# BUILDING UP ENERGY EFFICIENCY: AN ANALYSIS OF THE RELATIONSHIP BETWEEN ENERGY EFFICIENCY BUILDING CODES AND ELECTRICITY CONSUMPTION IN THE U.S. RESIDENTIAL SECTOR

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## ABSTRACT

The effects of climate change caused by the release of greenhouse gases (GHG) are a growing concern for state governments in the United States. The majority of state governments have attempted to mitigate GHG emissions through energy efficiency programs to combat the rising demand for electricity. In order to manage the increasing demand for electricity, states have adopted International Energy Conservation Codes (IECC) for new residential buildings to offset the demand for energy. This paper studies the relationship between state level residential building codes and electricity consumption rates. Using state-level panel data, I construct a database of state residential building code adoptions and energy use from 2000-2010 to measure the relationship between state regulation and residential electricity consumption using an OLS Fixed Effects model. My most conclusive findings suggest that there is a negative association between specific code adoption and electricity consumption, but only in states with low rates of new residential construction. I find that the adoption of the 2006 IECC building code in states with low rates of new residential construction is associated with a 1.7 percent decrease in electrical consumption per 10,000 residents. I also find that the adoption of an up-to-date building code is associated with a .7 percent decrease in electrical consumption per 10,000 residents in states with low rates of new residential construction.

First and foremost I would like to express my sincere gratitude to my thesis advisor Adam Thomas, Ph.D. for his continuous support and insight. I would also like to thank my colleagues Melissa Bennett and Joseph Ferrara, Ph.D. whose encouragement and understanding made writing this thesis possible.

Many thanks,
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## INTRODUCTION

Throughout history, building design has evolved to address the social, cultural and economic needs of society. Portable dwellings hastened the movement of ancient nomadic communities following food sources. High-rise buildings were designed to manage urban growth and spatial resources. Today, one hallmark of the building industry is the effort to conserve a vital resource: electricity. Fossil fuels, the source of greenhouse gases (GHG), are used to generate 69 percent of the electricity consumed in the United States (Gruenspecht, 2013). Although it is home to just 5 percent of the world's population, the U.S. consumes nearly 25 percent of the world's energy and emits 5 times the average country's carbon dioxide (Markham, 2008). The disproportionate energy consumption in the United States suggests that U.S. leadership is necessary for mitigating climate change. If GHG emission rates continue, it is estimated that the Earth's temperature will rise 4 degrees Celsius by the year 2100. This degree of temperature change may trigger massive climatic shifts, including rising sea levels, an increased frequency of severe storms, increased flooding and drought, and food scarcity (Markham, 2008). Reducing GHG emissions is essential to combating climate change (Intergovernmental Panel on Climate Change, 2007).

In order to abate an ever-increasing demand for electricity, states and local jurisdictions have adopted International Energy Conservation Codes (IECC) for new residential buildings to increase energy efficiency standards. The IECC building codes have been drafted every 3 to 5 years, beginning in 1998, by the International Code Council (ICC) in order to establish minimum energy efficiency standards for residential buildings (International Code Council, 2013). The adoption of energy-efficiency building codes and standards for residential buildings produces improvements in building products, heating, cooling and construction processes (International Code Council, 2013).

Advocates argue that the updating of these codes is critical for the reduction of carbon emissions from electricity generation (International Code Council, 2013). According to the Climate Policy Initiative, adoption of residential building codes was correlated with a 1.8 percent reduction in U.S. GHG emissions in 2008 (Deason, 2011). While new building energy efficiency codes have become law in most states, they still remain the subject of controversy. The National Association of Home Builders and the Home Innovation Research Labs opposed the 2012 IECC residential code updates, arguing that new homes with strict building codes were expensive to construct, took 200 years to recoup additional expenses, led to increased home prices with minute energy cost savings, and would reduce residential construction (National Association of Home Builders, 2009). Energy efficiency residential building codes are not mandatory. Individual state governments must choose to adopt, revise or reject the IECC recommendations. In order to make economically viable decisions, states must understand the relationship between building code adoption and residential electricity consumption.

This paper asks the following question: To what extent is the adoption of the most up-to-date IECC related to state-level residential electricity consumption? Using state-level panel data taken primarily from the U.S. Energy Information Administration (EIA), I examine the relationship between IECC building code adoption and residential electricity consumption per 10,000 people for the 48 mainland states and the District of Columbia between 2000 and 2010.

My findings suggest that the adoption of the 2006 IECC building code (in the previous year) in states with low rates of new residential construction is associated with a 1.7 percent decrease in electrical consumption per 10,000 residents. I also find that the adoption of an up-to-date building code is associated with a .7 percent decrease in electrical consumption per 10,000 residents in states with low rates of new residential construction.

## BACKGROUND

The volatile energy market and the growing environmental movement of the 1970s and 1980s were influential in stimulating the development of energy policies promoting energy efficiency in the U.S. In 1978, the first state building codes specifically targeting energy efficiency residential building enhancements were enacted in California with Title 24 (Bion and Prindle, 1991). This development in turn spurred action at the federal level in 1978 when the Energy Policy and Conservation Act was amended to require states to adopt energy efficiency programs, including the development of building energy codes, in order to receive federal funding (Alliance Commission on National Energy Efficiency Policy, 2013). In the 1980s, Florida, New York, Minnesota, Oregon, and Washington state developed individual voluntary statewide codes. Over the next two decades, many other states adopted the Model Energy Code (MEC), which was developed by the Council of American Building Officials (CABO) (Bion and Prindle, 1991). The 1992 enactment of the Energy Policy Act (EPAct) included a provision requiring that states review and/or revise their residential building codes regarding energy efficiency in order to meet the CABO Model Energy Code (U.S. Congress, 1992). In 2000, the MEC was updated and replaced by the IECC building codes.

Growing concerns over climate change have increased political pressure to continue improving energy efficiency. On February 17, 2009, President Barack Obama signed the American Recovery and Reinvestment Act (ARRA) into law (Phillips, 2009). The ARRA included an allocation of 3.1 billion dollars for the State Energy Program, which provided funds for state energy offices (SEOs) that adopted and enforced the most recent 2009 residential building code and conducted residential building energy audits (U.S. Government Accountability Office, 2010). In June of 2009, Title II of The American Clean Energy and Security Act (Waxman-Markey Bill) called for the establishment of mandatory national energy codes for residential buildings, based upon the 2006 IECC code. This legislation was passed by the U. S. House of Representatives but was defeated in the Senate (U.S. Congress, 2009).

Today, 43 states plus the District of Columbia have adopted the 2003, 2006, 2009, or 2012 version of the IECC for residential buildings, creating a patchwork of residential codes across the country. Alaska, Arizona, Kansas, Mississippi, Missouri, South Dakota and Wyoming are the only states that have not implemented any mandatory statewide version of the IECC building codes (Building Code Assistance Project, 2014).

The IECC covers new construction, additions, remodeling, window replacement, and repairs of specified buildings. The residential portion of the code applies to buildings that are detached one- and two-family dwellings and buildings that contain three or more housing units and are three stories or less in height. County code officials typically enforce residential state building standards at the local level. Compliance varies by state, as does the quality and quantity of technical training that inspectors receive in order to perform their jobs effectively (American Council for an Energy-Efficient Economy, 2006).

According to the Environmental Protection Agency, well-designed, implemented and enforced building codes can eliminate inefficient construction practices and substantially reduce residential electricity consumption (U.S. Environmental Protection Agency, 2011). In California, Title 24 and its revisions have saved citizens more than $56 billion in electrical and natural gas expenses, according to the California Energy Commission (Franks, 2010). Although per capita electricity use in the U.S. has increased by nearly 50 percent since the 1970s, California's per capita electricity usage has remained essentially unchanged over this period (U.S. Environmental Protection Agency, 2005).

My analysis provides insight into this topic by analyzing the relationship between the adoption of energy efficiency building codes and residential electricity consumption rates at the state level. More specifically, I seek to measure the relationship between adoption of up-to-date IECC residential building codes and annual per capita state electricity consumption rates.

## LITERATURE REVIEW

There is a large body of literature on the environmental and economic logic underlying the implementation of energy efficiency regulations, including building codes. However, literature on nationwide and multi-state electricity consumption reductions resulting from the actual implementation of energy efficiency building codes is relatively limited. Previous studies typically relied on simulated engineering models that compare the electricity usage of real-world pre-building code-adoption residences with the projected electricity usage of simulated post-building code-adoption model residences. More recent studies have used real-world data to study the relationship between electricity usage and building code adoption. Other studies have focused on the relationship between electricity usage and other factors such as electricity price and political ideology. I review this literature here.

At the request of the DOE's Building Energy Program, Lucas (2007) studied the energy savings and costs associated with implementing the 2006 IECC codes in Louisiana and

Mississippi during the Hurricane Katrina reconstruction process. The author used a simulation tool to estimate the savings yielded under various energy efficiency scenarios. The author's estimates suggested that adoption of the 2006 IECC energy efficiency standard produced energy cost savings of between 24 percent and 28 percent. Engineering models can be useful for making static energy savings predictions, but they do not control for fluid factors related to behavioral changes, political dynamics, economic considerations, or variation in enforcement.

Costa and Kahn (2010) used household-level data from Sacramento to investigate California's flattening electricity use per capita. Their regression results suggested that decreases in electricity consumption after 1983 were correlated with the implementation of California's residential building codes. In a similar study, Horowitz and Haeri (1990) conducted a cross-sectional regression analysis of annual electricity consumption in Tacoma, Washington residences built before and after building codes were implemented. They found (with a relatively small sample size) that adopting a new building code was associated with a 13.7 percent decrease in electricity consumption. In contrast to these studies, I consider the effects of strengthening existing codes in addition to implementing new ones. The former may be more policy-relevant because forty-three states have already adopted a version of the IECC as a model energy code for residential buildings and will likely continue increasing their stringency (U.S. Environmental Protection Agency, 2011).

Jacobsen and Kotchen (2011) also conducted a single state study but compared household-level electricity and gas consumption data between residences constructed before and after an increase in the stringency of Florida's energy code in 2002 in order to determine the relationship between energy consumption and updating residential building codes. The authors found that energy code adoption was associated with a 4 to 6 percent decrease in energy consumption. They also control for weather variability by including variables for average monthly heating and average monthly cooling degree days to account for temperature variation and found a positive correlation between immoderate temperatures and electricity consumption.

Aroonruengsawat et al. (2009) studied the relationship between the adoption of a variety of state-level residential building codes and per capita electricity consumption for the 48 mainland U.S. states from 1960 to 2006. Hawaii and Alaska were excluded from the model due to missing climate data. The results of their analysis suggested that the adoption of any building code (even non-IECC codes) was associated with a decrease in per capita electricity consumption between .3 and 5 percent in 2006. This relationship was stronger in states with higher rates of new residential construction and more strictly enforced building codes.

Changes in energy codes may not affect energy consumption if the codes are not effectively enforced. According to the American Council for an Energy-Efficient Economy, state building codes vary in stringency (ACEEE, 2008). Aroonruengsawat et al. utilizes a score based on the 2008 ACEEE state energy efficiency scorecard to measure building code variation in their model.[a] Moreover, the authors fail to control for the degree of enforcement across states. Before the Department of Energy required states to consider adopting the IECC as the model residential code, states adopted a variety of building codes. Many of these codes were voluntary or applicable only to local municipalities. In order to ensure the variation underlying my state building code variables is consistently measured, I only include observations from years in which

[a] The ACEEE State Energy Efficiency Scorecard reports a score for compliance for residential and commercial building codes ranging from one to five.

the IECC is the model building code and identify states as having adopted building codes only if the code is mandatory and implemented statewide.

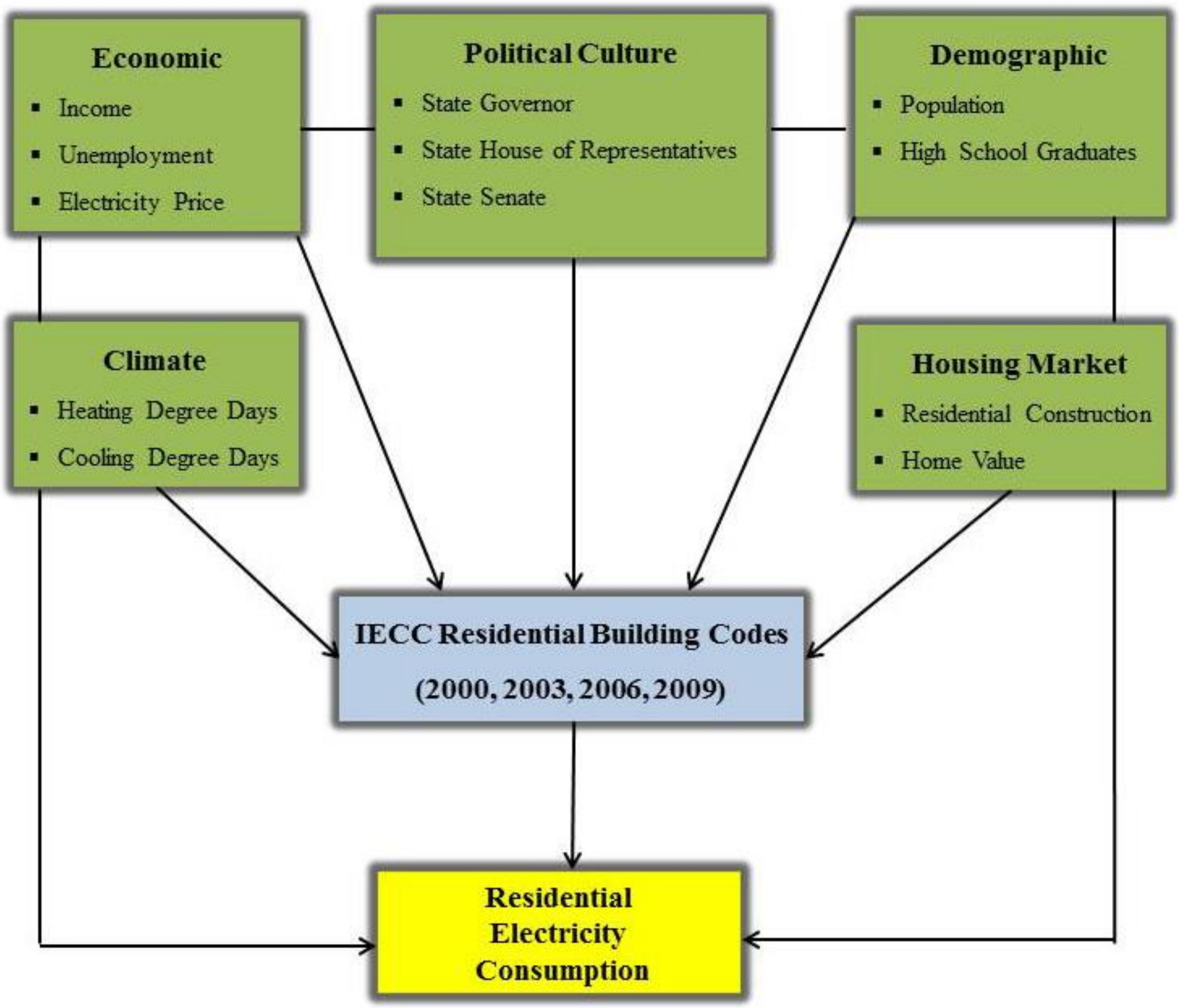
Alberini et al. (2010) studied the behavioral determinants of energy consumption. The authors focused specifically on the relationship between electricity demand in the residential sector and energy price change. They used nationwide household-level data that cover a relatively recent time span (1997-2007) and found that the household response to energy prices, both in the short and long terms, was substantial. The price elasticity of electricity demand was estimated to be in the -0.860 to -0.667 range. The authors' results indicate that there is a consumer response to changing energy prices. This finding suggests that there may be greater potential for reducing energy consumption from policies that affect energy prices than was previously thought.

Costa and Kahn (2008) conducted another study that used household-level data to investigate the relationship between household political party designation and electricity use per household. Their regression results suggest that, in summer months, being a liberal was associated with a 6.6 percent lower level of electricity consumption relative to the consumption of conservatives (Costa and Kahn 2008).

## CONCEPTUAL FRAMEWORK

In order to reduce omitted variable bias, my regressions will control for climate, economic, political, demographic and housing market factors that might be associated with IECC code adoption and energy use. Figure 1 shows the state level characteristics that are plausibly associated with the adoption of different versions of the IECC building code and with residential electricity consumption. These characteristics include climate, economic, political, demographic, and housing market factors. As suggested in Figure 1, many of the state-level characteristics associated with the adoption of a building code are also associated with state electricity consumption.[b] First, climate factors may be associated with both electricity consumption and the adoption of building codes. Having a higher number of average monthly heating and cooling degree days is associated with increased electricity consumption (Jacobsen and Kotchen, 2011).

**Figure 1: Factors Affecting Energy Efficiency Building Code Adoption**




[b] Unless otherwise noted, all assertions are previously discussed in the Literature Review section.

However, states that have a higher number of heating and cooling degree days may also be more likely to adopt building codes, which would reduce electricity consumption.

Economic factors are also associated with electricity consumption and the adoption of building codes. Income and unemployment rates are indicators of the economic wellbeing of a state. States with high levels of unemployment and low income per capita may consume less electricity (Aroonruengsawat et al., 2009). States also may be less likely to adopt or update their residential building codes if doing so is potentially burdensome to its low-income residents. Electricity prices can influence how much electricity a household consumes (Alberini et al., 2010).

The third group of factors associated with electricity consumption and the adoption of building codes is political culture. States considered to be more politically liberal are also likely to consume less electricity (Costa and Kahn, 2008). Policymakers in such states may also be more likely to adopt building codes or continue to update newer codes.

Demographic factors may also be associated with both electricity consumption and the adoption of building codes. States with larger populations likely have a greater number of residences and a higher rate of new residential construction. As a result, these states will likely have higher rates of electricity consumption than states with smaller populations. Highly populated states may also have a greater incentive to adopt or update new residential building codes because they are more likely to see more substantial reductions in energy consumption. States with a greater number of high school graduates per capita may be more likely to have higher electricity consumption rates. States that have populations with higher levels of education attainment may also be more willing to pay a premium for energy efficiency programs like IECC building codes (Zarnikau, 2002).

Finally, housing market factors are associated with both the adoption of building codes and with electricity consumption as explained in the Literature Review. Households with higher home values may be more likely to consume more electricity as a result of greater square footage or number of rooms. States with higher value homes are also more likely to have a population that is able to afford the increased costs of new or updated building codes. New residential construction is also a factor that may influence both the adoption of building codes and electricity consumption. Since only new buildings and additions to existing residences are subject to building code restrictions, states with higher rates of new residential construction are likely to see more substantial electricity consumption reductions from adopting building codes (Aroonruengsawat et al., 2009).

## DATA AND METHODS

I use panel data to estimate an Ordinary Least Squares model with state and year fixed effects. The sample size for all analyses is 539 observations from 48 states, plus the District of Columbia, over 10 years. Hawaii and Alaska were omitted due to missing climate data.

My dependent variable measures annual state residential electricity consumption per 10,000 people in British Thermal Units (BTU). Data for this variable were taken from State Energy Data Systems (SEDS) within the Energy Information Administration (EIA). The key independent variables are a series of dummy variables for state IECC building code adoption for 48 states plus the District of Columbia (Building Energy Codes Program, 2014). These data were obtained from the U.S. Department of Energy's Building Energy Codes Program (BECP) and the

Building Code Assistance Project (BCAP). Both the BECP and the BCAP maintain databases containing detailed information on the current and historical statuses of state level residential building codes. These dummies have a value of “1” if a state has adopted the 2000, 2003, 2006, or 2009 IECC codes between 2000 and 2010 and a “0” if it has not. For example, if Alabama adopted the 2000 IECC code in 2001, the data entry for Alabama in 2001 would be a “1” (Building Code Assistance Project. 2014).

In other analyses, the key independent variable is a dummy variable set equal to “1” for states that have adopted the most up-to-date IECC building code. The year of adoption for *uptodate* and the individual IECC dummies is lagged by one year to account for the delay in implementation that occurs when enacting new regulations. The variable *uptodate* has a value of “1” if the state-year adopted the 2000 IECC code between 2000 and 2003, adopted the 2003 IECC code between 2004 and 2006, adopted the 2006 IECC code between 2007 and 2009, or adopted the 2009 IECC code in 2010.

I also include a dummy variable set equal to “1” for states with high rates of new residential construction (*highbuild*). These dummies have a value set equal to “1” if a state has an above mean new residential construction rate. I interact this variable with my IECC building code variables. Precise data measuring completed new residential construction were not available, so the number of new residential construction permits issued per year, obtained from the U.S. Census Bureau, is used as a proxy control variable.

My model includes other time-varying state-level control variables that are likely correlated with both the dependent variable (electricity consumption) and the key independent variable (building-code adoption). These variables include home values, income, unemployment rates, electricity prices, population, number of students graduating from high school per capita, heating and cooling degree days, state governor party affiliation, state house of representatives party affiliation, and state senate party affiliation. See Table 1 for variable definitions.

The variable median home value (*homevalue*), measured in $1000, is included to control for housing market factors. These data were obtained from the Lincoln Institute of Land Policy. The variables per capita income (*income*), unemployment rate (*unemployment*), and electricity price (*elecprice*) were included to control for economic factors. These economic variables control for the variation in electricity consumption that is correlated with changes in consumer purchasing power. Per capita income data (measured in $1000) were obtained from the U.S. Department of Commerce's Bureau of Economic Analysis, data for unemployment were provided by the U.S. Bureau of Labor Statistics, and electricity price data was obtained by SEDS (U.S. Bureau of Labor Statistics, 2013).

The average state population (*population*), measured per 1000 people, and the number of students graduating high school per capita (*lngraduates*) were also included in the model to control for demographic factors that may be correlated with electricity consumption rates and the adoption of building codes. Population data were provided by the U.S. Census Bureau and data for high school education were obtained from the National Center for Education Statistics (National Center for Education Statistics, 2013).

The climate variables *heat* and *cool* measure a state's average number of monthly heating and cooling degree days (National Oceanic and Atmospheric Administration, 2011). These data were obtained from the National Oceanic and Atmospheric Administration (NOAA). Roughly speaking, when average monthly temperature falls below 65 degrees F, the difference is the number in heating degrees for that day. When the average temperature rises above 65 degrees F, the difference is the number of cooling degrees for that day (Jacobsen and Kotchen, 2011). Climate data were not available for Alaska and Hawaii and were excluded from my model. Heating and cooling degree day data for District of Columbia were also not available, but were included in this model by averaging the monthly data totals from the surrounding states Maryland and Virginia.

I also control for the political environments that are plausibly correlated with building code adoption and electricity consumption. Dummy variables serve as proxies for measuring the state political affiliation by denoting the presence of a Democratic governor (*demgov*), a Democratic majority in the state Senate (*demsen*), and a Democratic majority in a state's House of Representatives (*demrep*). Each of the political variables are set equal to "1" if a state has a Democratic governor or majority and is set equal to "0" if the state has a Republican or Independent governor or majority. Data for these variables were obtained from the U.S. Census Bureau. Data for *demgov* were obtained from the National Governor's Association.

State fixed effects permit me to control for unobserved characteristics unique to a state that do not vary over time. Year fixed effects permit me to control for unobserved national characteristics that change over time but are common to all states in a given year. Incorporating state and year fixed effects reduces the extent of omitted variable bias in my coefficients of interest.

I estimate the following fixed effects regression model:

$$electrates_{it} = \beta_0 + \beta_1 buildcode2000_{it} + \beta_2 buildcode2003_{it} + \beta_3 buildcode2006_{it}$$

$$+ \beta_4 buildcode2009_{it} + \beta_5 income_{it} + \beta_6 elecprice_{it} + \beta_7 unemployement_{it} + \beta_8 population_{it} +$$

$$\beta_9 lngraduates_{it} \ \beta_{10} newresyear_{it} + \beta_{11} homevalue_{it} + \beta_{12} heat_{it} + \beta_{13} cool_{it} + \beta_{14} demgov_{it} +$$

$$\beta_{15} demrep_{it} + \beta_{16} demsen_{it} + \alpha_i + \gamma_t + u_{it}$$

where $\alpha_i$ represents state fixed effects and $\gamma_t$ represents time fixed effects.

In order to estimate the difference in the relationship between electricity consumption and the adoption of the most up-to-date IECC building code between states with high versus low new residential construction, I estimate the following fixed effects regression:

$$electrates_{it} = \beta_0 + \beta_1 uptodate_t + \beta_2 highbuild_{it} + \beta_3 uptodate{*}highbuild_{it}$$

$$+ \beta_4 income_{it} + \beta_5 elecprice_{it} + \beta_6 unemployement_{it} + \beta_7 population_{it} + \beta_8 lngraduates_{it}$$

$$\beta_9 newresyear_{it} + \beta_{10} homevalue_{it} + \beta_{11} heat_{it} + \beta_{12} cool_{it} + \beta_{13} demgov_{it} + \beta_{14} demrep_{it} +$$

$$\beta_{15} demsen_{it} + \alpha_i + \gamma t + u_{it}$$

**Table 1: Variable Definitions**

| Variable | Definition |
|---|---|
| State Residential Electricity Consumption Rate | A continuous variable measuring a state's annual per capita residential electricity consumption (British Thermal Units (BTU) per 10,000 people) |
| IECC Building Code 2000 | This is a dummy variable indicating whether a state has adopted the 2000 IECC residential building code |
| IECC Building Code 2003 | This is a dummy variable indicating whether a state has adopted the 2003 IECC residential building code |

| | |
|---|---|
| IECC Building Code 2006 | This is a dummy variable indicating whether a state has adopted the 2006 IECC residential building code |
| IECC Building Code 2009 | This is a dummy variable indicating whether a state has adopted the 2009 IECC residential building code |
| Up-to-date IECC Building Codes | This is a dummy variable indicating whether a state has adopted the most up-to-date IECC residential building code |
| Annual per capita Income | This is a continuous variable measuring annual per capita state income in $1000 |
| Annual Unemployment Rate | This is a continuous variable measuring states' annual unemployment rate |
| Average State Population | This is a continuous variable measuring state's average population measured per 1000 people |
| Average High School Graduates | This is the per capita number of students graduating high school in a given state |
| States with High Rates of New Residential Construction | This is a dummy variable indicating if a state has high new residential construction (proxy for new residential construction permits granted) |
| Median Home Value | This is a continuous variable measuring state median home value in $1000 |
| Electricity Price | This is a continuous variable measuring the annual price of electricity for a given state |
| Average Number of Heating Degrees per Day | This is a continuous variable measuring the number of degree days the daily temperature is below 65° Fahrenheit (F) |
| Average Number of Cooling Degrees per Day | This is a continuous variable measuring the number of degree days the daily temperature is above 65° Fahrenheit (F) |
| Political Party Control by State Governor | This is a dummy variable indicating if the state's Governor's political affiliation is Democrat |
| Political Party Control by State Senate | This is a dummy variable indicating if a state has a Democratic majority in the state Senate |
| Political Party Control of State House of Representatives | This is a dummy variable indicating if a state has Democratic majority in the state House of Representatives |

## DESCRIPTIVE RESULTS

*Tables 2* and *3* present descriptive statistics for each variable in my model. *Table* 2 summarizes descriptive statistics for the dependent variable and the key independent variables. *Table 3* summarizes descriptive statistics for housing market, economic, demographic, climate, and political variables. These results are generated using data for 48 states plus the District of Columbia from 2000-2010.

The dependent variable, state electricity consumption per 10,000 people measured in British Thermal Units (BTU), was weighted to account for the variation in state populations. Table 2 reports a 2.8 percent adoption rate of the 2009 IECC code, a 12.8 percent state adoption rate of 2006 IECC code, a 12.8 percent adoption rate of the 2003 IECC code, and a 10.2 percent adoption rate of the 2000 IECC code. Nearly 21 percent of states have adopted the most up-to-date building code. The share of states with high rates and low rates of new residential construction is near even.

Descriptive statistics for housing market, economic, and climate control variables are listed in *Table 3*. The variables *homevalue*, *income*, *heat,* and *cool* are all plausibly correlated with my dependent and key independent variables. *Table 3* reports a standard deviation of $104,004 for home value. In comparison to the mean for home value of $216,694, this is a moderately high standard deviation. This suggests that the variable should also be weighted to account for the housing market and economic variation in state populations. The average income ranges from $37,471 to $77,506. This variation in income is an illustration of the wide range of economic conditions between states. The large standard deviation in heating and cooling degree days also suggests that there is substantial variation in electricity consumption between states, as different climates require different quantities of electricity.

**Table 2: Descriptive Statistics for Key Dependent and Independent Variables**

| Variable | Variable Name | Sample Size | Mean | Minimum | Maximum | Standard Deviation |
|---|---|---|---|---|---|---|
| Residential electricity consumption per 10,000 people (BTU) | ***electrates*** | 539 | 160.53 | 75.54 | 253.33 | 42.81 |
| | | **Value** | **Frequency** | | **Percent** | |
| Lagged 2000 ICEE building code | ***buildcode2000*** | **0** | 484 | | 89.8 | |
| | | **1** | 55 | | 10.2 | |
| Lagged 2003 ICEE building code | ***buildcode2003*** | **0** | 470 | | 87.2 | |
| | | **1** | 69 | | 12.8 | |
| Lagged 2006 ICEE building code | ***buildcode2006*** | **0** | 470 | | 87.2 | |
| | | **1** | 69 | | 12.8 | |
| Lagged 2009 ICEE building code | ***buildcode2009*** | **0** | 524 | | 97.22 | |
| | | **1** | 15 | | 2.78 | |
| Up-to-date building code | ***uptodate*** | **0** | 427 | | 79.22 | |
| | | **1** | 112 | | 20.78 | |
| High Rates of New Residential Construction | ***highbuild*** | **0** | 264 | | 48.98 | |
| | | **1** | 275 | | 51.02 | |

**Table 3: Descriptive Statistics for Housing Market, Economic, Demographic, Climate, and Political Variables**

| Variable | Variable Name | Sample Size | Mean | Minimum | Maximum | Standard Deviation |
|---|---|---|---|---|---|---|
| Median home value in $1000 | ***homevalue*** | 539 | $216,694 | $86,187 | $752,043 | $104,004 |
| Average per-capita annual income in $1000 | ***income*** | 539 | $53,572 | $37,471 | $77,506 | $7,939 |
| Annual residential electricity price | ***elecprice*** | 539 | 28.05 | 15.04 | 59.59 | 8.12 |
| Unemployment rate | ***unemployment*** | 539 | 5.10% | 2.25% | 13.42% | 1.66% |
| Annual estimated population | ***population*** | 539 | 5,995,387 | 494,300 | 37,300,000 | 6,518,339 |
| Number of students graduating high school per capita | ***graduates*** | 539 | 0.001 | 0.005 | 0.015 | 0.04 |
| Annual heating degree days | ***heat*** | 539 | 5,119.94 | 552 | 10,046.00 | 1,977.08 |
| Annual cooling degree days | ***cool*** | 539 | 1,124.70 | 135 | 3,673 | 811.97 |
| | | **Value** | **Frequency** | | **Percent** | |
| Democratic Governor | ***demgov*** | **0** | 249 | | 46.2 | |
| | | **1** | 290 | | 53.8 | |
| Democratic State House of Representatives | ***demrep*** | **0** | 262 | | 48.61 | |
| | | **1** | 277 | | 51.39 | |
| Democratic State Senate | ***demsen*** | **0** | 265 | | 49.17 | |
| | | **1** | 274 | | 50.83 | |

## REGRESSION RESULTS

Results from my regressions are summarized in *Table 4*. Robust standard errors are reported directly below each coefficient, and regressions are estimated using analytic weights measuring state population size.  All regression models include a one-year lag on relevant variables to account for any delayed influence building code adoption and other control variables may have on residential electricity consumption. Residential electricity consumption is measured in BTU's per 10,000 people.

*Model 1* reports the raw correlation between IECC state residential energy efficiency building code adoption (the key independent variables) and residential electricity consumption per 10,000 people (the dependent variable). *Model 2* adds control variables. As previously detailed in the *Data and Methods* section, these control variables represent the time-varying economic, housing, climate and political factors that may contribute to both residential electricity consumption and IECC building code adoption. *Model 3* adds state fixed effects that control for state specific characteristics that do not vary over time. *Model 4* adds year fixed effects that control for national characteristics that vary over time but do not vary across states. *Model 5* adds interaction variables. The lagged interaction variables *highbuild*2000*, *highbuild*2003*, *highbuild*2006*, and *highbuild*2009* report the difference between residential electricity consumption and adoption of each IECC building code between states with high versus low rates of new residential construction.

*Model 6* includes state and time fixed effects, all control variables, and adds the new variable *uptodate* in place of the four individual building code variables. The dummy variable *uptodate* reports the relationship between the adoption of the most up-to-date building codes and residential electricity consumption. *Model 7* includes state and year fixed effects, control variables, and adds the interaction variable *highbuild*uptodate.* This variable measures the difference between residential electricity consumption and adoption of the most up-to-date building codes between states with high versus low rates of new residential construction.

**Table 4. Regression Analysis for State Electricity Consumption**

| Variable | Variable Name | Coefficient (Robust Standard Error) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 5** | **Model 6** | **Model 7** |
| State-Fixed Effects? | | No | No | Yes | Yes | Yes | Yes | Yes |
| Time-Fixed Effects? | | No | No | No | Yes | Yes | Yes | Yes |
| **Dependent Variable** | | | | | | | | |
| Per 10,000 people residential electricity consumption rate (BTU) | **elecrates** | | | | | | | |
| **Key Independent Variables** | | | | | | | | |
| Lagged 2000 ICEE building code | **buildcode2000** | -4.69 | 15.89*** | 2.32 | -0.49 | -0.07 | | |
| | | (15.60) | (3.35) | (2.20) | (0.81) | (0.69) | | |
| Lagged 2003 ICEE building code | **buildcode2003** | -20.99* | 16.66*** | 3.192** | -0.26 | -0.90 | | |
| | | | (2.87) | (1.41) | (0.89) | (0.82) | | |
| Lagged 2006 ICEE building code | **buildcode2006** | 0.47 | 19.57*** | 4.32** | -1.08 | -2.73** | | |
| | | (12.65) | (4.07) | (1.74) | (1.15) | (1.30) | | |
| Lagged 2009 ICEE building code | **buildcode2009** | -44.18*** | 4.78 | 7.0*** | 1.222 | 1.309 | | |
| | | (3.61) | (4.50) | (1.93) | (1.32) | (1.32) | | |
| Lagged High Rates New Residential Construction | **highbuildlag** | | -3.4 | -0.12 | -1.97*** | -1.95** | | |
| | | | (2.73 | (0.91) | (0.60) | (0.74) | | |
| Lagged High Rates of New Residential Construction * 2000 | **highbuild*2000** | | | | | -1.75 | | |
| | | | | | | (1.81) | | |
| Lagged High Rates of New Residential Construction * 2003 | **highbuild*2003** | | | | | 0.98 | | |
| | | | | | | (1.02) | | |
| Lagged High Rates of New Residential Construction * 2006 | **highbuild*2006** | | | | | 1.93* | | |
| | | | | | | (1.08) | | |
| Lagged High Rates of New Residential Construction * 2009 IECC building code | **highbuild*2009** | | | | | 0 | | |
| | | | | | | (0) | | |
| Up-to-date building code | **uptodate** | | | | | | -0.306 | -1.11* |
| | | | | | | | (0.477) | (0.58) |
| High Rates of New Residential Construction | **highbuild** | | | | | | -2.25*** | -2.47*** |
| | | | | | | | (0.64) | (0.66) |
| High Rates of New Residential Construction * Up-to-date building | **highbuild*uptodate** | | | | | | | 1.346* |
| | | | | | | | | (0.68) |
| **Housing Variables** | | | | | | | | |
| Median home value in $1000 | **homevalue** | | -0.011 | 0.031** | -0.011* | -0.01* | -0.008 | -0.009 |
| | | | (0.016) | (0.014) | (0.005) | (0.005) | (0.005) | (0.005) |

**Table 4. Regression Analysis for State Electricity Consumption (continued)**

| Variable | Variable Name | Coefficient (Robust Standard Error) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 |
| **Economic Variables** | | | | | | | | |
| | **income** | | -1.031*** | 0.344** | -0.016 | -0.018 | -0.016 | -0.005 |
| Annual per capita income in $1000 | | | (0.188) | (0.169) | (0.105) | (0.010 | (0.105) | (0.107) |
| Annual median unemployment rate | **unemployment** | | 127.4* | 6.424 | -102.6*** | -102.6*** | -94.22*** | -95.66*** |
| | | | (67.96) | (22.09) | (31.31) | (31.67) | (30.92) | (29.75) |
| Lagged annual residential electricity price | **elecprice** | | -1.530*** | -0.187* | -0.727*** | -0.723*** | -0.745*** | -0.748*** |
| | | | (0.185) | (0.106) | (0.102) | (0.101) | (0.099) | (0.101) |
| **Demographic Variables** | | | | | | | | |
| Average state population per 1000 people | **population** | | -0.004*** | -0.002*** | -0.004*** | -0.004*** | -0.003*** | -0.003*** |
| | | | (0.0003) | (0.0006) | (0.001) | (0.001) | (0.0009) | (0.0009) |
| Percent of high school graduates per capita | **lngraduates** | | 14.90*** | 21.20** | -4.84 | -5.08 | -5.09 | -5.21 |
| | | | (2.39) | (9.83) | (5.98) | (5.96) | (5.89) | (5.89) |
| **Climate Variables** | | | | | | | | |
| Annual heating degrees per day | **heat** | | -0.008*** | 0.006*** | 0.008*** | 0.008*** | 0.008*** | 0.008*** |
| | | | (0.001) | (0.001) | (0.0008) | (0.0009) | (0.0008) | (0.0008) |
| Annual cooling degrees per day | **cool** | | 0.016*** | 0.025*** | 0.023*** | 0.023*** | 0.023*** | 0.023*** |
| | | | (0.003) | (0.002) | (0.003) | (0.003) | (0.003) | (0.003) |
| **Political Variables** | | | | | | | | |
| Democratic Governor | **demgov** | | 0.168** | 0.006 | -0.005 | 0.0002 | -0.0008 | 0.011 |
| | | | (0.067) | (0.022) | (0.014) | (0.016) | (0.017) | (0.017) |
| Democratic State House of Representatives | **demrep** | | 0.587 | -0.099 | 0.233 | 0.250 | 0.174 | 0.184 |
| | | | (2.32) | (0.74) | (0.33) | (0.34) | (0.33) | (0.33) |
| Democratic State Senate | **demsen** | | -2.74 | 0.852 | 0.699* | 0.644 | 0.515 | 0.489 |
| | | | (2.49) | (0.69) | (0.38) | (0.41) | (0.37) | (0.38) |
| Constant | | 155.9*** | 137.7*** | -141.1 | 210.9*** | 213.7*** | 208.5*** | 209.5*** |
| | | (3.53) | (24.27) | (105.3) | (60.57) | (60.77) | (59.59) | (59.65) |
| Observations | | 539 | 539 | 539 | 539 | 539 | 539 | 539 |
| R-squared | | 0.022 | 0.845 | 0.573 | 0.817 | 0.819 | 0.817 | 0.818 |
| **F-statistics abd p-values of Joint Hypothesis** | | | | | | | | |
| High Rates of New Residential | **highbuild*2000** | | | | | 0.50 | | |
| | | | | | | (0.61) | | |
| High Rates of New Residential | **highbuild*2003** | | | | | 0.83 | | |
| | | | | | | (0.44) | | |
| High Rates of New Residential | **highbuild*2006** | | | | | 2.55 | | |
| | | | | | | (0.09)* | | |
| High Rates of New Residential | **highbuild*2009** | | | | | 0.98 | | |
| | | | | | | (0.33) | | |
| High Rates of New Residential | **highbuild*uptodate** | | | | | | | 2.36 |
| | | | | | | | | 0.01** |

Robust standard errors in parentheses
$P$-values are given in parenthesis under $F$-statistics
*** p<0.01, ** p<0.05, * p<0.1

In *Model 1*, the coefficients for the lagged 2003 and 2009 IECC building code variables are statistically significant and the adoption of either code is associated with a decrease in residential electricity consumption per 10,000 people in the following year. However, this model likely suffers from omitted variable bias, as it excludes many variables that are likely associated with the dependent and key independent variables.

In *Model 2*, the coefficients for the lagged 2000, 2003, and 2006 IECC building code variables are all statistically significant. The adoption of all three IECC codes is associated with an increase in residential electricity consumption per 10,000 people in the following year. The positive coefficient sign is likely a reflection that residential electricity consumption is increasing over time as our populations grow and electricity needs increase. However, this model excludes characteristics that vary over time and by state that are likely correlated with electricity consumption and the adoption of building codes and likely suffers from omitted variable bias. This data omission is likely positively biasing my key independent coefficients.

In *Model 3*, the coefficients for the lagged 2003, 2006, and 2009 IECC building code variables are statistically significant and indicate that adopting any of these three IECC building codes are associated with increased residential electricity consumption per 10,000 people in the following year. Including state fixed effects in *Model 3* dramatically diminishes the magnitude of the coefficients for the building code variables found in the previous models. The omission of a control for trends that vary over time in electricity consumption are likely leading to omitted variable bias in this model. In other words, the exclusion of year fixed effects is likely positively biasing my key independent coefficients.

In *Model 4*, all of the coefficients for the four lagged IECC building code variables are statistically insignificant. In other words, adding year fixed effects to the model controls for all national characteristics that vary over time, and as a result, captures additional variation not included in previous models.

In *Model 5*, I add the lagged variable *highbuild*, and the lagged interaction variables *highbuild*2000*, *highbuild*2003*, *highbuild*2006*, and *highbuild*2009*. In this model, the coefficients for the lagged variable *buildcode2006*, and the lagged interaction variable *highbuild*2006* are both statistically significant. According to my results, adopting the 2006 IECC building code in the previous year is associated with a 2.7 BTU decrease in electrical consumption per 10,000 residents in states with low rates of new residential construction. By dividing the coefficient of *buildcode2006* by the mean value of BTU per 10,000 people, I calculate that the adoption of the 2006 IECC building code in the previous year is associated with a 1.7 percent decrease in electrical consumption per 10,000 residents in states with low rates of new residential construction. Though the coefficients for both *buildcode2006* and *highbuild*2006 (*the sum of which represents the relationship between electricity consumption and adopting the 2006 IECC code for states with high rates of new residential construction) are statistically significant, the result of a joint significance test indicates that the relationship is not statistically significant. All results of joint significance tests are displayed in *Table 4*. The regression results for the interaction variable *highbuild*2009* were thrown out of the model. This exclusion is the result of having no states with high rates of residential construction that also adopted the 2009 IECC building code.

In *Model* 6, the dummy variable *uptodate* replaces the building codes as the key independent variable. *Uptodate* reports the relationship between the adoption of the most up-to-date building codes and residential electricity consumption. The coefficient for *uptodate* is not statistically significant in this model.

In *Model 7,* the new interaction variable *highbuild*uptodate* reports the difference in the relationship between residential electricity consumption and the adoption of up-to-date building codes between states with high versus low rates of new residential construction. These results show that adopting the most up-to-date IECC building code is associated with a 1.1 BTU decrease in electrical consumption per 10,000 residents in states with low rates of new residential construction. Using the same approach laid out in *Model 5,* I calculate that adopting an up-to-date building code is associated with a .7 percent decrease in electrical consumption per 10,000 residents in states with low rates of new residential construction. The result of a joint significance test for *uptodate and highbuild*uptodate* reports that there is no statistically significant relationship between electricity consumption and adopting the most up–to-date building code for states with high rates of new residential construction.

Throughout *Table 4*, some of the coefficients for my climate, economic and demographic control variables were statistically significant and of notable magnitude. In particular, the coefficients for *cool* and *heat* were consistently statistically significant, had a positive association with increased electrical consumption, but did not have a notable magnitude. The economic variables *population* and *unemployment* were both consistently statistically significant, had a negative association with increased electrical consumption, but did not have notable magnitudes.

The variable *elecprice* was consistently statistically significant, had a negative association with increased electrical consumption, and had a notable magnitude.

The state and year fixed effects analyses in this study do provide evidence of a relationship between adopting new state energy efficiency building codes and annual state electricity consumption, specifically the 2006 building code and the most up-to-date building codes for states with low rates of new residential construction.

## DISCUSSION

My results suggest that adopting the most up-to-date IECC energy efficiency building codes may be a viable avenue for reducing residential electricity consumption in some states. According to the results in *Model 7*, adopting the most up-to-date IECC building code is associated with a .7 percent decrease in electrical consumption per 10,000 residents in states with low rates of new residential construction.

My results also suggest adopting the 2006 IECC building code in states with low rates of new residential construction is associated with a decrease in electricity consumption. According to my results in *Model 5*, adopting the 2006 IECC building code in the previous year is associated with a 1.7 percent decrease in electrical consumption per 10,000 residents in states with low rates of new residential construction.

While it is not surprising that the adoption of up-to-date building codes would be associated with lower residential electricity consumption, it is surprising that in states with high rates of residential construction, neither adopting the IECC building codes nor having the most up-to-date building codes produced any statistically significant relationship.[c] I hypothesized that states with higher rates of new residential construction would experience the greatest benefit from adopting more stringent energy efficiency building codes, and thus greater reductions in residential electricity consumption. These results for states with higher rates of new residential construction are not consistent with my hypothesis.

In contrast to the study conducted by Aroonruengsawat et al. (2009), this analysis found no statistically significant relationship between the adoption of building codes and residential electricity consumption in states with high rates of new residential construction. In their examination of 48 states, Aroonruengsawat et al. found that the adoption of residential building codes was associated with a .3 to 5 percent decrease in per capita residential electricity consumption. This relationship was stronger in states with higher rates of new residential construction and more strictly enforced building codes.

My results suggest that during the development of new building codes, especially among states with high rates of residential construction, a cost-benefit analysis of residential expenditures and construction should be considered. Policymakers should consider whether or not enforcing potentially cumbersome building codes on citizens and on residential construction is cost-effective.

Future studies seeking to expand on the results of this study and others like it should control for the differing trends by state in the use of electronics and appliances, which has increased dramatically in the recent years. According to the U.S. Energy Information

[c] Though both the coefficients for *uptodate* and *highbuild*uptodate* are statistically significant, the results of a joint significance test show that the relationship between the adoption of up-to-date building codes and electricity consumption in states with high rates of new residential construction is not statistically significant.

Administration, heating and cooling no longer account for the majority of U.S. home energy use as of 2013 because of the increase in the use of electronics during the last decade. Appliances, electronics, and lighting now account for 52 percent of energy consumption, though this type of electricity usage varies from region to region (U.S. Energy Information Administration, 2013). Controlling for non-heating and non-cooling energy consumption data in the model may reduce significant omitted variable bias associated with the new technology-based electricity state trends.

Future studies should also include controls for the variety of carbon-reducing and energy-saving programs throughout the United States. The U.S. Environmental Protection Agency has long worked collaboratively with state governments, gas and electric utilities, utility regulators, and other partner organizations to create a sustainable and aggressive national commitment to energy efficiency (U.S. Environmental Protection Agency, 2014). The adoption of energy efficiency programs, which include green pricing programs and older residential home retrofitting programs, is likely positively correlated with the adoption of IECC building codes. Excluding these energy program variables are likely negatively biasing the IECC coefficients in my model and future studies.

The results of this analysis show that adopting the 2006 IECC code or adopting the most up-to-date code has a statistically significant negative correlation with residential electricity consumption rates in states with low rates of new residential construction. These results suggest that the IECC energy efficiency building code program does have the potential to reduce electricity consumption, and thereby decrease any negative environmental impact associated with increased electricity generation. Significant energy conservation might also be achieved in further research that identifies what features of the IECC building code most effectively reduce residential electricity consumption in states with high rates of new residential construction, where the greatest impact could be realized.

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