures. The achievable potential is of particular interest because it captures the portion of efficiency improvements with high probability of being realized by policy interventions.

Nevertheless, the achievable potential is difficult to measure due to the complex behavioral aspect of efficiency adoption. The literature reveals this difficulty with a wide range of potential estimations reported by assessments applying vastly diversified methods (Table 6.1). The recent studies estimating the energy-efficiency potential in the U.S. clearly demonstrate that estimates of efficiency potential range widely from 8% to 59% (Table 1.2). These studies focus on different measures of the efficiency gap, with the technical and economic potentials usually higher than the achievable potential estimation. These assessments are derived from theory, simulation, and real-world practices, and they have been conducted at various geographic scales, covering different time periods. These methodology differences also contribute to the disparity of the estimates.

Table 6.1 Measurement Difficulties

Mixed Definitions	Technical Economic Achievable
Focus Sector	Residential buildings Commercial buildings Single/multiple Industries Transportation
Applied Fuel	Total energy Electricity Natural gas
Varied Methods	Post evaluation Linear projection Statistical analysis Computer modeling Direct metering and monitoring
Cost Estimation	Total cost Cost/benefit analysis (CBA) Lifetime cost Cost of conserved energy (CCE) Levelized cost of electricity (LCOE)

Some of the energy efficiency potential assessments are coupled with cost estimates with widely varying results due to the application of variable cost accounting methods. A review by Gellings, Wikler, & Ghosh (2006) found that the full life-cycle cost ranges from 0.8 -22.9 cents/kWh (in 2002$) for energy saved from DSM programs. Many studies use modeling tools to forecast and estimate potential energy savings and the cost of energy saved. For example, the McKinsey & Co. report estimates the average annualized cost for energy efficiency measures to range from $0.4-16 /MMBtu, averaging at $4.4 per MMBtu energy saved (McKinsey & Co., 2009). The EPRI report

(2009) estimates the levelized costs to be $0.022 - 0.032/kWh associated with utility efficiency programs.

These studies generally suggest high cost-effectiveness for energy efficiency while many ex post assessments tend to estimate higher costs than ex ante studies. An ex post study estimated the utility cost (excluding private costs) based on utility and state evaluations and reports for electricity programs in 14 states. It finds the cost of saved energy to be $0.016-0.033/kWh, with an average of $0.025/kWh (Friedrich, et al., 2009). Other ex post estimations have reported higher levelized costs for energy efficiency. For example, Arimura, et al. (2011) estimate that utility-operated demand-side management programs between 1992 and 2006 saved electricity at a program cost averaging $0.05/kWh using a 5% discount rate, with a 90% confidence interval ranging from $0.03 to $0.98/kWh. Auffhammer, Blumstein and Fowlie (2008) use utility panel data to construct weighted average cost estimates for demand-side management programs. Their findings suggest low cost-effectiveness for DSM programs, with costs ranging from $0.053 to $0.151/kWh.

Cost estimates can be coupled with potential estimations to draw an energy-conservation supply curve, also called energy-efficiency supply curve. The supply curve can be used to align energy-efficiency measures, to illustrate achievable potentials, and to identify the most cost-effective options (Gellings, Wikler, & Ghosh, 2006; Koopmans & te Velde, 2001). Technology supply curves for energy-efficient equipment have been evaluated since the early 1980’s (Brown, et al., 1998; Meier, et al., 1982), culminating with the well-known study by McKinsey & Co. (2009).

This chapter applies scenario analysis with the National Energy Modeling System (NEMS) to estimate the energy efficiency potential and construct a policy supply curve for electricity efficiency improvements. With sophisticated analysis of a representative suite of policies, we estimate the achievable potential and the levelized cost of electricity saved from these policies. The hypotheses 3.1 - 3.3 are tested based this information. At the same time, this dissertation attempts to extend the supply curve approach to examine energy-efficiency policies with regard to the cost-effectiveness in improving energy efficiency. Rather than aligning energy-efficient technologies by cost and impact, our policy supply curves portray the cost and impacts of policies, a focus which should be appealing to policy analysts and energy program managers.

6.1 Energy Modeling and Cost Estimation

It is difficult to quantify the exact magnitude of the electricity-efficiency potential because assumptions have to be made about current efficiency level and the achievable/optimal/maximal efficiency level. One bottom-up approach to quantify the efficiency potential is through modeling. This typically involves enumerating on a technology-by-technology basis the difference between current practice and best practice, where best practice is defined as the utilization of the most energy-efficient technology that is also cost-effective. Keeping in mind the natural rate of equipment turnover through consumer purchases, one can then estimate the amount of energy consumption that can be reduced by policy efforts.

A portfolio of eleven energy-efficiency policies is modeled with the Georgia Institute of Technology's version of National Energy Modeling Systems (GT-NEMS) to estimate the long-term achievable potential in the U.S. Supplemental spreadsheet analysis is used to estimate the levelized cost of electricity (LCOE), based on GT-NEMS output for each of the financial, regulatory and information policies. Similarly, estimates of carbon dioxide emissions and reductions in fuel consumption for all end-use sectors can also be extracted from GT-NEMS output.

6.1.1 National Energy Modeling System

GT-NEMS is the principal modeling tool used supplemented by spreadsheet calculations. Specifically, we employ the version of NEMS that generated Annual Energy Outlook (AEO) 2011 by the U.S. Energy Information Administration (EIA, 2012), which forecasts energy supply and demand for the nation up to 2035. NEMS models the U.S. energy markets and is the principal modeling tool used to forecast future energy supply and demand. Twelve modules represent supply (oil and gas, coal, and renewable fuels), demand (residential, commercial, industrial, and transportation sectors), energy conversion (electricity and petroleum markets), carbon emissions, and macroeconomic and international energy market factors. A thirteenth "integrating" module ensures that a general market equilibrium is achieved among the other modules. Beginning with current resource supply and price data and making assumptions about future use patterns and technological development, NEMS carries through the market interactions represented by the thirteen modules and solves for the price and quantity of each energy type that balances supply and demand in each sector and region represented (EIA, 2009). Outputs are intended as forecasts of general trends rather than precise statements of what will happen in the future. As such, NEMS is highly suited to projecting how alternative assumptions about resource availability, consumer demand, and policy implementation may impact energy markets over time.

In addition to its high modeling capacity, NEMS is chosen as the tool for estimating efficiency potential because it accounts for the naturally occurring adoption of energy efficiency. The reference scenario considers the efficiency improvement due to the natural rate of technology improvements, and existing codes, standards and demand-side management programs (EIA, 2011).

The NEMS reference case projections are based on federal, state, and local laws and regulations in effect at the time of the analysis. The baseline projections developed by the EIA via NEMS are published annually in the Annual Energy Outlook, which is regarded as a reliable reference in the field of energy and climate policy. The reference case forecast has incorporated the impacts of current national-level policies on energy consumption. Technology advances are also assumed in the reference case so that efficiency improvements can happen when new, high-efficiency technologies are available in the market. Therefore, the naturally occurring adoption of efficiency measures is embedded in the baseline forecast.

We have used GT-NEMS to perform scenario analysis under a consistent modeling framework in order to compare policy options to the reference case projections. The GT-NEMS is different from the NEMS used by EIA to produce the AEO 2011 because it applies different assumptions about technology characteristics and customer behaviors in its policy scenarios. The GT-NEMS also updates the NEMS assumptions for discount rates in major commercial building to reflect the time preference of private investments reported in the literature (Cox, Brown, & Sun, 2013). Further details about these differences are provided in Appendix B.

GT-NEMS also provides estimates of the carbon intensity of electricity generation based on generation resources over time. The benefit of reduced CO2 emissions are estimated by subtracting the emissions in the reference case from the policy scenario and then multiplying by the “social cost of carbon” (SCC). The SCC is an estimate of the monetized damages caused by a metric ton of CO2 emitted in a given year. The social cost of carbon used in this analysis is the central value of the U.S. Government Interagency Working Group on the Social Cost of Carbon (EPA, 2010), growing from $23/metric ton in 2011 to $47/metric ton in 2050 (all values are in 2008-$ and account for global avoided damages).

6.1.2 Energy Efficiency Policy Levers

We define the achievable potential as the portion of energy savings from the deployment of cost-effective measures with enabling policies. In this sense, the choice of policies to be modeled is critical to our analysis. The U.S. energy market is under multiple levels of governance. Energy-efficiency programs are operated by federal, state and local governments, utility companies, and non-government organizations such as the Alliance to Save Energy and the Southeast Energy Efficiency Alliance (SEEA). Two recent ACEEE reviews summarize the current energy-efficiency policies and programs in the U.S. building and industrial sectors. The first report reviews 21 programs and policies for building energy efficiency, with building codes, appliance and equipment standards, appliance labeling, Energy Star, financing, and energy efficiency tax credits standing out as the programs having long-lasting impacts (Nadel et al., 2013). The second report reviews industrial efficiency policies, including seven programs for research and development (R&D), six programs for financial and technical assistance, and regulations, standards, and labeling programs such as Energy Star, industrial motor and motor systems standard, energy credits for combined heat and power (CHP), etc (Rogers, et al., 2013).

In general, these programs can be characterized as regulation-oriented, information-oriented, and incentive-oriented. To be representative, we choose a set of policies such that each end-use sector has policies in the three categories. It is not the goal to model every energy efficiency program and policy. Rather, we use GT-NEMS to model a set of policies that have long-lasting impacts geographically and temporally. For example, to model the financial support from state, local governments and utilities, we characterize two policy scenarios (Appliance Incentives for residential buildings and Commercial Financing for commercial buildings) to provide incentives for the investment in the energy-efficient equipment and appliances in buildings. Similarly, the On-bill Financing scenario describes a program run by utility companies to support energy-efficiency penetration with financing options.

In total, a suite of eleven policies was selected to characterize the achievable potential for energy efficiency: four regulatory policies, four financial policies, and three information policies (Table 6.2). Note that the eleven selected policies for energy modeling have overlap with the policies selected for state level fixed effect model. The policies selected in the previous two chapters do not cover financing options, appliance standard or motor standard. Also, the information policies modeled in this chapter are more comprehensive and representative than the Lead by Example program modeled in the previous chapters.

For residential buildings, five policies are designed to accelerate the adoption of energy-efficient technologies and to promote the installation of energy-efficient building envelopes. For commercial buildings, three policies are designed to expand investments in energy-efficiency improvements. In the industrial sector, the policies target motor systems and other efficiency improvements in various industrial processes, as well as CHP systems to make use of waste heat in industrial processes.

Financial incentives, such as subsidies, on-bill financing and other financing options, are offered to energy-efficient technologies. For residential buildings, 25 energy-efficient home appliances and equipment were selected from the NEMS technology menu. Financial incentives (either a subsidy or zero-interest loan) were then modeled by reducing the capital costs of these selected technologies. Similarly, 110 vintages of commercial building technologies were selected and offered flexible financing options. For industries, combined heat and power systems are consider energy-efficient technologies when they utilize waste heat to produce electricity. Incentives are provided for the installation of industrial CHP systems for ten years.

Regulatory policies impose standards and mandates to enhance efficiency improvements. Building energy codes were modeled to represent equipment and shell efficiency improvements in buildings. As described in detail in the supplemental material, we model the gradual replacement of existing codes by an "IECC+" code that is about 30% more stringent than the 2006 IECC code (the International Energy Conservation Code), approximating the stringency of the 2012 IECC code, the national model residential code.6

Table 6.2 Selected Policies for Electric End-Use Efficiency

Sector	Policy Type	Policy	Scenario Description
Residential	Financial	Appliance Incentives	Providing a 30% subsidy to cut down capital costs for the most efficient technologies
	Financial	On-Bill Financing	Offering zero-interest loans for the most efficient technologies
	Regulatory	Building Codes	Adding four new building codes to improve shell and equipment efficiency
	Regulatory	Aggressive Appliance Policy	Accelerate market penetration for energy efficiency technologies by eliminating the least efficient ones from the market
	Information	Market Priming	Reducing high discount rates (10-50%) to 7% for private investment in efficient technologies
Commercial	Financial	Financing	Offering flexible financing options to lower the up-front costs of highly energy-efficient equipment
	Regulatory	Building Codes	Requiring higher building shell efficiency and more stringent standards on space heating and cooling equipment
	Information	Benchmarking	Requiring utilities to submit whole building energy consumption data to a uniform database accessible by building owners
Industrial	Regulatory	Motor Standard	New motor standard in 2017 requiring efficiency improvement and 25% more savings for motor system
	Financial	CHP Incentives	Offering a 30% investment tax credit (ITC) for industrial CHP systems for 10 years
	Information	Plant and Technology Upgrade	Promoting plant utility upgrades by identifying efficiency opportunities with cost assessments and estimations of potential energy savings.

[6] http://www.resnet.us/uploads/documents/conference/2012/pdfs/Barcik-Energy_Code-IECC2012_vs_2009IECC.pdf

In the residential building code scenario, policy modeling takes into account the effects of both code adoption and compliance due to training, technical support, code simplification, and stronger inspection/enforcement activities. Compliance with new building codes was assumed to increase with time when less stringent codes were gradually replaced by new codes.

For commercial buildings, the policy case assumes building codes impact new buildings and the retrofit of existing buildings in terms of envelope efficiency improvement and heating, ventilation, and air conditioning (HVAC) equipment upgrades. The boost in energy savings results from increased code stringency and compliance. We assume the entire commercial building stock gradually reaches the efficiency level equivalent to the most recent code, ASHRAE 90.1-2010 in 2035. Code compliance during retrofit projects is particularly challenging and represents fertile ground for developing policy innovations. Appliance standards were applied to remove inefficient residential appliance technologies from the market. We also model a new 2017 motor standard that raises the minimum efficiency of industrial motors by 5% for small motors (50 horsepower or smaller) and by 3% for larger motors. It also requires systems using motors to save more energy, for example with variable speed drives, better controls, and reduced fluid distribution system losses.

In addition, a broad set of information instruments was explored in the policy scenario. For homes, the Market Priming policy is a combination of several information options, including mandated disclosure of home energy consumption or performance at the point of sale or lease of a residential unit, home rating, green labeling, and other technical assistance features such as home energy audits and assistance with green leases, etc. For commercial buildings, the benchmarking policy requires utilities to submit whole building energy consumption data to a uniform database accessible by building owners. Studies suggest that providing information can reduce discount rates used in investment decisions from 3% to 22% (Coller & Williams, 1999; Goett, 1983). Thus, adjusting discount rates was the NEMS lever used for modeling Market Priming and Benchmarking.

For industries, Plant and Technology Upgrade involves the provision of information about efficiency enhancement opportunities along with plant utility upgrades. This policy case takes into account efficiency improvement due to technology advances, R&D, process improvement, as well as non-energy-saving reasons such as replacing failed equipment, facility upgrades, etc. Information about improvement opportunities is shared and facility owners can follow the best practices to acquire energy savings when plant facilities and technologies get upgraded. In GT-NEMS modeling, the impact of this information is based on the potential efficiency improvements from the Industrial Assessment Centers (IAC) database.

We do not model an exhaustive set of energy-efficiency policies. For example, our treatment of technological progress from an accelerated R&D policy is limited to partial coverage in the industrial sector. We also do not include utility programs (except for on-bill financing) and particular policies such as Qualifying Energy Conservation Bonds (QECB) and low-income weatherization programs. The target markets and technologies addressed by many omitted policies are likely to overlap to some extent with other policies that we do include (e.g., on-bill financing and the retrofit feature of residential energy codes). For this reason, our estimate of the policy-achievable energy savings in the U.S. is not complete. But it still provides valuable information about the electricity-savings potential and cost-effectiveness of energy-efficiency policies.

In general, the eleven selected policies are modeled with distinct levers which reflect the differences in policy mechanisms (Table 6.3). It is clear that the levers chosen for modeling the policies match the three types of policy mechanisms. Testing the hypotheses is then based on the prediction of modeling the three types of policies.

Table 6.3 Modeling Levers by Policy Type

Policy Type	Policy Mechanism	Modeling Lever
Financial • Appliance Incentives • On-bill Financing • Commercial Financing • CHP Incentives	Reducing the cost	• Providing subsidies to reduce upfront cost • Reducing the cost of capital
Regulation • Aggressive Appliance Policy • Residential Building Codes • Commercial Building Codes	Mandating adoption behavior	• Setting performance floor for energy-using equipment and building envelope
Information • Market Priming • Benchmarking • Plant and Technology Upgrade	Offering information /training to invoke awareness, educate consumers, and assist adoption	• Lowering the hurdle rate in consumer decisions • Increasing productivity due to learning

The eleven energy-efficiency policies were first modeled in individual policy scenarios, with carefully selected NEMS levers to avoid overlap. These policies were then modeled in a single integrated case to examine the policy dynamics and combined effects. Modeling details can be found in the Appendix B. GT-NEMS offers the capacity for an engineering-economic analysis of the energy-efficiency policies, while it is constrained by the pre-defined parameters and variables. Although this approach may shed little light on the underlying psychology of policy adoption and diffusion, it still stands as one of the best tools for evaluating policy impacts on energy demand and supply, cost-effectiveness, and carbon dioxide emissions.

6.1.3 Calculation of Levelized Cost of Electricity

The LCOE of each policy was calculated to estimate the cost of achieving the electricity-savings potentials in individual policy scenarios. The calculation of LCOE is based on the total resource cost test, where costs include the incremental private investment in energy-efficiency measures, program costs for providing incentives, information, technical and other assistance, and program administrative costs.

We estimate the magnitude of technology investment costs differently for the three end-use sectors. In the residential sector, costs are defined as the increased equipment expenditure extracted directly from GT-NEMS model output. Equipment expenditure are calculated separately for new purchases and replacements, as a function of the number of units purchased and purchase costs for a range of technologies. In the commercial sector, investment costs are estimated separately for new purchases, replacements, and retrofits for approximately 350 technologies uniquely defined by technology type, fuel use, purchase price, energy efficiency, and time frame of availability in the marketplace. In each case, the calculation is based on GT-NEMS estimates of service demand for energy (SD), costs per unit of SD, and capacity factors. In industry, costs for CHP investments are based on the installed costs per kW of capacity for eight different types of CHP systems. These revised costs per kW of installed capacity are codified in GT-NEMS. Other costs for plant upgrades are based on multipliers derived from audit information produced by DOE's Industrial Assessment Centers as described in Brown, et al. (2011).

The LCOE is the weighted average cost, calculated by dividing the present value of total costs by total electricity savings, following the methodology described by the EPRI report (EPRI, 2009). In addition to electricity benefits, natural gas savings also result from some of the energy-efficiency policies. For example, the envelope upgrades from better building codes would reduce natural gas for home heating in some homes and electricity for home heating in others. Reduced air conditioning would occur in most new homes. We singled out the part of the cost needed to achieve electricity savings by proportioning total cost to the value of electricity versus natural gas savings through 2035. Present-value calculations for the levelized cost of electricity use a 3% discount rate from a social perspective and 7% discount rate for the private-sector assessment. This is consistent with Office of Management and Budget guidelines (OMB, 2002, 2009), which recommend the use of 3% and 7% discount rates when evaluating regulatory proposals. Our use of a 7% discount rate for evaluating the private perspective is less than the 10% value used in some other energy-efficiency studies such as McKinsey & Co.'s analysis (2009). Since the social appropriateness of policies is being examined, a sensitivity was conducted where all costs were discounted at 3% for LCOE calculations.

Other main assumptions in the LCOE calculation include:

- The consumption reduction in delivered electricity does not include electricity related losses in transmission and distribution. To account for all benefits, avoided transmission and distribution losses are included as part of savings. A multiplier of 1.07 (EIA, 2012) was applied to electricity savings to account for the benefit of avoided electricity related losses.

- Program administrative costs are estimated specifically for five of the eleven policies, including the residential and commercial Building Codes, Benchmarking, CHP Incentives, and Plant and Technology Upgrade. Otherwise, they are estimated to be $0.13 per MMBtu energy saved (see the Appendix B and Brown, et al., 2009, for details on these estimates).
- We assume the eleven policies start from 2012 and end in 2035. Any costs stimulated from the policies occur through 2035.
- These energy-efficiency policies are assumed have residual benefits after the policies end. Specifically, electricity savings are modeled to degrade at a linear rate of 5% after 2035, such that benefits from the policy have ended by 2055.

In addition to examining each of the eleven energy-efficiency policies individually, all eleven energy-efficiency options are modeled in the Integrated Policy scenario to explore the combined effects of these policies. By comparing the Integrated Policy scenario and the reference case we estimate the achievable potential in electricity efficiency and its economic effects.

6.2 The Achievable Potential

In the reference case, electricity consumption is forecasted to grow at an average rate of 0.8% per year and to rise to 4,481 TWh in 2035. In the Integrated Policy case, energy-efficiency policies are estimated to drive the growth rate of electricity consumption down to 0.4% per year. U.S. ratepayers could benefit from these policies, saving 261 TWh of electricity in 2020, and 457 TWh in 2035 (Figure 6.3).

The electricity savings potential is forecasted to come largely from the residential sector, which is consistent with the fact that we examined more residential policies (5) than commercial and industrial policies (3 each). From 2012 to 2035, electricity savings can accumulate to 3,713 TWh, 2,085 TWh, and 1,270 TWh for residential, commercial, and industrial users, respectively. In addition to the reductions in consumption, electricity is also generated by industrial CHP systems to satisfy on-site demands with the excess being sold back to the grid. It is estimated that about 322 TWh of electricity are produced by CHP systems, 22% of which is sold back to the grid (the rest is consumed at the industrial plant) in 2020.

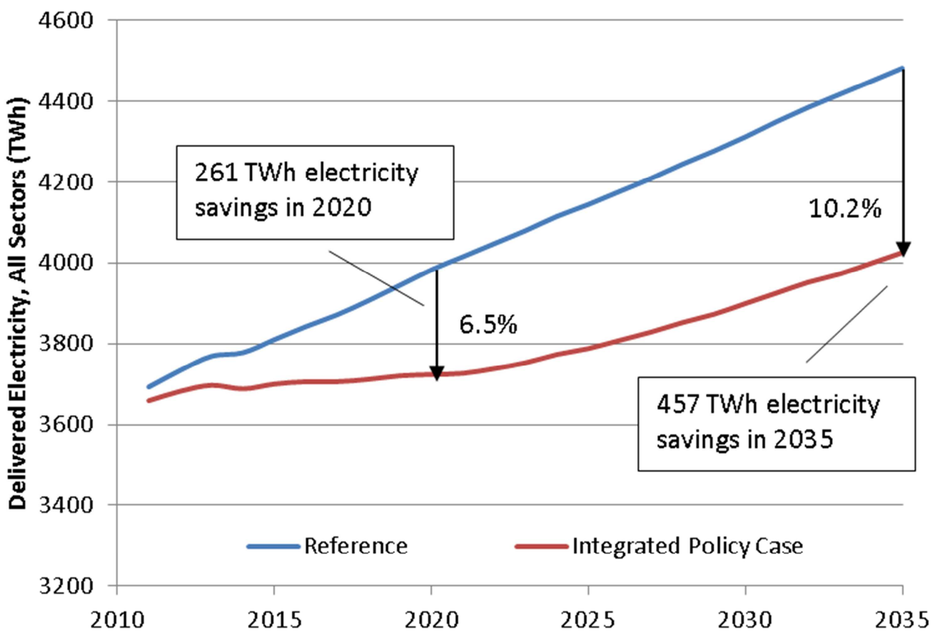

Figure 6.3 Electricity Savings from the Energy-Efficiency Policy Case

With the selected energy-efficiency policies, GT-NEMS predicts high per capita electricity savings, averaging at 763 kWh for the U.S. Analysis of the regional difference suggests that the East South Central, West South Central, and South Atlantic divisions have higher per capita electricity savings potential than other regions of the nation.

Our assessment of the achievable energy-efficiency potential, 10.2% of electricity savings in 2035, is comparable to estimates reported by some other studies, but less than estimates reported by other studies. Previous studies have used different time frames in their analysis, resulting in different estimates. For comparison, we calculated the compound annual saving rate to levelize the estimations by study time period. These annual saving rates range from 0.36% to 0.88% for achievable potential, while our estimation is 0.45% per year. In contrast, the saving rates for estimates of economic and technical potentials are generally higher, ranging from 0.36% to 2.26%. This estimation of savings potential is above and beyond the magnitude of energy savings to date. According to an analysis of electric efficiency programs in 2010, existing programs are saving the nation about 0.49% per year, while 9 states are saving more than 1%/year of their retail sales (Foster, Chittum, Hayes, Neubauer, Nowak, Vaidyanathan, Farley, Schultz, Sullivan, et al., 2012).

This estimation appears low relative to some of the achievable potential assessments. It does not include the naturally occurring adoption of energy-efficiency measures due to current policies, such as the Clean Air Interstate Rule, California's Assembly Bill 32, the California Low Carbon Fuel Standard, etc., because these policies are embedded in the reference projection of NEMS. The reference case also accounts for the efficiency improvement due to a typical rate of technology improvement. On top of the naturally occurring potential, this estimation articulates a part of energy-efficiency potential that can be achieved with a sample of policies. In the assessments that include the endogenous efficiency improvement, detaching the naturally occurring potential would result in lower energy savings (EPRI, 2009).

6.3 Policy Supply Curve for Electricity End-use Efficiency

Policy impacts on electricity efficiency and levelized costs of electricity saved were examined in eleven stand-alone scenarios constructed for each policy. The results are summarized in Table 6.4. The estimated electricity savings from individual policies sum up to reach 364 TWh in 2020, which is higher than the estimation from the Integrated Policy case (Figure 6.3). This indicates that part of the policy impacts cancels out when all energy efficiency policies are implemented together. Some of the policies target the same set of technologies, the same group of consumers, and the same barriers. It is quite possible that their ability to promote energy efficiency diminishes when multiple incentives co-exist. A related impact is the rebound effect, where energy usage increases when customers consume more energy in the Integrated Policy case because of electricity bill reductions.

The estimations of efficiency potential from individual policy scenarios were carefully studied against the estimation from the Integrated Policy case. This approach helps determine whether applying multiple policies at once would enhance or reduce the achievable energy-savings potential. GT-NEMS estimates that the integrated energy-savings potential is 24% less than the sum of the individual policy savings potentials because the policies target overlapping technologies, barriers, and energy consumers. In addition, the rebound effect causes consumers to buy more energy services in the policy case with lower electricity rates.

Table 6.4 Savings Potential and Levelized Cost of Electric End-Use Efficiency, by Policy

Sector	Policy	Electricity Savings (TWh)		LCOE [a] (cent/kWh)
		2020	2035	
Residential	Appliance Incentives	17.6	35.5	6.7-8.0
	On-Bill Financing	20.2	33.4	6.6-7.4
	Building Codes	27.0	51.0	0.5-0.8
	Aggressive Appliance Policy	23.4	59.2	0.6-0.7
	Market Priming	136.9	164.1	2.7-3.6
Commercial	Financing	22.6	82.6	7.8-8.1
	Building Codes	11.1	46.3	3.4-4.6
	Benchmarking	44.3	107.0	0.9-1.4
Industrial	Motor Standard	8.4	12.3	2.4-3.9
	Plant and Technology Upgrade	7.6	21.7	3.0-4.8
	CHP Incentives	33.4	39.3	1.5-2.3

a. The ranges for levelized costs result from discounting private cost at different rates: 7% and 3%. See Appendix B for details of levelized cost calculation.

On the other hand, synergistic policy combinations could produce greater energy-savings potential. For example, by providing better energy benchmarking data, consumers might be more responsive to an opportunity to secure low-cost financing to invest in more energy-efficient equipment. Such synergistic pairings have been Zrecognized by local policymakers who have matched benchmarking with mandated disclosure laws and with financing programs, (Cox, Brown, and Sun, 2013). Similarly, learning effects stimulated by a financing policy could reduce technology costs, leading to an enhanced response to information programs and accelerating adoption of the efficient equipment. While the NEMS tool is somewhat limited in this regard, the results from the Integrated Policy scenario can help us understand the dynamics among the selected policies and their interactive effects on the energy-efficiency potential of the U.S.

In particular, by using the integrated macro-economic module in GT-NEMS, we are able to model price effects across sectors, allowing the price suppression impact of energy efficiency to be quantified, while also incorporating rebound effects.

Although the target technologies, barriers, and energy consumers may be common to two or more policies, the modeling of policy integration is straightforward since the modeling levers for each individual policy have no overlap. The distinct modeling levers are the result of diverse policy mechanisms: direct subsidy/financing mechanisms, regulatory requirements, or information/technical assistance. By doing this, the eleven policies are well represented in GT-NEMS modeling. In addition, the non-energy impacts of these policies were examined with GT-NEMS by incorporating feedback loops between multiple segments of the economy. Using the IHS Global Dynamics general equilibrium model, the GT-NEMS analysis optimizes energy prices and quantities across energy fuels and across sectors of end-use demand.

A careful reconciliation of the estimates of potential electricity savings from individual policies versus the Integrated Policy scenario reveals the dynamics among energy-efficiency policies. Together with the levelized cost estimations, the reconciled electricity-savings potentials produce a policy supply curve (Figure 6.4). Currently, the national average electricity price for rate payers is approximately 9.0 cent/kWh. Taking this price as a benchmark, all eleven policies are cost-effective (i.e., having LCOEs lower than the average electricity price).

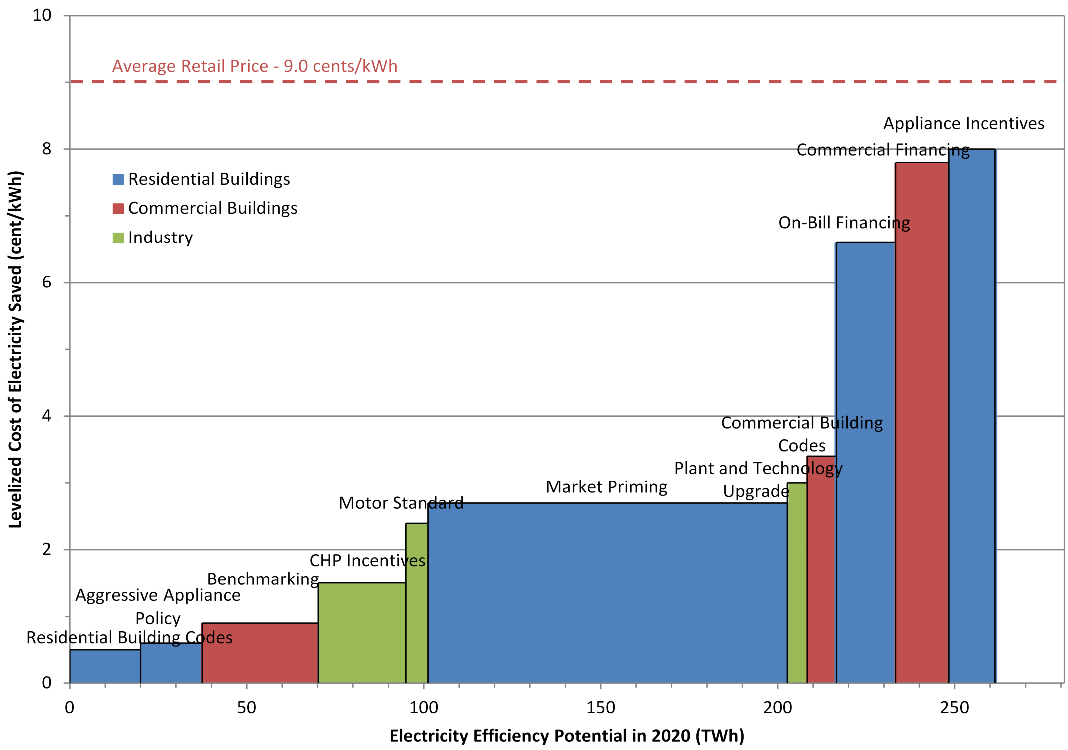

Figure 6.4 Supply Curve for Electricity Efficiency Resources in 2020 [7]

All financial policies except for the CHP Incentives have levelized costs higher than information-based and regulatory policies. CHP Incentives also represent the industrial policy with the largest electricity-savings potential. This policy provides a 10-year ITC to reduce capital costs for CHP systems to utilize waste heat in industrial processes. With the incentives, installed CHP capacity is estimated to increase by 20% in 2020. This CHP capacity expansion drives up natural gas consumption and therefore

[7] The weighted average wholesale price is derived from the Intercontinental Exchange (ICE) data which report price and volume information for daily transactions among the ten largest hubs in the U.S.(EIA, 2013b).

increases natural gas prices slightly while lowering electricity rates. A similar phenomenon is documented by Kim, Baer, and Brown (2013) .

The greatest electricity savings in commercial buildings comes from the benchmarking policy. This policy mandates the provision of energy performance information for U.S. commercial buildings. Utilities are required to submit energy data to a uniform database accessible to building owners and tenants. The compliance effort is estimated to cost utilities about $2.28 million (present value, discounted at 7%) in 2020. Investment in energy-efficient building equipment increases significantly in the policy scenario. Taking the total costs to utilities and consumers into account, the policy is highly cost-effective with a levelized cost ranging from 0.9 to 1.4 cent/kWh.

Market Priming is the energy-efficiency policy with the largest savings potential and relatively low levelized cost. Information-based instruments, such as green labeling and leasing, home energy audits, etc., when coupled with regulations that mandate the disclosure of home energy performance with home ratings, are able to promote inclusion of energy efficiency when selling or renting. Efficiency improvements from these policies can generate noticeable home equity premiums (Fuerst & McAllister, 2011; Zheng, et al., 2012). Because of the potential policy impacts on efficiency improvements and equity value, the U.S. Office of Management and Budget (OMB) suggests that regulations designed to alleviate asymmetric information should be given preference over other measures, as a general rule-of-thumb (OMB, 2003).

Overall, the policy supply curve suggests that a potential of roughly 208 TWh of electricity savings can be achieved with energy-efficiency policies at a cost lower than the average wholesale price. Typical policy instruments include building energy codes, standards, and information policies.

The policy supply curve is created by accumulating individual measures that are applied to specific policy scenarios with savings assessments and cost estimations. It is useful to align options to illustrate energy-efficiency opportunities and compare the costs. This policy supply curve does not intend to reflect diminishing returns. Rather, it intends to encourage in-depth analysis of policy options for energy efficiency.

The policy supply curve also indicates that regulatory policies have relatively low levelized costs and financial policies have relatively high LCOEs (Table 6.5). This is consistent with a previous study of energy efficiency in the U.S. South, which found that the two least cost-effective policies involved financial subsidies (Brown, et al., 2010). The CHP Incentives, as an exception, offers subsidies for industrial CHP systems with low levelized cost because its generation can satisfy most on-site electricity demand, and even with excess being sold back to the grid.

Table 6.5 The LCOE and Electricity Savings by Policy Type

Policy Type	LCOE in cents/kWh[a]	Electricity Savings in 2020 (TWh)	Electricity Savings in 2035 (TWh)
Financing	6.2-6.4	93.8 (3.3%)	190.8 (5.9%)
Regulation	1.3-1.8	69.9 (2.4%)	168.8 (5.3%)
Information	2.1-3.0	188.8 (6.6%)	292.8(9.1%)

a. The lower bound is calculated based on the 3% discount rate for public and private costs. The upper bound is calculated based on the 7% discount rate for private costs and 3% discount rate for public costs.

The weighted average LCOE of all energy efficiency policies ranging from 3.4 - 3.9 cents/kWh is in the middle range of cost estimates from previous studies. Cost estimations of energy efficiency depend on accurate assessments of energy savings, which can be problematic because of free ridership (Gellings et al., 2006). Alcott and Greenstone (2012) also question ex ante estimates of cost-effectiveness by noting that programs typically reduce electricity demand by only 1-2%, which does not suggest a large energy-efficiency gap. Alternatively, it could be that energy-efficiency programs have simply been underfunded and unable to completely address market failures.

In 2035, the predicted potential of electricity savings for financing policies is about 5.9% of electricity demand, 5.3% for regulations, and 9.1% for information policies. The estimated levelized costs of electricity for the three types of policies are below the retail prices for electricity. The results suggest that we do not reject the hypotheses 3.1 – 3.3 because the policies are effective in promoting energy efficiency with costs acceptable to consumers.

6.4 Policy Impacts on the Energy Market

Generally, the energy-efficiency policies are projected to reduce electricity retail rates. Although the price decreases are not large, a paired t-test of differences between the policy and reference cases, using residential, commercial and industrial rates for each of the nine census divisions and the national average in 2020 as observations, suggests that the price difference is significant (p-value = 0.002).

Although the degree of rate decrease is small, savings in energy expenditure is estimated to be significant for customers. Residential customers are estimated to save about $26.2 billion (2009$) on their energy bills in 2020. Similarly, commercial and industrial customers would experience bill savings of $9.3 billion (2009$) and $4.8 billion (2009$) respectively in 2020.

Long-term effect suggests that electricity rates drop across the board in the Integrated Policy case in comparison with the Reference case after 2025. In addition, low consumption levels and low electricity retail rates impact the power sector's future supply investments. Table 6.6 suggests that fewer power plants (6.8% fewer in 2020 and 11.2% fewer in 2035) would be built as a result of the energy-efficiency policies in the Integrated Policy case. Natural gas power plants experience the greatest declines in added capacity relative to the reference case (8.8% less generation in 2020, and 24.7% less generation in 2035).

Table 6.6 Electricity Generation by Source in the U.S. (in TWh)

Fuel Type	2010	2020		2035		
	Reference Forecast	Reference Forecast	Integrated Policy Case (% Change)	Reference Forecast	Integrated Policy Case	% Change
Coal	1,812	1,879	1,744 (-7.2%)	2,082	1,914 (-8.1%)	
Petroleum	39	39	37 (-5.8%)	41	40 (-4.1%)	
Natural Gas	779	696	635 (-8.8%)	914	688 (-24.7%)	
Nuclear	803	877	828 (-5.6%)	874	826 (-5.5%)	
Renewables	371	519	497 (-4.4%)	567	510 (-10.1%)	
Total	3,804	4,013	3,741 (-6.8%)	4,483	3,981 (-11.2%)	

In the Integrated Policy case, electricity generated from renewable sources does not decrease as much as generation from other sources in 2020. By 2035, however renewables are reduced proportionately more than coal or nuclear (10.1% versus 8.1% and 5.5%), but natural gas generation is offset most dramatically – by more than 200

TWh, when compared with the reference case. If natural gas hydrofracking continues to produce low-cost gas in the U.S., coal, nuclear and renewables might be further reduced while combined cycle natural gas plants would likely retain more of their market share.

Moreover, most of the eleven energy-efficiency policies have spillover benefits that may also cause significant savings in natural gas and other energy sources. In 2020, the U.S. could save 0.9 quadrillion Btu of natural gas due to energy-efficiency policies. The natural gas savings could grow to 2.3 quadrillion Btu in 2035, accounting for 40% of the total energy-savings potential.

6.5 Policy Impacts on Carbon Emissions and Energy Intensity

These sizable reductions in energy consumption are associated with reductions in carbon dioxide emissions. GT-NEMS forecasts that the energy-efficiency policies can slow down the growth in carbon dioxide emissions. More specifically, the reference case projects CO2 emissions reaching 5,802 million tonnes in 2020, and 6,316 million tonnes in 2035. The Integrated Policy case forecasts CO2 emissions reaching 5,584 million tonnes in 2020, and 5,990 million tonnes in 2035. This is equivalent to 3.8% of emission reduction in 2020, and 5.2% of emission reduction in 2035 (Figure 6.5). Based on the social cost of carbon, we estimate the benefit of avoided carbon emissions to be $6.0 Billion (in 2009$) in 2020 and $12.2 Billion (in 2009$) in 2035.

Our eleven energy-efficiency policies not only reduce carbon emissions, but also decrease the carbon intensity of the economy by targeting the carbon-intensive electricity sector. GT-NEMS output of per capita CO2 emission suggests that energy-efficiency policies drive emission down from 17.0 - 16.3 mmtCO2/capita in 2020. With regard to economic activities, carbon intensity decreases from 333 mmtCO2/million $GDP in the reference case to 321 mmtCO2/million $GDP in the Integrated Policy case in 2020.

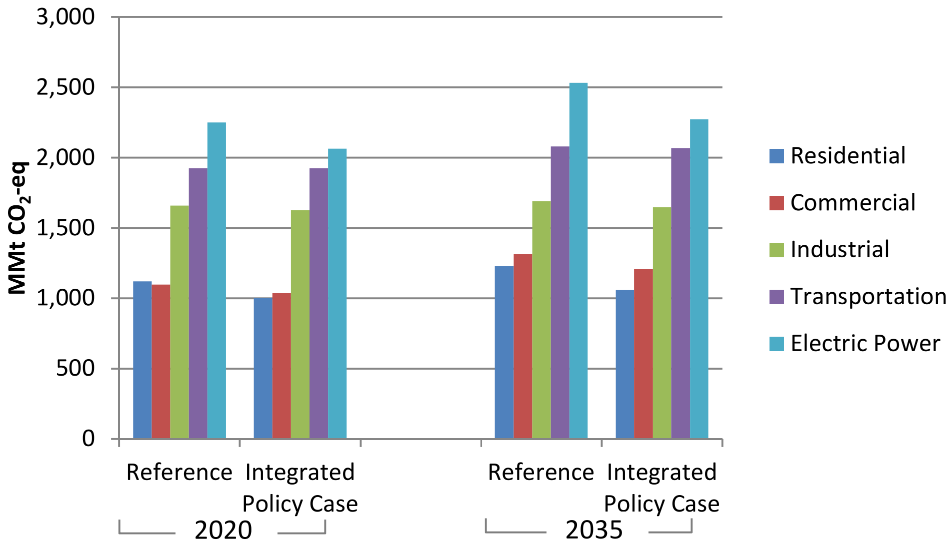

Figure 6.5 Projected CO2 Emissions, Reference versus Policy Case

The impact of energy-efficiency policies on different sectors of the economy can be compared through energy intensity metrics. Residential building energy intensity is measured by primary energy per household, while commercial building energy intensity is measured by primary energy use per square footage of floor space. The energy intensity of the whole economy is represented by primary energy use per gross domestic product (GDP).

An electricity intensity measures was constructed for the industrial sector. The three industrial energy efficiency policies particularly target electricity usages, which accounts for merely one third of total energy consumption in the industrial sector. The impact of these policies on energy intensity cannot be well reflected by the metric, energy per dollar of shipment. We constructed an electricity intensity factor, defined as electricity per dollar of shipment, to quantify industrial electricity efficiency.

Figure 6.6 suggests that energy-efficiency policies and programs would reduce household energy intensity more than the energy intensity of other end-use sectors. For example, in 2020, energy use per household decreases by 10.6%, while energy use per square footage of commercial building decreases by 4.8%, and electricity per dollar of shipment decreases by 5.3%. For the economy as a whole, energy use per GDP declines by only 3.2% in the same year.

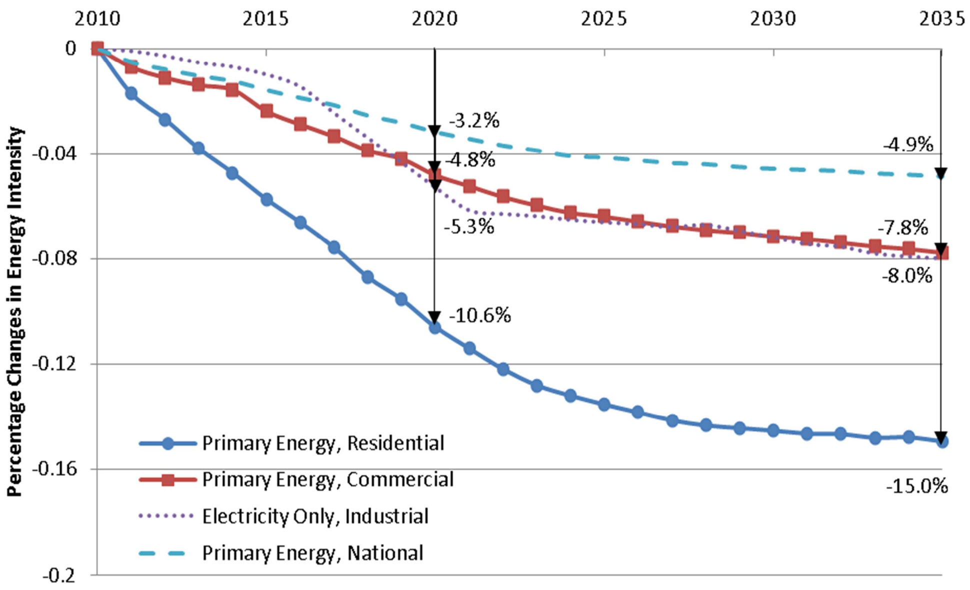

Figure 6.6 Decline in Energy Intensity by Economic Sectors

GT-NEMS incorporates national economic trends. The energy-efficiency policies have a negligible negative impact on GDP. The national GDP is estimated by NEMS to grow by $18 Billion (0.09%) less in the policy case in 2020, which is equivalent to only 9 hours of delay in GDP growth. In 2035, the GDP is estimated to drop by $52 Billion (0.18%), which is equivalent to about 30 hours of delay in GDP growth.

The higher equipment investments prompted by the eleven policies would divert the capital that could have been invested in other economic activities. Results from GT-NEMS suggest that this reallocation of capital resources would affect the national GDP, albeit to a small extent. In addition, the policies would reduce energy consumption and production, which also has GDP consequences. As an energy-economic model, GT-NEMS is capable of modeling the macroeconomic impact of any energy policy by incorporating Global Insight's model of the U.S. economy in its Macroeconomic Activity Module (MAM). Both energy demand and supply sides interact with MAM through a Cobb-Douglas production function to calculate the national GDP. However, the IHS Global Insights model assumes the U.S. economy has a 0.07 energy elasticity, which means that a 1% decrease in energy supply decreases potential GDP by 0.07% (EIA, 2012), but unlike input-output models the reduction in energy expenditures is not recycled back into the economy to reflect re-spending of the energy savings. As a result, NEMS tends to produce estimates of decreased GDP when energy-efficiency investments increase (Laitner, 2013).

6.6 Discussion and Conclusion

With a well-designed sample of policies, we estimate that the U.S. could cost-effectively achieve significant electricity savings. By 2035, the demand for 457 TWh (or 10.2% of the reference case forecast by EIA) could be eliminated by investments in more efficient technologies. Driven by policy, this achievable potential for greater end-use efficiency is somewhat lower than prior assessments of the technical and economic potentials. Our review of the literature, however, indicates that this estimated potential for the U.S. is comparable to many estimates of the achievable potential for increased electric end-use efficiency at various scales of analysis, ranging from the metropolitan to the national.

The policy supply curve illustrates that each of the eleven policies evaluated here are cost-effective with levelized costs lower than the average retail prices for electricity. Regulatory and information-based policies are particularly cost-effective, while financing policies tend to have higher LCOEs, although there are exceptions to this pattern.

The estimated efficiency potentials and levelized costs suggest that we do not reject the hypotheses of the three types of policies are able to generate significant electricity savings in the future.

The electricity savings benefit of energy-efficiency policies is accompanied by other benefits, including natural gas savings, savings of other fuel types, and reduced carbon emissions. In addition, the eleven energy-efficiency policies are able to drive electricity retail prices down in many regions and produce large energy bill savings for consumers. The electric power sector is also affected by these policies, in that generation growth is slowed in the Integrated Policy case, reducing the need for capital-intensive new generation. Overall, these policies are able to decrease the energy and carbon intensity of the U.S. with no significant impact on GDP growth.

In sum, this dissertation offers a novel assessment of achievable potential and an in-depth analysis of the impacts of energy-efficiency policies in the U.S. The policy supply curve can serve as a powerful tool for decision makers seeking policy solutions to energy efficiency. However, this engineering-economic approach is constrained by our choice of policies, which are characterized by pre-defined parameters of the modeling tool. Generalization of our findings to specific markets within the U.S. will require prudence and deliberation.

CHAPTER 7

CONCLUSIONS

State policymakers are facing challenges in population growth, economic development, environment protection, and climate change. Many of the issues are related to the use of energy, including excessive demand for energy, the depleting reserves of fossil fuels, air pollution, energy-water nexus limitations, and CO_2 emissions. In dealing with the energy related problems, energy efficiency serves as an important solution to meet the fast-growing energy demand. As the “low hanging fruit”, energy efficiency has been reducing the energy intensity of our economy with low costs, successfully avoiding a large amount of energy consumption in the end-use sectors. The U.S. would consume twice as much energy if there had been no improvement in energy efficiency since the 1970’s. With the long-term concern of energy security and fossil fuel conservation, energy efficiency helps alleviate the burdens of many countries for energy consumption and energy imports.

Recently, the energy efficiency market is growing fast. In the U.S., both the private and public sectors are paying more attentions to energy efficiency. Utilities, including investor-owned utility companies and utilities operated by rate-payers, started to find energy efficiency makes a good business case and started to invest heavily in energy efficiency. Federal, state and local governments have made various policy interventions to promote energy efficiency. Consumers who invest in energy efficient products find shortened pay-back times when they receive support from government agencies and utility programs.

According to the Sustainable Energy in the America 2014 Factbook, the energy efficiency market attracts $12 billion of investment from the public and private sectors in 2012 (Bloomberg New Energy Finance, 2014). Energy efficiency has been a success in the past few decades, and probably will continue its success in the future. Energy efficiency is not just the reflection of ideology or environmental awareness, but also a good business case providing great benefits. Because of this, most of the states turn to energy efficiency when faced with energy-related problems, as well as problems in economic development and climate mitigation.

7.1 State Drivers of Policy Innovation

States have adopted distinct approaches to promote energy efficiency with policy interventions. The state level panel data is considered as the quasi-experimental treatments for energy efficiency policies. In fact, states adopt distinct strategies in promoting energy efficiency, providing sufficient variations in policy treatments across states and across years. This dissertation is interested in state behavior of adopting a certain type of energy efficiency policy, defined as policy innovation. The quantification of policies depends on the specific policies and programs. Five policies were selected and classified into three types: financial, regulation, and information policies. Policy innovation is either quantified in interval variables (EE program budget and EERS targets) or coded into ordinal variables (all other policies).

The dissertation investigates the factors leading to the differences in state policy strategies. It assumes that constituent pressure affects state decisions of policy innovation. Constituent pressure is measured by the seriousness of problems in electricity consumption, electricity price, unemployment, and CO_2 emissions. Internal Determinants models with state fixed effects were developed to test the second hypothesis that different constituent interests lead to different types of policy innovation. The models also examine how policy innovations affect each other, while controlling for state socioeconomic factors, state fiscal capacity and ideology.

The results suggest that financial incentives are correlated with electricity consumption and unemployment rate. State unemployment rate is positively related to the investment in energy efficiency. States with high electricity consumption invest less in energy efficiency programs and are less likely to adopt building energy codes. Other constituent interests in electricity price and CO_2 emissions have no significant impact on policy innovation. In addition, the adoption of EERS, Decoupling and the Lead by Example program is not influenced by any of the constituent pressures.

However, the Internal Determinants models do find that policy innovations are affected by other internal state determinants, such as GSP, state fiscal capacity, environmental awareness, and state government ideology.

The dynamics among policy innovations are statistically significant. State spending/budget on energy efficiency programs and building codes are positively related to EERS targets. However, EERS targets are negatively related to the adoption of Lead by Example programs. This indicates that states tend to choose one policy from EERS and Lead by Example, rather than taking a combined approach of adopting both policies.

7.2 Significant Impacts of Policy Innovation

States undertake a variety of policy efforts to promote energy efficiency, including financial incentives, regulations, and information programs. However, mysteries and misleading arguments cloud the relationship between policy and energy efficiency. Controversy exists on whether the energy efficiency programs are effective and whether the policies actually improved energy efficiency. Many studies evaluate the savings from energy efficiency programs, but skeptics question the methodology of these studies and the credibility of policies.

The second section of the dissertation investigates the policy dynamics with energy efficiency, trying to examine the policy impacts on energy efficiency. This task faces two challenges: a) how to measure energy efficiency; and b) how to quantify policy. In measuring energy efficiency, many studies construct and use energy efficiency indicators such as energy intensity, per capita energy usage, and total factor efficiency index. Unlike the previous studies, this dissertation adopts the concept of index decomposition and separates the efficiency effect from the activity and structure effects in electricity productivity. It uses electricity productivity in a fixed effect model and controls for the activity and structure factors. By doing this, the estimation represents the effects of the policy variables on the actual underlining efficiency component of electricity productivity.

The impact of policy innovation was tested with fixed effect models to account for the unobserved state fixed effects. Controlling for the activity and structure effects, policy innovation, together with electricity price, is tested with linear regression to explain the efficiency effects of electricity productivity. Results suggest that financial incentives and building energy codes have significant positive impacts on energy efficiency. Building codes also have positive time-lagged effects. Other policies, such as decoupling and the Lead by Example program, have no significant impact on energy efficiency. However, the annualized targets of EERS tend to have negative time-lagged impacts.

The caveat is that the state panel data is biased due to heteroskedasticity, autocorrelation and cross sectional dependence, although the fixed effect model uses robust standard errors to control for heteroskedasticity. The impacts of policy innovation estimated by the two-way fixed effect model are confirmed by the fixed effect model with log forms and the feasible generalized least squares model which return similar results.

7.3 Achievable Potential of Energy Efficiency

The third part of the dissertation takes the perspective into the future to explore the potential of efficiency improvement. Some economists argue that energy efficiency is "tapped out" because the market has already exploited all cost-effective potentials. This dissertation questions this claim and tests the hypothesis that financial, regulatory, and information policies are able to continue driving energy efficiency improvement in the future.

Energy modeling was applied to eleven selected policies to represent the most influential financial incentives, regulations and information programs. The achievable potential was estimated using predictions of energy consumption assuming the selected policies are implemented. Levelized cost of electricity (LCOE) was estimated for each of the policies. The results suggest that the three types of policies are able to save 5.3-9.1% of electricity in 2035, with levelized costs lower than the retail prices of electricity. The selected policies are estimated to be efficient and cost-effective in improving energy efficiency. More specifically, information and regulatory policies are more cost-effective than financial incentives.

It is recommended that states adopt a combined approach of financial incentives, regulations, and information programs to improve energy efficiency. Financial incentives may require significant capital investment, but the benefits in energy savings will exceed the costs in the long run. Regulations such as building energy codes, EERS, and decoupling, are also recommended because they are enablers and mandates with very low costs. However, deliberation and scrutiny is required in the design of regulations.

In general, the dissertation offers an in-depth investigation of the relationship between policy innovation and electric end-use efficiency. It answers three related questions: a) what drives policy innovation? b) was policy innovation relevant in the past? and, c) will policy innovation be relevant in the future? Findings from the statistical and energy models suggest that different constituent concerns lead to different strategies in policy innovation. Financial, regulatory, and information policies have been increasing electricity productivity in the past, and they are estimated to continue driving energy efficiency improvement in the future.

This dissertation represents the first attempt to evaluate policy impacts on energy efficiency by decomposing electricity productivity. It provides rigorous statistical analysis of state panels covering the most important energy efficiency policies. It models a relatively comprehensive set of policies to estimate the achievable potential in energy efficiency. However, the statistical models and energy models are subject to limitations and future research is needed to improve the models.

Appendix A. Quantification of the Policy Variables

Table A.1 State Electricity Efficiency Program Spending/Budget

State	2004 Total Spending (Million$)	2006 Total Spending (Million$)	2007 Total Spending (Million $)	2008 Total Budget* (Million $)	2009 Total Budget (Million $)	2010 Total Budgets (Million $)	2011 Total Budget ($million)
Alabama	$0.44	$0.46	$2.29	$2.73	$9.1	$17.70	10.7
Alaska	$0.10	$0.16	$0.30	$0.36	$0.0	$0.40	0.0
Arizona	$4.00	$16.40	$31.90	$38.03	$49.2	$92.30	126.1
Arkansas	$0.23	$0.00	$1.57	$1.87	$7.7	$13.10	25.2
California	$380.01	$357.00	$755.28	$900.52	$998.3	$1,158.10	1,162.5
Colorado	$13.72	$11.00	$15.29	$18.23	$46.7	$64.70	64.1
Connecticut	$58.10	$69.60	$95.72	$114.12	$73.4	$126.90	138.3
Delaware	$0.00	$0.00	$0.21	$0.25	$0.0	$3.60	3.3
District of Columbia	$2.20	$8.50	$0.00	$0.00	$12.5	$9.40	7.7
Florida	$72.01	$67.00	$92.56	$110.36	$132.6	$123.20	188.5
Georgia	$1.36	$10.00	$4.82	$5.75	$21.3	$21.60	21.7
Hawaii	$9.19	$12.90	$16.56	$19.74	$35.5	$19.30	35.6
Idaho	$7.02	$20.42	$16.64	$19.84	$31.5	$36.10	39.9
Illinois	$3.00	$3.22	$0.83	$0.99	$89.9	$165.50	115.7
Indiana	$2.06	$3.73	$4.04	$4.81	$13.6	$16.50	58.2
Iowa	$28.83	$52.24	$56.49	$67.36	$55.6	$67.80	88.8
Kansas	$0.00	$0.34	$6.78	$8.09	$3.7	$5.40	9.1
Kentucky	$4.15	$5.94	$17.87	$21.31	$17.2	$27.10	28.2
Louisiana	$0.32	$0.00	$0.00	$0.00	$2.3	$0.00	9.0
Maine	$13.12	$11.00	$16.88	$20.13	$20.8	$14.00	22.8
Maryland	$0.05	$0.09	$2.52	$3.01	$38.0	$88.80	156.4
Massachusetts	$133.33	$125.00	$120.16	$143.26	$183.8	$301.90	453.0
Michigan	$8.00	$10.00	$0.00	$0.00	$50.1	$91.50	127.6
Minnesota	$55.78	$48.11	$91.24	$108.78	$111.2	$160.20	191.2
Mississippi	$0.50	$0.44	$0.31	$0.37	$9.2	$12.50	4.9
Missouri	$0.93	$2.18	$1.32	$1.57	$22.7	$40.50	47.2
Montana	$8.00	$8.31	$6.66	$7.94	$13.2	$8.90	21.1
Nebraska	$4.35	$0.87	$0.95	$1.13	$7.1	$13.00	16.5
Nevada	$8.47	$24.00	$28.27	$33.71	$41.9	$45.00	47.2
New Hampshire	$15.12	$17.54	$18.68	$22.27	$15.2	$26.30	25.6
New Jersey	$92.75	$83.18	$95.91	$114.36	$132.3	$198.10	225.0
New Mexico	$2.00	$1.00	$2.96	$3.53	$14.4	$17.50	26.2
New York	$147.19	$224.90	$241.54	$287.99	$378.3	$583.60	1,073.2
North Carolina	$3.72	$3.80	$6.78	$8.08	$64.3	$45.30	57.4

North Dakota	$0.47	$0.51	$0.67	$0.80	$0.1	$1.30	0.0
Ohio	$16.20	$28.76	$28.76	$34.29	$18.6	$152.80	134.4
Oklahoma	$0.32	$0.02	$0.17	$0.21	$3.8	$27.90	39.6
Oregon	$62.89	$63.32	$69.11	$82.40	$84.7	$91.10	171.8
Pennsylvania	$3.45	$3.81	$4.07	$4.85	$96.9	$110.00	225.0
Rhode Island	$13.99	$17.18	$17.94	$21.39	$29.5	$32.10	54.2
South Carolina	$4.92	$5.88	$8.93	$10.64	$14.6	$12.30	16.3
South Dakota	$0.54	$0.62	$2.35	$2.80	$2.7	$3.50	4.3
Tennessee	$10.94	$5.48	$9.97	$11.88	$24.2	$48.90	36.7
Texas	$80.00	$57.80	$79.50	$94.79	$98.7	$128.40	144.1
Utah	$16.45	$16.80	$13.95	$16.63	$45.4	$55.50	49.2
Vermont	$14.00	$15.81	$23.69	$28.25	$30.7	$34.00	40.7
Virginia	$0.00	$0.08	$0.00	$0.00	$0.4	$0.20	0.1
Washington	$88.52	$113.29	$126.68	$151.04	$146.5	$184.90	274.9
West Virginia	$0.99	$0.00	$0.00	$0.00	$0.0	$0.00	0.0
Wisconsin	$53.73	$73.29	$80.58	$96.08	$101.1	$92.30	92.3
Wyoming	$0.00	$0.00	$0.00	$0.00	$2.6	$4.30	5.4

*The 2008 budgets are estimations based on the growth rate of 19.23% (data source: ACEEE State Energy Efficiency Scorecard 2006, 2008, 2009, 2010, 2011, and 2012)

Table A.2 State Electricity Efficiency Program Budget as Percent of Utility Revenue

State	2004	2006	2007	2008*	2009	2010	2011
Alabama	0.0%	0.0%	0.0%	0.06%	0.12%	0.20%	0.13%
Alaska	0.0%	0.0%	0.0%	0.00%	0.00%	0.04%	0.00%
Arizona	0.3%	0.3%	0.5%	0.60%	0.70%	1.26%	1.74%
Arkansas	0.0%	0.0%	0.0%	0.12%	0.23%	0.38%	0.70%
California	1.3%	1.1%	2.2%	2.53%	2.86%	3.42%	3.35%
Colorado	0.3%	0.3%	0.4%	0.76%	1.11%	1.35%	1.28%
Connecticut	1.8%	1.5%	2.0%	1.68%	1.36%	2.18%	2.83%
Delaware	0.0%	0.0%	0.0%	0.00%	0.00%	0.22%	0.25%
District of Columbia	0.7%	0.7%	0.0%	0.40%	0.79%	0.57%	0.52%
Florida	0.3%	0.3%	0.4%	0.46%	0.52%	0.50%	0.77%
Georgia	0.1%	0.1%	0.0%	0.10%	0.19%	0.16%	0.16%
Hawaii	0.6%	0.6%	0.7%	1.18%	1.65%	0.77%	1.13%
Idaho	1.8%	1.8%	1.2%	1.67%	2.13%	2.43%	2.67%
Illinois	0.0%	0.0%	0.0%	0.36%	0.72%	1.23%	0.91%
Indiana	0.1%	0.1%	0.05%	0.12%	0.18%	0.18%	0.69%
Iowa	1.1%	1.7%	1.4%	1.59%	1.78%	1.93%	2.55%
Kansas	0.0%	0.0%	0.2%	0.16%	0.12%	0.14%	0.25%
Kentucky	0.1%	0.1%	0.4%	0.35%	0.30%	0.43%	0.44%
Louisiana	0.0%	0.0%	0.0%	0.02%	0.04%	0.00%	0.13%

Maine	1.1%	0.8%	1.0%	1.15%	1.30%	1.16%	1.59%
Maryland	0.0%	0.0%	0.06%	0.26%	0.46%	1.07%	2.05%
Massachusetts	2.2%	1.5%	1.4%	1.80%	2.20%	3.69%	5.77%
Michigan	0.1%	0.1%	0.0%	0.27%	0.53%	0.88%	1.50%
Minnesota	1.4%	1.0%	1.7%	1.95%	2.19%	2.80%	3.24%
Mississippi	0.0%	0.0%	0.0%	0.12%	0.23%	0.29%	0.11%
Missouri	0.0%	0.0%	0.0%	0.20%	0.39%	0.60%	0.67%
Montana	1.0%	0.9%	0.5%	0.83%	1.16%	0.82%	1.86%
Nebraska	0.1%	0.1%	0.05%	0.20%	0.35%	0.58%	0.71%
Nevada	0.7%	0.7%	0.8%	0.99%	1.18%	1.37%	1.55%
New Hampshire	1.2%	1.1%	1.3%	1.13%	0.95%	1.40%	1.60%
New Jersey	1.2%	0.9%	1.1%	1.14%	1.18%	1.63%	2.05%
New Mexico	0.1%	0.1%	0.2%	0.51%	0.82%	0.94%	1.31%
New York	1.0%	1.1%	1.6%	1.67%	1.73%	2.47%	4.69%
North Carolina	0.0%	0.0%	0.06%	0.33%	0.60%	0.38%	0.50%
North Dakota	0.1%	0.1%	0.2%	0.11%	0.01%	0.12%	0.00%
Ohio	0.2%	0.2%	0.2%	0.17%	0.14%	1.09%	0.96%
Oklahoma	0.0%	0.0%	0.0%	0.05%	0.10%	0.64%	0.85%
Oregon	2.2%	2.0%	2.1%	2.22%	2.34%	2.60%	4.51%
Pennsylvania	0.0%	0.0%	0.0%	0.35%	0.70%	0.71%	1.44%
Rhode Island	1.6%	1.6%	1.9%	2.28%	2.66%	2.92%	5.34%
South Carolina	0.1%	0.1%	0.2%	0.22%	0.23%	0.17%	0.23%
South Dakota	0.1%	0.1%	0.7%	0.52%	0.34%	0.39%	0.46%
Tennessee	0.1%	0.1%	0.4%	0.35%	0.29%	0.55%	0.40%
Texas	0.2%	0.2%	0.9%	0.60%	0.29%	0.39%	0.43%
Utah	1.2%	1.1%	0.8%	1.62%	2.44%	2.86%	3.19%
Vermont	2.2%	2.4%	3.4%	3.90%	4.40%	4.57%	5.64%
Virginia	0.0%	0.0%	0.0%	0.00%	0.00%	0.00%	0.00%
Washington	1.9%	2.2%	2.6%	2.54%	2.48%	3.35%	4.36%
West Virginia	0.0%	0.0%	0.0%	0.00%	0.00%	0.00%	0.00%
Wisconsin	1.1%	1.3%	1.2%	1.42%	1.64%	1.37%	1.31%
Wyoming	0.0%	0.0%	0.0%	0.13%	0.26%	0.41%	0.47%

*The 2008 percentage numbers are the average of 2007 and 2009 percentages (Data source: ACEEE State Energy Efficiency Scorecard 2006, 2008, 2009, 2010, 2011, and 2012)

Table A.3 Annualized Energy Saving Target of EERS

State	2005	2006	2007	2008	2009	2010	2011
Alabama	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Alaska	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Arizona	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.25%
Arkansas	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.25%
California	0.80%	0.80%	0.80%	1.00%	0.90%	1.00%	1.00%

Colorado	0.00%	0.18%	0.18%	1.00%	1.00%	1.00%	0.80%
Connecticut	1.00%	1.00%	1.00%	1.00%	1.00%	0.00%	0.00%
Delaware	0.00%	0.00%	0.00%	0.00%	2.50%	0.00%	0.00%
District of Columbia	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Florida	0.00%	0.00%	0.00%	0.00%	0.35%	0.35%	0.35%
Georgia	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Hawaii	0.00%	0.00%	0.00%	0.00%	1.00%	1.00%	1.50%
Idaho	0.00%	0.00%	0.00%	1.50%	1.50%	1.50%	1.50%
Illinois	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Indiana	0.00%	0.00%	0.00%	0.20%	0.40%	0.60%	0.80%
Iowa	0.00%	0.00%	0.00%	0.00%	0.00%	0.30%	0.50%
Kansas	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Kentucky	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Louisiana	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Maine	0.00%	0.00%	0.00%	0.00%	0.00%	1.00%	1.00%
Maryland	0.00%	0.00%	0.00%	1.80%	1.80%	1.80%	1.80%
Massachusetts	0.00%	0.00%	0.00%	0.00%	2.40%	1.40%	2.00%
Michigan	0.00%	0.00%	0.00%	0.00%	0.30%	0.50%	0.75%
Minnesota	0.00%	1.00%	1.50%	1.50%	1.50%	1.50%	1.50%
Mississippi	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Missouri	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Montana	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Nebraska	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Nevada	0.60%	0.60%	0.60%	0.60%	0.60%	0.60%	0.60%
New Hampshire	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
New Jersey	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
New Mexico	0.00%	0.00%	0.00%	0.70%	0.70%	0.70%	0.70%
New York	0.00%	0.00%	0.00%	1.90%	1.90%	1.90%	1.90%
North Carolina	0.00%	0.00%	0.25%	0.75%	0.75%	0.25%	0.25%
North Dakota	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Ohio	0.00%	0.00%	0.00%	0.00%	0.30%	0.50%	0.70%
Oklahoma	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Oregon	0.00%	0.00%	0.00%	0.00%	0.00%	0.80%	0.87%
Pennsylvania	0.00%	0.00%	0.00%	0.00%	0.00%	1.00%	1.00%
Rhode Island	0.00%	0.00%	0.00%	0.00%	1.00%	1.25%	1.50%
South Carolina	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
South Dakota	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tennessee	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Texas	0.10%	0.10%	0.10%	0.30%	0.30%	0.40%	0.40%
Utah	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Vermont	1.00%	1.00%	1.00%	1.80%	2.00%	2.25%	2.25%
Virginia	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Washington	0.00%	0.00%	0.00%	0.00%	1.00%	1.00%	1.00%
West Virginia	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Wisconsin	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Wyoming	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table A.4 State Score of Decoupling Mechanisms

State	2005	2006	2007	2008	2009	2010	2011
Alabama	0	0	1	0	0	0	3
Alaska	0	0	0	0	0	0	0
Arizona	2	2	2	2	2	3	3
Arkansas	0	0	1	0	0	0	3
California	2	2	3	3	3	3	3
Colorado	1	1	2	2	2	3	3
Connecticut	2	2	3	3	3	3	3
Delaware	0	0	1	0	2	2	2
District of Columbia	0	0	1	0	3	3	3
Florida	1	1	1	0	2	2	3
Georgia	0	0	2	2	3	3	3
Hawaii	0	0	1	2	3	2	3
Idaho	1	1	2	2	2	2	2
Illinois	1	1	1	0	0	0	0
Indiana	0	0	3	3	2	2	3
Iowa	1	1	1	0	0	0	0
Kansas	0	0	1	2	2	2	3
Kentucky	0	0	3	2	3	3	3
Louisiana	0	0	0	0	0	0	3
Maine	1	1	1	0	3	3	3
Maryland	0	0	0	2	2	2	3
Massachusetts	2	2	3	3	3	3	3
Michigan	0	0	0	0	3	3	3
Minnesota	2	2	3	3	3	3	3
Mississippi	0	0	1	0	0	0	0
Missouri	0	0	1	0	2	2	3
Montana	1	1	2	2	3	3	3
Nebraska	0	0	0	0	0	0	0
Nevada	2	2	2	2	3	3	3
New Hampshire	2	2	3	2	2	3	3
New Jersey	1	1	1	0	1	1	2
New Mexico	0	0	1	0	3	3	3
New York	0	0	2	2	3	3	3
North Carolina	0	0	0	0	3	3	3
North Dakota	0	0	0	0	0	0	0
Ohio	1	1	3	2	3	3	3

Oklahoma	0	0	0	0	3	3	3
Oregon	1	1	2	1	2	2	2
Pennsylvania	0	0	1	0	0	0	0
Rhode Island	2	2	3	2	2	3	3
South Carolina	0	0	1	2	3	3	3
South Dakota	0	0	0	0	2	3	3
Tennessee	0	0	0	0	0	0	0
Texas	1	1	1	0	2	2	2
Utah	0	1	1	0	3	3	3
Vermont	2	2	3	3	3	3	3
Virginia	0	0	0	0	2	2	3
Washington	1	1	1	0	2	2	3
West Virginia	0	0	0	0	0	0	0
Wisconsin	1	1	1	2	3	3	3
Wyoming	0	0	0	0	0	2	2

Note: the scores of state decoupling policy are based on the three legged stool: the recovery of administrative and program costs, decoupling and the recovery of lost revenue, and performance incentives. Each of the three parts has a score of 1. The maximum is 3.

Table A.5 State Score on the Stringency of Building Energy Codes

State	2005	2006	2007	2008	2009	2010	2011
Alabama	0	0	0	0	0	0	10
Alaska	3	3	4	4	4	4	5
Arizona	4	4	4	4	0	4	4
Arkansas	5	5	5	6	5	5	5
California	8	8	8	10	10	10	12
Colorado	4	4	4	4	4	2	4
Connecticut	6	6	6	6	7	7	10
Delaware	4	4	4	4	10	10	10
District of Columbia	5	6	6	4	10	10	11
Florida	6	6	6	10	9	9	10
Georgia	6	6	6	8	7	8	12
Hawaii	2	2	2	3	3	7	10
Idaho	6	6	7	8	7	7	10
Illinois	4	4	6	6	6	10	10
Indiana	2	2	2	2	3	10	9
Iowa	6	6	7	8	7	10	10
Kansas	6	6	6	4	3	3	2
Kentucky	5	5	6	8	7	7	9
Louisiana	5	5	5	8	7	7	8

Maine	3	3	3	4	10	10	10
Maryland	6	6	7	8	10	10	12
Massachusetts	3	3	3	5	10	10	12
Michigan	0	0	0	3	7	8	10
Minnesota	6	6	6	7	7	7	8
Mississippi	0	0	0	0	0	0	0
Missouri	2	2	2	2	2	2	4
Montana	6	6	7	6	5	10	10
Nebraska	6	6	6	6	5	5	10
Nevada	6	6	6	6	7	7	10
New Hampshire	4	4	8	8	10	10	10
New Jersey	3	3	8	8	7	10	10
New Mexico	6	6	6	8	7	10	10
New York	4	4	4	8	7	10	10
North Carolina	5	5	6	6	7	8	10
North Dakota	0	0	0	0	0	0	0
Ohio	6	6	6	7	7	7	9
Oklahoma	3	3	3	6	5	2	2
Oregon	6	6	7	10	8	9	12
Pennsylvania	6	7	7	8	10	10	10
Rhode Island	6	6	6	8	10	10	10
South Carolina	6	6	6	8	7	7	8
South Dakota	0	0	0	0	0	1	1
Tennessee	1	1	1	1	2	4	8
Texas	6	6	6	6	5	5	10
Utah	6	6	7	8	7	9	9
Vermont	4	4	4	6	5	5	10
Virginia	6	6	6	8	7	10	9
Washington	6	6	8	10	8	8	12
West Virginia	6	6	6	6	5	5	5
Wisconsin	4	4	4	10	7	7	9
Wyoming	0	0	0	0	0	0	0

Table A.6 State Score on the Lead by Example Program

State	2005	2006	2007	2008	2009	2010	2011
Alabama	0	1	1	1	1	1	1
Alaska	0	0	0	0	0	1	2
Arizona	0	2	1	2	2	2	2
Arkansas	2	1	2	1	1	2	2

California	0	2	2	2	2	2	2
Colorado	1	1	1	1	1	2	2
Connecticut	0	1	1	1	1	1	2
Delaware	1	0	1	1	1	2	2
District of Columbia	0	1	1	2	2	2	2
Florida	1	1	1	1	1	1	1
Georgia	0	0	0	0	0	2	2
Hawaii	0	1	1	1	1	2	2
Idaho	0	1	0	0	1	1	1
Illinois	0	1	1	1	1	1	1
Indiana	0	0	0	0	1	1	1
Iowa	1	1	1	2	2	2	2
Kansas	0	0	0	0	1	1	0
Kentucky	0	1	0	2	2	1	2
Louisiana	0	0	1	1	1	1	1
Maine	1	1	1	1	1	1	1
Maryland	1	1	1	1	1	1	1
Massachusetts	0	2	1	1	1	1	2
Michigan	1	2	2	2	2	2	2
Minnesota	1	1	1	1	1	1	2
Mississippi	0	0	0	0	0	0	1
Missouri	1	1	1	1	1	1	1
Montana	0	1	0	1	1	1	1
Nebraska	0	0	0	0	0	0	1
Nevada	0	1	0	1	1	1	1
New Hampshire	0	1	0	1	1	2	2
New Jersey	0	1	1	1	1	1	2
New Mexico	0	1	0	1	1	1	1
New York	0	1	0	1	1	1	2
North Carolina	0	1	1	1	1	1	2
North Dakota	0	0	0	0	0	0	0
Ohio	0	1	2	2	2	2	2
Oklahoma	0	0	0	0	1	1	1
Oregon	1	1	1	1	1	1	2
Pennsylvania	1	1	1	1	1	1	1
Rhode Island	0	1	0	1	1	1	1
South Carolina	0	1	1	1	1	1	2
South Dakota	0	0	0	0	1	1	2
Tennessee	0	0	0	0	1	1	2
Texas	1	1	2	2	2	2	2
Utah	0	1	1	2	2	2	2

Vermont	1	1	1	1	1	1	2
Virginia	0	0	0	1	1	1	1
Washington	2	2	2	2	2	2	2
West Virginia	0	0	0	0	0	0	1
Wisconsin	0	1	1	1	1	1	1
Wyoming	0	0	0	0	0	0	0

Note: the scoring of the Lead by Example program is based on two parts: the efficiency requirement, and the rating/benchmarking requirements. Each of the two parts has the score of 1. The maximum is 2.

Table A.7 Correlation Table of Explanatory Variables

	Electricity Productivity	Population	Per Capita Income	Electricity Price	% Post 2000 Homes	Household Size - Owner	Household Size - Renter	% Electric Heating	CDD	HDD	% Financing	% Electricity Intensive Industries	% Food and Health	Total EE Program Budget	EE Budget % Utility Revenue	EERS	Decoupling	Building Code	Lead By Example
Electricity Productivity	1																		
Population	0.2033	1																	
Per Capita Income	0.605	-0.0745	1																
Electricity Price	0.7731	0.1174	0.2895	1															
% Post2000 Homes	-0.297	-0.0055	-0.1592	-0.1877	1														
Household Size-Owner	0.3614	0.3431	-0.1239	0.399	0.1755	1													
Household Size-Renter	0.1129	0.369	-0.1092	0.2011	0.5907	0.722	1												
% Electric Heating	-0.4013	0.1493	-0.116	-0.171	0.4977	-0.1262	0.3521	1											
CDD	-0.1294	0.1674	-0.0159	0.2148	0.3399	0.1915	0.4756	0.635	1										
HDD	0.0863	-0.3345	0.0366	-0.1776	-0.2806	-0.177	-0.5273	-0.6945	-0.8711	1									
% Financing	0.2782	-0.0207	0.1341	0.1435	0.0001	0.0427	-0.0416	-0.206	-0.1246	0.0966	1								
% Electricity Intensive Industries	-0.4619	0.0582	-0.3524	-0.3332	-0.0138	-0.1608	-0.0933	0.1977	0.0452	-0.1907	0.0156	1							
% Food and Health	-0.0379	-0.0402	-0.3094	0.1129	-0.2311	-0.3087	-0.4262	-0.1916	-0.1735	0.1744	0.0311	0.0928	1						
Total EE Program Budget	0.434	0.6776	0.0671	0.2918	-0.0681	0.3172	0.2936	-0.0901	-0.0886	-0.0828	0.063	-0.1351	-0.0121	1					
EE Budget % Utility Revenue	0.3868	0.1015	0.0367	0.2796	-0.0524	0.1522	-0.0142	-0.3203	-0.3321	0.2519	0.0762	-0.2418	0.2203	0.5075	1				
EERS	0.3133	0.1966	0.0307	0.2838	0.0431	0.1104	0.0541	-0.1983	-0.1356	0.0956	0.1115	-0.2024	0.1667	0.3903	0.6128	1			
Decoupling	0.2482	0.1167	0.0556	0.2528	0.2644	0.111	0.158	-0.1334	-0.0513	0.0375	0.0829	-0.1256	0.243	0.2985	0.4942	0.4611	1		
Building Code	0.2426	0.2643	0.076	0.0658	-0.0239	0.1789	0.1224	0.0043	-0.1274	-0.0551	0.0049	-0.0937	-0.0682	0.4287	0.4585	0.2344	0.1854	1	
Lead By Example	0.3896	0.2255	0.1927	0.3766	0.0665	0.2215	0.1903	-0.1115	0.0736	-0.1174	0.0533	-0.1802	0.1248	0.3122	0.3579	0.2266	0.429	0.2287	1

Appendix B: GT-NEMS Modeling and Cost Estimations of Energy Efficiency Policies

A portfolio of eleven policies was modeled with GT-NEMS to assess the achievable potential of electricity efficiency. NEMS outputs from individual policy scenarios were used in supplemental spreadsheet analysis to calculate the levelized cost of electricity saved. This appendix provides information about modeling details and cost estimations policy by policy.

(1) Appliance Incentives offer a 30% subsidy to reduce the capital cost for the most efficient technologies in residential buildings based on the GT-NEMS technology menu. This amount of subsidy is chosen because many state and federal programs offer financial incentives of 30% for clean energy investments. For instance, the American Taxpayer Relief Act of 2012 renewed the residential energy efficiency tax credit through December 31, 2013. Its credit ranges from about 10 to 30% for various envelope retrofits and equipment upgrades, including for example $300 for a heat pump water heater or a 90% efficient gas water heater. The State Energy Efficient Appliance Rebate Program offered similar levels of subsidies for appliances from 2009 - 2011. In 2008, the American Recovery and Reinvestment Act created a 30% investment tax credit for solar energy. The Energy Policy Act of 2005 established a tax credit for commercial and residential PV and solar hot water heaters of 30%, up to $2000 per home. For this reason, the other two financial incentives in this analysis, the Commercial Financing policy and the CHP Incentives policy, apply the same amount of subsidies to reduce the capital costs of energy-efficient technologies.

A list of 25 selected technologies from the major end-uses eligible for incentives can be found in Table B.1. A subsidy was provided to these technologies to reduce their capital costs by 30% in this policy scenario.

Table B.1 Most Efficient Home Appliances and Equipment [a]

End-Use	Equipment Type	Average Cost [b] ($2007)	Average Efficiency	Available Years
Space Heating	Fuel Oil Furnace 3	4,983	0.95	2009-2023
	Fuel Oil Radiator 3	4,513	0.95	2012-2022
	Electric Heat Pump 4	3,567	3.14	2014-2021
	Geothermal Heat Pump 2	6,414	5	2010-2018
	Kerosene Furnace 3	4,983	0.95	2009-2023
	LPG Furnace 5	2,470	0.96	2009-2019
	Natural Gas Furnace 5	2,470	0.96	2009-2020
	Natural Gas Radiator 3	4,513	0.95	2012-2022
Space Cooling	Central Air Conditioner 4	5,290	6.504	2011-2019
	Electric Heat Pump 4	3,567	5.325	2014-2021
	Geothermal Heat Pump 2	5,749	30	2011-2021
	Room Air Conditioner 3	900	3.52	2012-2026
Clothes Washing	Clothes Washer 3	958	0.114	2008-2022
Dishwashing	Dishwasher 3	1,181	1.1	2010-2020
Water Heating	Fuel Oil Water Heater 3	2,400	0.68	2012-2026
	Electric Water Heater 5	1,430	2.4	2009-2023
	LPG Water Heater 4	852	0.746	2014-2022
	Natural Gas Water Heater 4	852	0.746	2014-2023
Cooking	Electric Stove 2	400	601	2006-2050
	LPG Stove 2	500	0.42	2006-2050
	Natural Gas Stove 2	500	0.42	2006-2050
Clothes Drying	Electric Clothes Dryer 2	500	3.74	2009-2023
	Natural Gas Clothes Dryer 2	515	0.931	2007-2028
Refrigeration	Refrigerator 4	1,107	399	2009-2023
Freezing	Freezer 3	626	290	2010-2032

a. The costs and performance of these technologies vary by census division. The efficiency for different equipment types are measured by different metrics.

The Appliance Incentives policy would incur two types of costs. The private investment which is the expenditure spent by residential consumers to purchase equipment. Table B.2 shows the difference in equipment expenditure between the policy case and the reference. The negative private costs suggest that the subsidy can offset the incremental cost of purchasing energy-efficient equipment. The cost burden is borne by the program with over $3 Billion every year spent by the public sector to provide subsidy. The total cost of the policy is the sum of both the private and public costs, and it is estimated to be $2.9 billion in 2035. By weighting the cost with electricity savings, the levelized cost of electricity saved (LCOE) in this policy case is estimated at 6.7-8.0 cent/kWh (Table B.2).

Table B.2 Cost Estimations from Appliance Incentives

Cost (Billion $2009) [a]	2020	2025	2030	2035
Private Cost	-1.37	-1.01	-0.73	-0.53
Subsidy Cost	4.51	4.25	3.83	3.42
Administration Cost	0.01	0.01	0.01	0.01
Total	3.15	3.25	3.11	2.90
LCOE (cent/kWh)	6.7 [b] -8.0			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.
b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.

(2) In the residential Building Energy Codes case, four new codes were added to the building codes profile to force shell efficiency improvements. These codes were modeled with relatively high heating and cooling shell efficiency, and relatively high shell installation costs, in the attempt to mimic the periodic code updates.

In the Reference case, new residential buildings are built either to no code, or in compliance with four different levels of codes: IECC 2006, Energy Star, FORTY code (40% above IECC 2006 code), and PATH code (50% above IECC 2006). We constructed a policy scenario where existing building codes are replaced by new codes to ensure efficiency improvements roughly 5% every five years. The Building Codes scenario was set up based on EIA's Expanded Standards and Codes side case (EIA, 2011), where four new codes were added including 'IECC 2006+' (about 30% above IECC 2006), 'IECC 2006++' (about 5% above IECC 2006 +) , 'IECC 2006+++' (about 5% above IECC 2006 ++), and 'NEW CODE' (about 5% above IECC 2006 +++) to mimic gradual code improvements. Each newly added code has higher cost associated with efficiency improvements. Table B.3 shows the details about the residential building codes in our policy case.

Table B.3 Building Energy Codes Profile for Residential Buildings [a]

Building Codes	Average Shell Installation Cost	Average Heating Shell Efficiency Factor	Average Cooling Shell Efficiency Factor
'No IECC'	7	1.21	1.15
'IECC 2006'	5,251	0.81	1.06
'Energy Star'	5,508	0.79	1.03
'FORTY%'	6,797	0.68	0.97
'PATH'	7,868	0.51	0.93
'IECC 2006+'	5,580	0.69	0.90
'IECC 2006++'	6,018	0.65	0.85
'IECC 2006+++'	6,128	0.61	0.80
'NEW CODE'	7,392	0.56	0.85

a. The cost and efficiency factors for each building shell type vary by census division.

The policy case also accounts for regional differences in code adoption (Figure B.1). For example, the Pacific division is the early adopter of the IECC 2006, Energy Star, Forty, and IECC 2006+ codes, while the East South Central division is the most lagged adopter of these codes. Energy Star, Forty and IECC 2006+ retire five years later than IECC 2006 with time variance among census divisions. But the IECC 2006++ retires at

2023 for all regions; and the IECC 2006+++ code retires at 2028 for all regions. The 'New Code' and the PATH code, the two most stringent codes, stay available for all years and all regions.

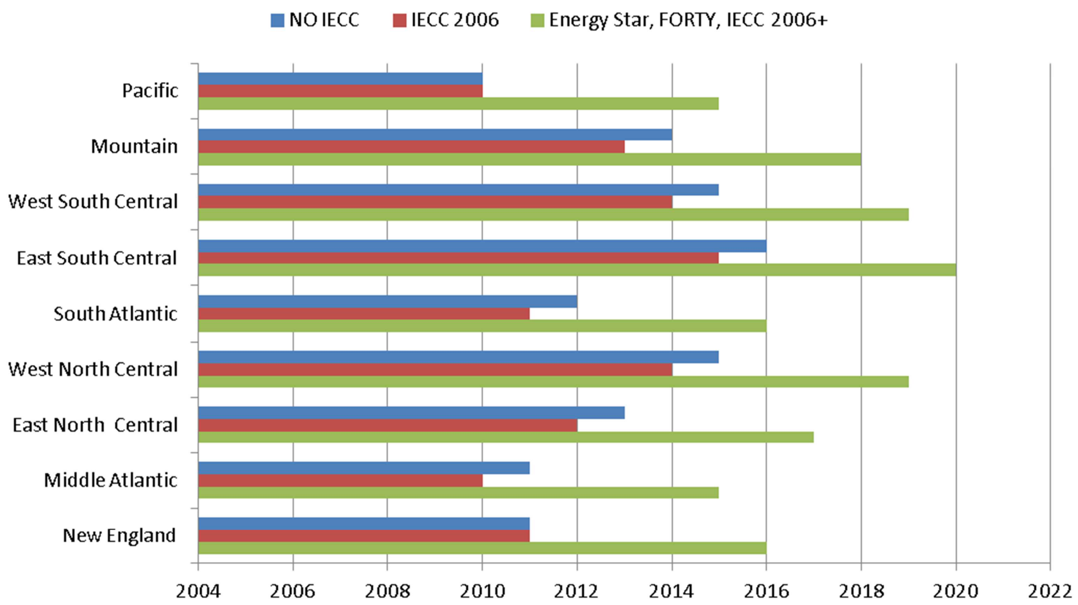

Figure B.1 Building Energy Code Retirement Years by Census Division

New houses built in compliance with new codes consume less energy due to better insulation and building design. Although under new codes installation costs get higher, compliance to the new codes improves over time (Figure B.2).

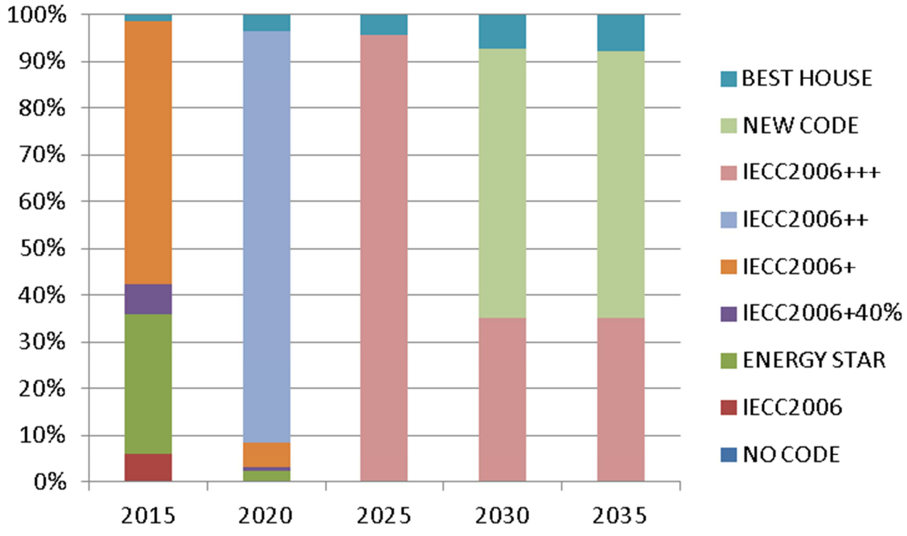

Figure B.2 Share of New Houses Built in the Policy Case

The LCOE was calculated based on the difference in private and public costs between the policy scenario and the reference. Cost to the private sector is the incremental cost of equipment plus the installation cost for better building envelopes. By installing more thermally efficient envelopes, HVAC equipment can be down-sized due to lower service demand. This phenomenon is reflected by the negative equipment expenditure, suggesting less money spent on building equipment in the policy case than the reference case (Table B.4). To estimate program administrative costs, we assume cost associated with building code enforcement would be represented by the budget of each state hiring their building code officials and inspectors. The administrative costs are based on each state adding one administrative office run at $150,000 per annum budget and one code official at $75,000 salary per annum. It also includes two additional building code inspectors for the verification of every 100 million square feet in the state at $75,000 per year (Brown, et al., 2009). The levelized cost is estimated to be 0.5-0.8 cent/kWh (Table B.4).

Table B.4 Cost Estimations from Residential Building Energy Codes

Cost (Billion $2009) [a]	2020	2025	2030	2035
Equipment Expenditure	-0.02	-0.02	-0.01	-0.01
Shell Installation Cost	0.33	0.28	0.39	0.25
Administration Cost	0.02	0.02	0.02	0.02
Total	0.33	0.29	0.40	0.26
LCOE (cent/kWh)	0.5-0.8[b]			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.

b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.

(3) The On-bill Financing program offers zero-interest loans to the most efficient home appliances and equipment. The technologies eligible for zero-interest loans are the same technologies that are eligible for appliance subsidies as listed in Table B.1. In GT-NEMS modeling, consumer choice of energy-using equipment is based on lifecycle cost. To model on-bill financing, we changed the equations of lifecycle cost calculation. In the reference case, the life-cycle costs for residential technologies are calculated as following:

$$LFCY_{y,es,b,r,v} = CAPITAL_{es} + OPCOST_{y,es,b,r,v} * \left(\frac{1-(1+DIST)^{-HORIZON}}{DIST}\right)$$

To bring in financing option with variable interest rates and payback periods, we changed the lifecycle cost equation to:

$$LFCY_{y,es,b,r,v} = (ANNUALPAY_{es} + OPCOST_{y,es,b,r,v}) * \left(\frac{1-(1+DIST)^{-HORIZON}}{DIST}\right)$$

When interest rate is 0%, we have,

$$ANNUALPAY = \frac{CAPITAL}{CAPHOR}$$

When interest rate is greater than 0%, we have,

$$ANNUALPAY = CAPITAL * \frac{CAPDISRT}{1-(1+CAPDISRT)^{-CAPHOR}}$$

Where, LFCYCLE is the lifecycle costs by equipment class, building type, and census division; CAPITAL is the capital costs for appliances; OPCOST is the operational costs for appliances; DIST is the discount rate for the operational cost during the life time of the appliances; HORIZON is the appliance life time; ANNUALPAY is the annual payment for on-bill financing equipment; CAPHOR is payback time; and CAPDIST is the interest rate offered by the on-bill financing program.

In the policy scenario, the 25 selected technologies were assigned a 0% interest rate and 10-year payback time. Other technologies were assigned non-zero interest rate, indicating their life-cycle costs were calculated with the original equation.

With on-bill financing, increased private investment is the increased expenditure for purchasing home appliances and equipment. Loan cost is the initial seed money put into the program for zero-interest loans. Program administrative cost is estimated as $0.13/MMBtu energy saved. The LCOE associated with On-bill Financing is estimated to be 6.6-7.4 cent/kWh (Table B.5)

Table B.5 Cost Estimations from On-Bill Financing

Cost (Billion $2009) [a]	2020	2025	2030	2035
Private cost	0.95	0.64	0.40	0.25
Loan Cost	1.48	0.02	-0.09	0.01
Administrative Cost	0.01	0.01	0.01	0.01
Total	2.44	0.67	0.32	0.27
LCOE (cent/kWh)	6.6-7.4 [b]			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.
b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.

(4) The Market Priming policy also targets the same set of technologies as shown in Table B.1, but was modeled with hurdle rate changes. Providing information is

assumed to lower discount rate when consumers make investment decisions. GT-NEMS modeling of this policy changed the hurdle rates of the efficient technologies to 7%.

With Market Priming, private investment increases when consumers purchase more of the efficient appliances and equipment. Public cost is represented by program administrative cost, estimated as $0.13/MM Btu energy saved. The levelized cost is estimated to be 2.7-3.6 cent/kWh for Market Priming (Table B.6).

Table B.6 Cost Estimations from Market Priming

Cost (Billion $2009) [a]	2020	2025	2030	2035
Private cost	6.91	3.76	2.90	1.44
Administration Cost	0.03	0.03	0.02	0.02
Total	6.94	3.79	2.92	1.46
LCOE (cent/kWh)	2.7-3.6 [b]			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.
b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.

(5) The Aggressive Appliance Policy forces retiring the least efficient technologies from the market place at 2012. In GT-NEMS, the selected technologies were made either unavailable after 2012, or assigned a hurdle rate equals to 100%, making these technologies never be chosen to meet energy service demands. A list of forced retired technologies is shown in Table B.7.

Table B.7 Residential Technologies Forced Early Retirement [a]

End-Use	Equipment Type	Average Efficiency	Available Years
Space Heating	Fuel Oil Furnace 1	0.82	2010 - 2032
	Fuel Oil Radiator 1	0.825	2010 - 2031
	Electric Heat Pump 1	2.35	2014 - 2028
	Kerosene Furnace 1	0.82	2010 - 2032
	LPG Furnace 1	0.818	2010 - 2032
	Natural Gas Furnace 1	0.818	2010 - 2032
	Natural Gas Radiator 1	0.815	2010 - 2031

Space Cooling	Central Air Conditioner1	3.899	2009 - 2039
	Electric Heat Pump 1	4.003	2014 - 2028
	Room Air Conditioner 1	3.103	2013 - 2027
Clothes Washing	Clothes Washer 1	0.160	2012 - 2022
Dish Washing	Dishwasher 1	0.587	2010 - 2024
Water Heating	Fuel Oil Water Heater 1	0.585	2011 - 2032
	Electric Water Heater 1	0.925	2011 - 2032
	LPG Water Heater 1	0.59	2006 - 2050
	Natural Gas Water Heater 1	0.605	2011 - 2032
Refrigeration	Refrigerator 1	428. 7	2013 - 2027
Freezing	Freezer 1	347.5	2010 - 2032

a. The performances of these technologies vary by census division. The efficiency for different equipment types are measured by different metrics.

Similar to the Market Priming policy, the cost estimation for the Aggressive Appliance Policy has private cost from the expenditure for purchasing equipment, and public cost from program administrative costs. The levelized cost is estimated to be 0.6-0.7 cent/kWh (Table B.8).

Table B.8 Cost Estimations from Aggressive Appliance Policy

Cost (Billion $2009) [a]	2020	2025	2030	2035
Private cost	0.25	0.16	0.11	0.08
Administration Cost	0.01	0.01	0.01	0.01
Total	0.26	0.18	0.13	0.09
LCOE (cent/kWh)	0.6-0.7 [b]			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.
b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.

Unlike the residential energy-efficiency policies where LCOEs were calculated based equipment units, cost estimation for commercial policies was based on service demand. We estimate the magnitude of technology investment costs in the commercial buildings separately for new purchases, replacements, and retrofits. In each case, the calculation is based on GT-NEMS estimates of service demand (SD) for energy.

For new purchases,

Investment Cost = SDnew * (Cost/8760) /CF

where CF is the equipment-specific capacity factor;

For replacements,

Investment Cost = SDreplacement * (Cost/8760) /CF

For retrofits, we assume the average amount of commercial floorspace undergoing a retrofit is 2.2%. We use the following equation to proportion the surviving service demand to the commercial sector retrofit average:

Investment Cost = SDsurviving * (Cost/8760) /CF * 0.022/(SDsurviving/SDtotal)

Where SDtotal = SDnew + SDreplacement + SDsurviving

(6) In the Benchmarking policy case, GT-NEMS uses a combination of discount rates and the rate for U.S. government ten-year Treasury notes to calculate consumer hurdle rates used in making equipment-purchasing decisions. While the macroeconomic module of GT-NEMS determines the rate for ten-year Treasury notes endogenously, the discount rates are inputs to the model. Modifying these inputs is the primary means of estimating the impact of benchmarking for the commercial sector in this analysis. This is done in two steps: first, by updating the discount rates to reflect a broader selection of the literature; and second, by adjusting the updated discount rates to account for the effects of a national benchmarking policy.

To illustrate, Table B.9 presents the 2015 hurdle rates used in GT-NEMS across scenarios for two major end-uses in the commercial sector, space heating and lighting (these values represent the sum of the Treasury bill rates and the discount rates).

Table B.9 Discount Rates across Scenarios for Space Heating and Lighting in 2015

% of Population		Discount Rate [a]	
Reference	**Bench-marking**	**Reference**	**Bench-marking**
Space Heating			
27	14.2	1005.75	40.4
23	14.3	**105.75**	19.6
19	14.3	50.75	15.4
18.6	14.3	30.75	**12.4**
10.7	14.3	20.75	9.8
1.5	14.3	12.25	7.4
0.2	14.3	5.75	4.8
Lighting			
27	14.2	1005.75	57.3
23	14.3	**105.75**	40.8
18.6	14.3	50.75	36.5
18.6	14.3	30.75	**33**
8.8	14.3	20.75	30.4
1.5	14.3	12.25	26.9
2.5	14.3	5.75	21.7

a. Discount rates presented include the projected Treasury bill rate for 2015. **Bold** numbers represent the median estimate for the specific scenario.

The Benchmarking policy provides energy performance information on commercial buildings. Equipment expenditure increases with this policy. Program administrative cost was estimated as $0.13/MMBtu energy saved. The levelized cost of electricity is estimated to be 0.9-1.4 cent/kWh (Table B.10).

Table B.10 Cost Estimations from Benchmarking

Cost (Billion $2009) [a]	2020	2025	2030	2035
Private Cost	1.27	1.01	0.97	0.92
Compliance Cost	0.002	0.002	0.002	0.001
Total	1.28	1.01	0.98	0.92
LCOE (cent/kWh)	0.9-1.4 [b]			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.
b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.

(7) The commercial Building Code is modeled, in part, by assuming a more rapid rate of commercial shell efficiency improvement, as shown in Table B.11. Code requirements of efficiency improvements for HVAC equipment is also incorporated in GT-NEMS modeling.

Table B.11 Commercial Building Shell Efficiency Improvement [a]

	New Construction	Existing Buildings
EIA Reference case	14%	6%
EIA High Tech Case	17.4%	7.5%
Building Code Scenario	30%	19%

a. Improvement of 2035 efficiency over 2003 efficiency

In this policy scenario, private investment is the incremental cost of equipment and building envelope expenditures to meet new building codes. This policy assumes costs associated with building code enforcement carried out by state building code officials and inspectors. The assumptions about code enforcement cost (the cost of running an administrative office and hiring inspectors) stay the same as in the residential building codes policy. The levelized cost is estimated to be 3.4-4.6 cent/kWh, with most of the cost burden fall on the private sector (Table B.12).

Table B.12 Cost Estimations from Building Codes

Cost (Billion $2009) [a]	2020	2025	2030	2035
Private Cost	1.14	0.74	0.39	0.27
Shell Improvement Cost	0.08	0.06	0.04	0.04
Administration Cost	0.04	0.04	0.04	0.03
Total	1.26	0.84	0.47	0.34
LCOE (cent/kWh)	3.4-4.6 [b]			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.
b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.

(8) In the Commercial Financing policy case, a 30% subsidy was provided to 107 technologies, based on a prior analysis of the impact of implementing a carbon tax (Brown, Cox, & Sun, 2012). The subsidized technologies are listed in Table B.13.

Table B.13 Incentivized Technologies in Financing Policy Case

End-use / Fuel Type	Technology (Vintages)
Space Heating	
Electricity	Commercial type ground source heat pump (vintages include 2011 high, 2011 high 10% ITC w MACRS, 2011 typical, 2011 typical 10% ITC w MACRS, and 2020-30 typical) Rooftop air source heat pump (vintages include 2007 high, and 2030 high)
Natural Gas	Gas boiler (2011 high vintage) Gas furnace (2011 high vintage) Residential type gas heat pump (vintages include 2020 typical and 2030 typical)
Space Cooling	
Electricity	Centrifugal chiller (vintages include 2007 high, 2007 mid range, 2010 typical, 2020 typical, and ASHRAE 90.1-2004) Commercial type ground source heat pump (vintages include 2011 high, 2011 high 10% ITC w MACRS, 2011 typical, 2011 typical 10% ITC w MACRS, and 2020-30 typical) Reciprocating chiller (vintages include 2007 high, 2020 high, 2020 typical, and 2030 high) Residential type central AC (vintages include 2003 installed base, 2030 typical, and NAECA standard-pre-2006) Rooftop AC (vintages include 2003 installed base, 2007 typical, 2010 high, 2011 typical, and 2030 high) Rooftop air source heat pump (2030 high vintage) Screw chiller (vintages include 2020 high, 2030 high, and 2007 typical)

	wall-window room AC (vintages include 2011 typical and 2020 typical)
Water Heating	
Natural Gas	Gas water heater (2020 high vintage)
Electricity	Heat pump water heater (vintages include 2011 typical, and 2020 typical) Solar water heater (vintages include 2010 typical south, 2011 typical 30 pct ITC south, 2020 typical south, and 2030 typical south)
Ventilation	
Electricity	Constant Air Volume Vent (vintages include 2008 high, 2020 typical, and 2030 typical) Variable Air Volume Vent 2030 typical 2008 high and 2020 typical)
Cooking	
Electricity	Range, Electric-induction, 4 burner, oven, 11
Natural Gas	Range, Gas, 4 powered burners, convect. oven, 11
Lighting	
Electricity	72W Incandescent (Halogena Type HIR) F28T5, F32T8 Super, F96T8 High, F96T8HO LB LED (vintages include 2011-2019 Typical for high tech and 2020-2029 Typical)
Refrigeration	
Electricity	Beverage Merchandiser (vintages include 2008 high, 2008 low, 2011 typical, 2020 typical, 2030 typical, and installed base) Ice machine (vintages include 2011-2020 typical and 2010 EPACT standard) Reach-in freezer (vintages include 2008 high, 2020 typical, 2030 typical, and installed base) Reach-in refrigerator (vintages include 2008/2010 high, 2011 typical, 2020 typical, 2030 typical, and installed base) Supermarket compressor rack (vintages include 2011 high, 2011 typical, 2020 high, 2020 typical, 2030 high, and 2030 typical) Supermarket condenser (vintages include 2008 high, 2020 typical, and installed base) Supermarket display case (vintages include 2008 high-2012 standard, 2011 typical, 2020 high, and installed base) Vend Machine (vintages include 2008 low, 2008-10 high-2013 standard, 2008-10 typical, 2011 high, 2011 typical, 2020 high, and 2030 high) Walk-In freezer (vintages include 2008 high, 2009 EISA stnd-2010 typical, 2020 typical, 2030 typical, and installed base) Walk-In refrigerator (vintages include 2008 high, 2009 EISA stnd-2010 typical, 2020 typical, 2030 typical, and installed base)

In the Financing case, total cost was estimated to be the sum of increased equipment expenditure (policy caser versus reference), the cost of subsidizing the most efficient technologies, and program administrative costs. The levelized cost is estimated to be 7.8-8.1 cent/kWh (Table B.14).

Table B.14 Cost Estimations from Financing

Cost (Billion $2009) [a]	2020	2025	2030	2035
Private Cost	0.87	0.79	0.57	0.50
Subsidy Cost	11.15	10.91	10.43	9.78
Administration Cost	0.07	0.08	0.08	0.07
Total	12.09	11.78	11.08	10.34
LCOE (cent/kWh)	7.8-8.1 [b]			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.
b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.

(9) In various industrial processes, systems using motors, such as compressor, pump, and fan systems, are big users of electricity. The Motor Standard policy describes a scenario where technology advances are mandated for manufactures to produce higher-efficiency motors and lower energy-consuming motor systems with improved system design and the use of variable-frequency drives. To model the impact of such mandate, we assumes new motor systems save 25% more energy in 2017. For new motors, we assume there will be 5% efficiency improvement for small motors (50 horsepower or lower) and 3% efficiency improvement for larger motors. The modification was made effective from 2017 when the new standard is introduced.

Facility owners have to pay the costs of rewinding and replacing failed motors. The cost associated with the new motor standard is the incremental cost in motor expenditures. The private cost listed in Table B.15 suggests that more failed motors are replaced with new motors in place of a new motor standard. The public sector pays the program administrative cost, which is much lower than the private cost. The LCOE in this policy case is estimated to be $-2.4-3.9cent/kWh (Table B.15)

Table B.15 Cost Estimations from Motor Standard

Cost (Billion $2009) [a]	2020	2025	2030	2035
Private Cost	0.408	0.224	0.182	0.204
Administration Cost	0.001	0.002	0.002	0.002
Total	0.410	0.226	0.184	0.207
LCOE (cent/kWh)	2.4-3.9 [b]			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.
b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.

(10) In the CHP Incentives scenario, subsidies were applied to industrial CHP systems to promote efficient usage of waste heat in various industrial processes. A 10-year subsidy increasing from 15% to 30% was applied to the total installed cost of CHP systems. We assume that in the CHP market, retailers are able to share the benefits of the subsidy with the consumers at the beginning. All benefits gradually go to the consumers. To reflect this phenomenon, a 15% subsidy was applied for the first three years, rising by 5% every year from 2015 and staying at 30% from 2017 to 2021. GT-NEMS represents CHP as a combination of eight technology systems, including two internal combustion CHP systems (ranging from 1 to 3 MW), five gas turbine CHP systems (3 to 40 MW) and one combined cycle system (with two 40 MW gas turbines and a 20 MW steam turbine).

We account for the increased natural gas consumption and increased equipment expenditure as the private cost associated with the CHP Incentives policy. Subsidy cost was estimated based on the amount of incremental cost in CHP investments, while program administrative cost was estimated as 2% of subsidy cost. The LCOE in this policy case is estimated to be 1.5-2.3 cent/kWh (Table B.16).

Table B.16 Cost Estimations from CHP Incentive

Cost (Billion $2009) [a]	2020	2025	2030	2035
Increased Natural Gas Expenditure	1.55	1.15	0.62	0.54
CHP system	0.25	-0.02	-0.01	0.00
Subsidy cost	0.56	0.00	0.00	0.00
Administration cost	0.01	0.00	0.00	0.00
Total	2.37	1.13	0.62	0.54
LCOE (cent/kWh)	1.5-2.3 [b]			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.
b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.

(11) The Plant and Technology Upgrade policy characterizes the voluntary plant upgrades by the private sector. It took the estimated electricity and natural gas savings from plant utility and technology upgrades reported from 2010 to 2012 in the Industrial Assessment Center (IAC) database (Table B.17). The percentage savings were applied to change the TPC parameter in the itech.txt input file.

The Plant and Technology Upgrade is a combination of R&D and demonstration programs, which aim at identifying the most significant energy-saving opportunities associated with new technologies that can be applied to various industrial processes and sectors. Information is shared among facility owners about energy savings with plant utility upgrades, including non-energy related upgrades. It is assumed that information and technical assistance is able to stimulate volunteer upgrades in plants and firms. In addition, plant utility can be upgraded for non-energy-saving reasons. For instance, the recent trend of price drop for natural gas may motivate some factories to switch from electronically operated equipment to fossil fuel equipment. This type of upgrades can results in involuntary electricity savings with higher natural gas consumption.

The GT-NEMS modeling account for policy impacts on both electricity and natural gas. This analysis is unavoidably limited to its data source, while the IAC database has small sample size with a majority of small and medium sized firms. The extremely large potentials are likely the result of fuel switching and small sample sizes. In some cases the large electricity savings are generally coupled with natural gas (or other fuels) penalties. For example, in the chemical industry, an increase of natural gas consumption of 65% in the West is skewed by one plant in California producing adhesives and sealants. It switched from electronically-operated equipment to fossil fuel equipment, resulting in a 200% increase in natural gas consumption with 60% savings in electricity. Another instance is the textile industry in the Northeast, where one plant in Massachusetts implemented an upgrade in the time period of investigation. This plant installed cogeneration equipment, which uses a fossil fuel engine, saving 89% of electricity while using 11% more natural gas.

Table B.17 Electricity and Natural Gas Saving Estimations from IAC Reports

Industry	Electricity savings				Natural Gas			
	Northeast	Midwest	South	West	Northeast	Midwest	South	West
311 Food	48%	48%	37%	47%	1%	26%	2%	0%
322 Paper	29%	31%	15%	12%	5%	16%	11%	0%
325 Chemicals	63%	13%	52%	26%	-33%	25%	-4%	-65%
327 Non Metals	10%	20%	46%	37%	5%	29%	0%	N/A
331 Iron and Steel	15%	57%	28%	5%	14%	18%	3%	3%
332 Fabricated Metals	29%	47%	43%	29%	-49%	17%	11%	N/A
333 Machinery	20%	54%	46%	40%	29%	54%	27%	N/A
334 Computers and Electronics	31%	58%	16%	31%	31%	23%	7%	N/A
336 Transportation Equipment	17%	40%	57%	10%	17%	5%	N/A	N/A
335 Electrical	9%	12%	24%	36%	22%	22%	4%	N/A
321 Wood	23%	38%	34%	76%	23%	4%	55%	N/A
326 Plastics Others	23%	26%	28%	24%	15%	19%	17%	10%
313 Textile	5%	N/A	24%	N/A	5%	N/A	9%	N/A

314 Textile product	89%	11%	13%	13%	-11%	95%	24%	29%
324 Petroleum and Coal	14%	16%	7%	13%	74%	17%	21%	4%

For LCOE calculation, private cost was estimated as the incremental investment for plant upgrades in the private sector (policy case versus reference). Following the division of industrial plants by Brown et al (2011), this study grouped firms into small, medium and large sized firms (Figure B.3). It is assumed that the private investment is $14/MMBtu energy saved for large firms and $12.6/MMBtu energy saved for small and medium firms (Brown, Jackson, Cox, et al., 2011).

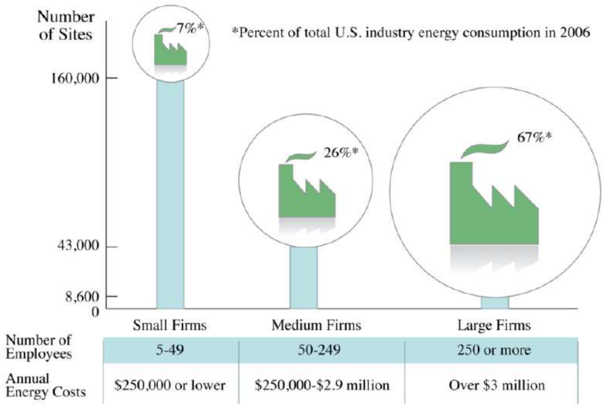

Figure B.3 U.S. Industrial Consumption by Size of Firm (Brown, et al., 2011)

The levelized cost associated with the Plant and Technology Upgrade is estimated to be 3.0-4.8 cent/kWh, with investment cost decreasing from $1.34 Billion in 2020 to $2.25 Billion in 2035 (present value, Table B.18).

Table B.18 Cost Estimations from Plant and Technology Upgrade

Cost (2009$Billion) [a]	2020	2025	2030	2035
Private Cost	1.34	1.26	0.89	0.94
Public Cost	0.02	0.03	0.03	0.03
Total	1.36	1.29	0.93	0.97
LCOE (cent/kWh)	3.0-4.8 [b]			

a. Private cost was discounted at 7%, and public cost was discounted at 3%.
b. Levelized cost calculated in a sensitivity when all costs were discounted at 3%.

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