CEP 15-04

Setting the Standard: Commercial Electricity Consumption Responses to Energy Codes

Maya Papineau

May 2015

CARLETON ECONOMIC PAPERS

Carleton University

Department of Economics

1125 Colonel By Drive
Ottawa, Ontario, Canada
K1S 5B6

Setting the Standard: Commercial Electricity Consumption Responses to Energy Codes*

Maya Papineau†
Carleton University

May 6, 2015

Abstract

The adoption rate of building energy standards in the US has been increasing since the mid-1990s as a result of the Energy Policy Act of 1992 (EPAct). However, most of the evidence on the energy savings that accrue from commercial building energy standards is based on engineering simulations, which do not account for realized behavior once a standard is actually adopted. This paper uses plausibly exogenous variation in commercial building energy standard adoptions, combined with a unique state-level dataset on electricity consumption, energy prices, and the prevalence of "plus-utilities" tenancy contracts in commercial buildings, to estimate the realized electricity consumption response to commercial energy codes. The results suggest that in states with a large fraction of post-EPAct new construction under a code, per capita commercial electricity consumption is lower by about 13%. In addition, a one percentage point increase in the rate of tenancy contracts where tenants pay directly for energy utilities is associated with a 1% decrease in per capita electricity demand. The realized energy savings are less than half of predicted simulated savings.

JEL classification: Q20, Q42, Q48,
Keywords: Energy Efficiency; Energy Consumption; Regulation

*Financial support from the Canadian Social Sciences and Humanities Research Council is gratefully acknowledged. I thank Joel Bruneau, Chuck Mason, Martino Pelli, Nic Rivers, and Brandon Scheifele for helpful comments and suggestions. The paper also benefitted from comments at presentations at the University of Ottawa and the Canadian Resource and Environmental Economists' study group. Any errors are my own.

†Department of Economics, Carleton University, 1125 Colonel By Drive, Ottawa, Canada, K1Z 1C1 E-mail: maya.papineau@carleton.ca.

1. Introduction

Direct regulatory approaches to reducing energy-related pollution are politically popular avenues to federal energy policy, as recently exemplified by the Environmental Protection Agency's coal-fired power plant standard (EPA (2013)), and the Government of Canada's regulatory approach to Greenhouse Gas (GHG) reductions (GOC (2013)). Several recent national and sub-national environmental legislation efforts incorporate regulations explicitly aimed at improving the stringency of building energy standards. These include California's Global Warming Solutions Act (A.B. 32 (2006)), the American Clean Energy and Security Act (H.R. 2454 (2009)), and the widespread implementation of state and provincial energy standards (Ontario (2012), GOC (2011)). Multiple studies have attempted to quantify the realized electricity demand impact of energy efficiency investments induced from utility demand-side management (DSM) programs, such as free energy audits, subsidized financing and other similar incentives for the purchase of energy efficient equipment (Fickett et al. (1990), Joskow and Marron (1992), Nadel (1992), Parformak and Lave (1996), Horowitz (2004), Horowitz (2004), Auffhammer et al. (2008), Arimura et al. (2012)). However, the literature evaluating the impact of building energy standards on energy demand is surprisingly sparse, and thus far no studies have assessed the impact of energy standards on realized aggregate commercial sector energy use.[1]

The prevalence of multi-tenancy structures in the commercial sector creates unique challenges in identifying the effect of energy codes on electricity use. Estimates suggest up to 70 percent of commercial space is non-owner occupied, and up 50 percent of tenancy contracts are structured to shield tenants from facing energy price volatility (Levinson and Niemann (2004), Papineau (2013)). Combined with the potential for a rebound effect in response to energy efficiency improvements, there remains an important gap in our ability to evaluate the benefits of these building energy standards at a time when their application by governments is increasing. As shown by Jessoe

[1] Two recent studies estimate the impact of building energy standards on residential energy demand (Aroonruengsawat et al. (2012), Jacobsen and Kotchen (2013)), and a recent study by Arimura et al. (2012) controls for an aggregate index of commercial and residential building energy standard adoptions in order to analyze the cost-effectiveness of DSM. However, while the approach in the latter study attempts to address the endogeneity of DSM spending using a non-linear GMM framework, they do not address the potential endogeneity of energy standard adoptions. More generally, it should be noted that Arimura et al. (2012) do not assess the potential for weak identification in their non-linear GMM IV approach. Given that no weak identification statistics are presented and their IV estimates are virtually identical to the OLS results, the IV results may be biased by a weak correlation between their instruments and electricity demand (Bound et al. (1995), Stock et al. (2002)).

and Rapson (2013), commercial sector consumers exhibit inelastic demand when exposed to price interventions, which may be due to unobserved contractual structures between owners and tenants dampening the transmission of price signals to energy users. Yet thus far the effect of tenancy contracts on energy use has not been addressed in the energy efficiency policy evaluation literature.

This paper makes three distinct contributions to the existing literature. First, the analysis focuses exclusively on the impact of commercial building energy standards on realized electricity consumption in the U.S., the only study to do so thus far. Second, the paper makes use of a unique data source to develop a state-level indicator of the rate of owner-paid utility bills in the commercial sector over time, to assess whether shielding tenants from energy price volatility affects commercial electricity demand. Third, exogenous variation in building energy standard adoptions as a result of the Energy Policy Act (EPAct) of 1992 is used to identify the impact of energy standards on electricity demand. Exploiting the variation in building energy code stringency in states that complied with EPAct results in a sample in which states are indistinguishable on the basis of observable covariates. States that were early movers in undertaking voluntary policies to adopt building energy standards, as well as states that have never adopted a building energy standard, differ significantly from states that were induced to adopt a standard as a result of the 1992 EPAct.[2] An advantage of this identification strategy is that it circumvents any concerns with respect to weak instruments.

The rest of the paper is organized as follows. Section 2 discusses background information on energy standard development in the U.S., and explains why the EPAct mandate is a desirable source of variation to exploit. Section 3 presents an overview of the data sources. Section 4 presents the empirical model and discusses the identification strategy. Section 5 discusses the results, and Section 6 concludes.

2. Empirical Setting

2.1 The 1992 Energy Policy Act

A primary objective in evaluating the impact of energy standards on electricity consumption is addressing the endogeneity between state-level standard adoptions and energy use. Building energy

[2] For example, early adopter states have significantly lower pre-existing per capita electricity consumption levels and much higher electricity prices than states that have never adopted a building standard

standard adoptions at the state level may be correlated with other unobserved demand shocks, as exemplified in Table 3 by the fact that early voluntary adopter states tended to have both lower energy consumption and higher energy prices. However, a number of administrative features of a compulsory adoption mandate proceeding from the 1992 Energy Policy Act (EPAct) render post-EPAct energy standard adoptions attractive for study.

The first national energy standard (Standard 90-1975) was published in 1976 by the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) as a response to the patchwork of local, state and federal energy conservation policies being placed on the building design and construction industries. The goal at the time was to provide a document with uniform guidance on energy conservation in buildings that could be adopted by jurisdictions wishing to regulate buildings' energy conservation characteristics. However, while a handful of states voluntarily adopted Standard 90-1975, the building industry and other local-level stakeholders charged with implementing the standard found it highly difficult to apply in practice, due to its inflexible options for achieving compliance, and lack of technical support Shankle et al. (1994).

Concurrent with ASHRAE's publication of Standard 90-1975, the Department of Energy (DOE) was mandated by the Energy Conservation Standards for New Buildings Act of 1976 to develop standards that would be implementable by all new buildings. DOE's efforts to promulgate its own standard, in 1979, were also stymied by the building industry, which viewed the standards development process as having proceeded without their input and relying too much on a complex, abstruse, and expensive computer program.

After encountering setbacks in the these early attempts at a widely accepted, uniform building energy standard to be adopted across the U.S., in 1982 ASHRAE and the DOE's Building Energy Standards Program joined forces with experts in building design, construction, and building energy simulation fields to develop a revised national standard that could be widely accepted by local building regulators. The emphasis was on developing separate standards for residential and commercial buildings that offered cost-effective design strategies and allowed flexibility in achieving compliance across a wide range of building designs. In 1985 a new draft commercial standard was published, and several years of collaboration and revision followed, which resulted in the publication of ASHRAE standard 90.1-1989 (Standard 1989), in December 1989. Publication of Standard 1989 was followed by a demonstration phase to establish and promote the standard to the building industry.

This process culminated in passage of the Energy Policy Act of 1992 (EPAct), which instituted Standard 1989 as a mandatory energy standard to be adopted by all states. The requirement to adopt standard 1989 at the state-level put in motion a new phase in the implementation process, shifting the focus from design and demonstration to undertaking legislative and regulatory actions at the state-level in order to achieve adoption. The energy code legislation process at the state-level has involved some combination of public hearings and commentary, approval by advisory bodies composed of building industry representatives, and signature by a governor, mayors, and/or other elected officials.

States were given until the end of 1994 to demonstrate compliance with the EPAct mandate, to allow time for training code enforcement officials and other members of the building industry (Hatrup (1995)). However, the large number of stakeholders involved in each step of the adoption process has caused large variations in the speed with which a state has been able to comply with the EPAct mandate. In many states, building industry representatives argued that a mandatory energy code would impose costs in excess of any energy-saving benefits. Such industry pressure successfully resulted in significantly delayed adoptions in a number of states that intended to comply with the EPAct, including Idaho, Illinois, Iowa, Louisiana, Michigan, New Mexico, Nebraska, Pennsylvania, and Texas, among others.

In Idaho, a bill to adopt ASHRAE 1989 was vetoed by the Governor in 1997 and subsequently voted down by the state senate in 1998 (BCAP (1997), BCAP (1998)). The bill was redrafted and taken up by the legislature again and finally signed into law in 2002. In Pennsylvania, an act to adopt ASHRAE 1989 failed to pass the state senate in 1996. The legislation was reintroduced in 1997, delayed in committee until the fall of 1998, and failed to pass once again. In 2000, Pennsylvania's Department of Labor and Industry began a new rule-making effort to adopt a standard, including public hearings on a draft energy standard bill, an effort to develop an energy inspector certification system, and a DOE technical request to evaluate the draft bill. The final draft bill was finalized in mid-2001, followed by publication of the proposed regulations in 2002 and another series of public hearings. A final version of the bill was agreed upon in late 2003 and went into effect in the spring of 2004 (BCAP (1997), BCAP (1998) BCAP (2000), BCAP (2002) BCAP (2003), BCAP (2004)).

To circumvent repeated legislative and regulatory delays brought about by the building industry, several states commissioned DOE reports to determine whether cost-effective savings could be achieved in settings specific to their states' climate conditions, which also contributed to increased lag times between intended and actual adoptions (Cort et al. (2002a), Cort et al. (2002b), Cort and Belzer (2002), Winiarski et al. (2003), Cort et al. (2004)).[3]

Subsequent versions of standard 90.1 were approved in 1999, 2004, 2007, and 2010. Each new version is associated with increased energy savings compared to its predecessor, and after demonstration phases the DOE has issued determinations for each standard version, certifying them as achieving cost-effective improvements across the U.S., thereby triggering mandates for states to adopt these more stringent versions.

The post-EPAct federal mandate to adopt an up-to-date building standard, in combination with substantial heterogeneity induced by the regulatory process in states attempting to comply with the mandate, leads to a source of exogenous variation that can be exploited to identify the effect of commercial building standards on electricity use. Thirty-three states have adopted an energy standard as a result of the EPAct mandate.

While I have argued above that EPAct-induced energy standard adoptions are a plausibly exogenous source of variation to study the impact of energy standards on commercial electricity use in thirty-three states, the same case cannot be made in fourteen other states. As illustrated in Figure 2, several states were early voluntary adopters of ASHRAE 1989, whereas others have never complied with the EPAct mandate. The latter category includes "home-rule" states in which state-level legislative or regulatory authorities are not legally able to enforce standards in municipal jurisdictions. In home-rule states, this unique legal setting has led multiple individual municipalities to voluntary adopt standards at different times. Since a causal interpretation of the impact of energy standards on electricity demand can only be estimated for "complier" states that were induced to adopt as standard as a result of the EPAct mandate, as shown by Angrist et al. (1996), the identification strategy elaborated in section 4 discards early adopter and never adopter states.

2.2 Tenancy Contract Structure

Building-level tenancy contracts stipulate whether whether tenants pay directly for their utility bill or if utility payments are included in rent and therefore paid by building owners. Two broad lease

[3] Previous DOE reports were based on national-level savings.

types can be identified: Gross leases and net leases. In a gross lease, tenants pay a predetermined rate that includes space rent and building operating expenses (including utilities). Gross leases may include escalation clauses that allows landlords to audit future building expenses and mandate tenants pay a prorated share of building-level expense increases (Jaffee et al. (2012)). Therefore, in gross leases, because any increases in rent due to higher building expenses are shifted to future periods and are prorated among all building occupants, total expenses are effectively independent of a given tenant's realized energy usage in any given billing period. In a net lease, tenants pay their electricity bill directly, and in some cases natural gas.

Since tenants are directly responsible for their own energy bills, net contracts are considered to be superior at incentivizing tenants to limit their energy use (Levinson and Niemann (2004)). However, data from the CoStar database, the largest database tracking tenancy contracts in the U.S. (see www.Costar.com), suggest that on average, only 50% of lease contracts involve tenants paying their own utility bills. Several factors have limited the prevalence of net lease structures in commercial buildings. First, while net contracts require individual (or "direct") metering of tenanted spaces, separate sub-metering can cost several thousand dollars to install (National Science and Technology Council (2011)), and legislation in many states restricts the ability of landlords to pass on sub-metering costs to their tenants. In certain jurisdictions owners have also been prohibited from retrofitting buildings with submeters due to consumer protection legislation. For example, Connecticut only changed its state legislation to allow owners to submeter and charge tenants for their individual energy use in July of 2013. Oklahoma and Georgia enacted legislation to allow submetering in 1999 and 2000, respectively, and Kansas was also a relatively late adopter of legislation to allow submetering, in 2003. Nine states explicitly do not allow landlords to charge tenants for submetering cost markups over the time period under consideration in this paper: Utah, Illinois, Indiana, Maryland, Missouri, Texas and Washington (Utility Management and Conservation Association (2014)). The EPAct sample states that have seen new legislation which eases submetering rules have relatively large measured growth rates in their net contract share between 1993 and 2010. These include Utah (20% growth), Texas (18% growth), South Carolina (10% growth), Georgia (9% growth), and Oklahoma (8.1% growth) (Treitler (2000), Utility Management and Conservation Association (2014)).[4]

3. Data

Data on total annual commercial electricity consumption (in billion BTUs), average annual commercial sector electricity prices (in cents/kWh), and average annual commercial natural gas prices (in $ per thousand cubic square feet), were obtained for each state from the Energy Information Administration for the years 1990-2010. The electricity consumption figures were converted to per capita consumption using total population data from the Bureau of Economic Analysis (BEA) (BEA (2013)). For purposes of comparison, the consumption data were also divided by the total state-level population of service workers (also from the BEA), which may be more representative of per capita electricity demand for the commercial sector.

Commercial building code adoptions in the post 1990 time-frame were obtained from a number of sources. These include an online database maintained by the Building Codes Assistance Project (hereafter BCAP) (BCAP (2013)); archives of BCAP's bi-monthly newsletters going back to 1997, obtained by e-mail from BCAP staff; the Department of Energy's online energy codes database (Department of Energy (2013)), two documents prepared by Department of Energy staff (Department of Energy (1996), Hatrup (1995)), and one report from the Department of Housing and Urban Development (HUD (1997)). Figure 2 presents the state-by-year variation in building energy standard adoptions across the U.S.

These data were used to create a variable capturing the effect of building standards on energy use. Energy use reductions due to standards are increasing in both the share of construction subject to a standard and the stringency of the applicable standard. To account for the fact that energy standards only apply to new construction, the energy code treatment was constructed as follows. The share of the value of new nonresidential construction since 1993 that was constructed under an energy code was interacted with a dummy variable equal to one if the state has adopted an energy standard as a result of EPAct. This variable is named the construction share variable hereafter. Annual state-level data on the value of new nonresidential construction is available from

[4] For example, in Utah recent legislative action clarified that a municipality may not interfere with a landlord's ability to contract with a tenant regarding who is responsible for the cost of utilities. In Georgia, a law was passed in 2000 that specifically allows sub metering programs, and in Texas the state energy agency specifically addressed sub metering in the early 2000s, clarifying that it is allowed (though charging fees for sub metering costs are not allowed).

the Census Bureau (U.S. Census (2013)), and the data series was converted to constant 2009 US$ using the Producer Price Index for all commodities.[5] An additional variable was calculated to capture the relative stringency of state-level codes in place. This 'intensity' variable varies from zero to one, to capture increases in the stringency of a code (which the EPAct also mandated). Initial code adoptions under EPAct were of the ASHRAE 1989 standard, with three subsequent updates observed in the time span of the data: IECC 2000, ASHRAE 1999, and ASHRAE 2004. Simulation studies have estimated the energy savings attributable to each new standard version, with estimates ranging from four to twelve percent relative to the previous code version (Hadley and Halverson (1993); Department of Energy (2002); Department of Energy (2008)). On average, a commercial building constructed to satisfy ASHRAE 1980 standard saves twelve percent in energy use per square foot relative to a building constructed under ASHRAE 1989. Similarly, the IECC 2000 is associated with a saving of four percent relative to ASHARE 1989; ASHRAE 1999 is associated with an eight percent average saving relative to ASHRAE 1989; and ASHRAE 2004 is associated with an eleven percent average saving, relative to ASHRAE 1999. Accordingly, the intensity variable ranges from 0 to 0.34, to 0.46, to 0.68, to 1 to capture the share of the total increase in stringency from no standard to ASHRAE 2004.[6]

As discussed in Section 2.2, a common assumption is that net contracts incentivize tenants to conserve energy compared to utilities-included, or 'gross', contracts, but empirical estimates of the precise magnitude of the effect are scarce. To measure this effect, I use information on tenancy contract structure obtained from CoStar, a multiple listing service that has been tracking the commercial real estate industry since the early 1980s. While CoStar is a private company that operates primarily as a service to advertise buildings for sale or commercial space for rent, it has accumulated a large database of detailed hedonic characteristics on industrial, office, and retail buildings in the US. This database includes cross-sectional information on tenancy contract structure in 185,192 commercial buildings across the U.S. The CoStar data also includes a time series for rent contract observations for about 10% of the dataset, and it suggests that at the building-level, tenancy contract structures have remained more or less constant over the observed sample

[5] The variable is constructed relative to 1993 because the value of nonresidential construction data series has only been published since 1993.

[6] Twelve percent represents 34.3% of the total savings, which is why the intensity variable associated with ASHRAE 1989 takes on value 0.34. Four percent represents 11.4 percent of the total, so the IECC 2000 dummy is 0.46, and so on up to ASHRAE 2004.

period. The variable of interest is the share of state-level net contracts between 1993-2010, in other words the percentage of tenancy contracts in which tenants pay their own utility bills. The share of net contracts in year t (t=1993, 1994,...,2010) is measured by the share of net contracts observed in buildings constructed up to year t.[7] This approach was used since it maximizes the number of observations used to make the calculation. Nevertheless, this may induce measurement error to the extent that contract types change in existing buildings over the sample period. A robustness check and estimate of attenuation bias due to measurement error is performed in Section 5 below.

Other data included as controls in the analysis are state-level per capita personal income (BEA (2013b)), deflated to constant 2009$ using the consumer price index, from the Bureau of Labor Statistics (BLS (2013)). To account for the impact of weather on electricity demand, data on state-level heating and cooling degree days were obtained from the National Oceanic and Atmospheric Administration (NOAA (2013)). To account for the effect of demand-side management (DSM) spending, cumulative state-level DSM spending per customer is also included, from the Energy Information Administration.

Figure 1 illustrates patterns of regional commercial electricity consumption between 1993 and 2010, for both consumption per capita and per service worker. With the exception of the western region, electricity use has been on an upward trend over this time frame, though the midwest and northeast exhibit a modest slowdown starting in 2005.

As shown in Figure 2, several states adopted ASHRAE 1989 before the EPAct mandate became binding, and some states have never complied with the EPAct mandate. Table 2 shows summary statistics for the EPAct sample, separated between high intensity and low intensity states to illustrate that although some states complied with the EPAct mandate later than others due to legal delays and variation in state-level regulatory processes, there is a high degree of overlap between states' explanatory variables.[8] The explanatory variables in Table 2 indicate a high degree of overlap among high and low intensity states as shown by the normalized differences in the last column.[9] A normalized difference of less than 0.25 is typically considered good overlap (Imbens and Wooldridge (2009)), and the minimum and maximum values of the explanatory variables indicates the support

[7] For example, the share of net contracts in 1995 is measured by the percentage of net contracts in buildings constructed between 1717 (the oldest building in the database), and 1995.

[8] High intensity states are defined as states that adopted a standard effective before 2001, whereas low intensity states adopted a standard after 2001 (inclusive).

[9] The same characteristics are observed if the sample is limited to averages from the mid 1990s.

of the high and low intensity distributions are approximately the same.

The treatment variable of interest, on the other hand, is substantially different between the high and low intensity states: the share of the value of new construction put in place since 1993 and building code stringency variables are significantly higher in the high intensity states, with normalized differences of 1.12 and 0.34, respectively. This is a reflection of the high degree of variation in the treatment variables, as illustrated in Figures 3, 4, and 5. The top panel of Figure 3 shows the time series for the share of new construction under an energy standard across the set of EPAct states, and the bottom panel shows the series for selected states. As shown in the bottom panel, Georgia, Iowa and Arkansas were relatively early adopters, whereas Texas, Illinois and Michigan were later adopters. This variation in adoption dates induced by regulatory processes at the state level (as discussed in Section 2), has resulted in significant variation in the value share of post-EPAct construction value in 2010, shown in Figure 4. Similar variation in the intensity of post-EPAct energy standard adoptions can be observed in Figure 5.

In contrast, the early adopter and never adopter states exhibit significantly different characteristics. Perhaps most importantly, average electricity consumption is 30% lower in the early adopter states relative to the never-adopters, electricity prices are almost 40% higher, and natural gas prices are 20% higher. In addition, note that in Table 2 DSM spending per customer in the early adopter states is 7 times greater than in the never-adopter states, whereas it is 4 times greater in the high intensity states relative to the low intensity states in Table 1 (which points to the importance of controlling for DSM spending in the analysis).

Figure 6 illustrates state-by-year variation in the share of net contracts, using CoStar data. The data depict significant variation both across states and within states over time. Some states, such as Michigan, New Hampshire, and North Carolina, have seen the net contract share remain relatively constant, whereas other states have seen marked increases in the share of net contract buildings, including Louisiana, Nevada, and Iowa. Some states have also seen a slight decline in the net contract share, including Delaware and Arkansas.

4. Empirical Model

The following model is estimated:

$$\log(Q_{it}) = \beta_1 p^e_{it} + \beta_2 p^{ng}_{it} + \beta_3 n_{it} + \beta_4 cdd_{it} + \beta_5 hdd_{it} + \beta_6 Code_{it} + \beta_7 Intens_{it} + \beta_8 Net_{it} + \rho_i + \gamma_t + \varepsilon_{it}, \quad (1)$$

where Q_{it} is either per capita or per service worker commercial electricity consumption (in million BTUs) in state i and year t; p^e_{it} and p^{ng}_{it} are electricity and natural gas prices, respectively; CDD_{it} measures cooling degree days and HDD_{it} heating degree days; and n_{it} is real per capita income (in thousands). $Code_{it}$ is the share of the value of new nonresidential construction since 1993 completed under an energy standard, and $Intens_{it}$ measures the stringency of the standard in place at time t. Stringency ranges from 0 for states that have not adopted ASHRAE 1989, 0.25 for states that have implemented ASHRAE 1989, 0.5 for states that have implemented the IECC 2000, 0.75 for states that have implemented ASHRAE 1999, and 1 for states that have implemented ASHRAE 2004. Net_{it} measures the share of state-level net contracts over time.

The γ_t term is an annual fixed effect that controls for time-specific shocks that apply to all states, and ρ_i is a state-level fixed effect that controls for time-invariant state-specific heterogeneity.

4.1 Identifying Assumptions

This paper aims to identify the effect of EPAct-induced commercial energy standard adoptions on state-level commercial electricity consumption. The key identifying assumption is that $\varepsilon_{it} \sim iid(0, \sigma^2)$ after controlling for time and state fixed effects. In addition, energy standards must be assumed to be as good as randomly assigned to states, which implies that standard adoptions must be orthogonal to random unobservable demand shocks. To satisfy this latter assumption, the sample is limited to states that adopted an energy standard as a result of the EPAct standard, which implies discarding early voluntary adopters and never-adopters.

5. Results

Columns (1) through (9) in Table 4 present results from estimating different specifications of equation (1) on the EPAct sample. Column (10) shows results solely for the never and early adopters. Column (1) does not include the treatment variables but controls for state and time fixed effects. All the variables have the expected signs: the electricity (own) price elasticity is -0.25, the natural gas (cross) price elasticity is 0.04 and the income elasticity is 0.42, where all three are measured at the sample mean. An increase in cooling degree days by one unit is associated with approximately a 0.10% increase in electricity demand, whereas an increase in heating degree days by one unit is associated with a 0.02% decrease in electricity demand. Both these signs are in line with expectations since cooling degree days are associated with an increase in air-conditioning load, an electricity-intensive activity, whereas heating degree days imply an increase in (typically) natural-gas intensive heating and less chance of air-conditioner use. Commercial buildings are highly electricity intensive, with over 75% of the energy consumption arising from electricity, and less than 20% from natural gas. Only 12% of heating energy demand is sourced from electricity compared to 95% of cooling energy demand. Therefore, a muted or even negative response of electricity consumption to heating degree days is not unexpected.

Incorporating lagged price instruments to control for the endogeneity of electricity prices in column (2) does not significantly change the results, though the price elasticity declines somewhat, to -0.22, which may be expected if there exists a simultaneity between consumption and the average price of electricity (see Baltagi et al. (2002)). Incorporating a dummy variable equal to 1 for states that have adopted a code, in column (3), suggests that having a code in place results is approximately 7% lower electricity demand. Columns (4) and (5) replace the energy code dummy variable with the construction share variable. The coefficient indicates that in states in which all of the value of new construction since 1993 is under a code, commercial electricity consumption is lower by about 12%, and the results are unchanged after adding a linear time trend in addition to the time fixed effects.[10]

The net contract share variable is incorporated in column (6) to account for the potential impact of the share of tenants paying their own energy bills on commercial electricity use. A one percentage point increase in the net contract share is associated with a 1.2% decrease in electricity demand (significant at the 1% level). Columns (7) and (8) include controls for the stringency (or intensity) of the standard in place, with and without separate linear time trends for the high and low intensity of treatment states, respectively. Column (9) controls for the effect of cumulative demand-side

[10]In addition, the Kleigergen-Paap F statistic is 234.58, which strongly rejects the Stock-Yogo (Stock et al. (2002)) weak identification null hypothesis, and the Hansen J statistic p-value is 0.587, suggesting that the model's overidentifying restrictions are valid.

management (DSM) spending per customer. Accounting for all of these variables, the treatment variable point estimate remains robust. The construction share variable in specification (9) indicates that in states in which all of the value of new construction since 1993 is under a code, commercial electricity consumption is lower by about 13%, and the effect is statistically significant at the 5% level. The treatment intensity variable is positive and statistically significant, and suggests that the most stringent standard is associated with about a 9% lower electricity demand compared to states with no standard in place. The net contract share estimate is also essentially unchanged across specifications.

Simulated energy code savings suggest that increasing energy code stringency from no code to ASHRAE 2004 would lead to maximum energy savings of approximately 31%. Therefore, the estimated realized energy savings of 13% are less than half of simulated savings. Further, the point estimate on the intensity variable suggests that shifting from no standard to ASHRAE 1989 leads to incremental energy savings of approximately 3%; moving from ASHRAE 1989 to IECC 2000 saves an additional 1.1%; shifting from ASHRAE 1989 to ASHRAE 1999 leads to savings of 3%; finally, shifting from ASHRAE 1999 to 2004 leads to incremental savings of just under 3%.

As shown in Column (10), running the full model only using the sample of early and never adopters results in a 4% higher effect of new construction share on electricity demand, which remains highly significant, and a positive but insignificant response of standard stringency. The construction share variable in this sample suggests that in early adopter states in which all of the value of new construction since 1993 is under a code, commercial electricity consumption is lower by about 17% relative to states that have never adopted a code. However, as discussed in Section 3, early adopter and never adopter states differ significantly from each other along many dimensions other than their adoption of building energy standards. For example, early adopter states have significantly higher electricity prices and have DSM spending levels over seven times larger than never adopter states. These differences, as highlighted in Table 3, mean their adoption of energy standards is highly likely to be endogenous to other characteristics affecting electricity demand. The results from column (10) therefore bolster the reasons for focusing the analysis on states that were induced to adopt a standard as a result of the EPAct mandate.

5.1 CoStar Data Robustness Check

As noted in Section 3, measurement error of the contract variable may cause attenuation bias. Mismeasurement of the time series of state-level net contract rates measured by the Net variable is likely to arise for a few reasons. First, most of the change in the share of net contracts rates over time is likely due to new building construction: new buildings are more likely to be constructed with installed sub-meters, and owners are therefore more likely to choose net contracts in these buildings. This is partly due to the fact that rent contracts where tenant don't pay for utilities do not incentivize conservation, potentially causing excessive energy consumption and therefore higher utility bills for owners (Gillingham et al. (2012)). It is costly to install sub-meters in an existing building (estimates suggest several thousand to over ten thousand dollars, depending on building size), and many states do not allow cost-recovery charges to be imposed on tenants Utility Management and Conservation Association (2014).[11] The inability to recover submetering costs disincentivizes submetering investments, particularly if a building was not constructed up front with a submeter. Instead, a common alternative to submetering and net contracts is a contract whereby energy costs are prorated over the whole building, either through a charge directly included in the rent or through monthly payments of average building energy costs. This latter option also discourages energy conservation, either through free-ridership or more generally by dissasociating tenants' energy use decisions and the cost of those decisions. Second, while sub-meter cost recovery is typically not allowed, state-level legislation over the past twenty-five years has tended to ease other restrictions on submetering, by simplifying the legal and administrative process building owners and managers must follow to sub-meter a building (Utility Management and Conservation Association (2014)). Third, it is possible that owners of sub-metered buildings may decide to switch to a 'utilities included' rent contract, whereby owners pay for utilities. This may be advantageous if owners seek to benefit from lower utility bills as a result of energy efficiency investments, if they believe they won't obtain rent premiums when tenants pay for utilities (Levinson and Niemann (2004), Papineau (2013)).

On the other hand, a very high degree of mismeasurement in the net contract proxy would

[11] At present, even states where submetering fees can be charged to tenants (in states other than Utah, Illinois, Indiana, Maryland, Missouri, Texas and Washington), in many if not most cases permitted fees are typically limited to administrative costs and any sub metering costs imposed on the landlord by the utility. Therefore, cost recovery of the initial investment is typically not allowed.

have to be present in order to significantly affect the widespread cross-sectional variation in net contract rates exhibited in Figure 6. Much of this cross-sectional variation is likely due to path-dependent state-level characteristics (Jaffee et al. (2012)). A formal robustness check on the effect of measurement error in the net contract rate is presented below.

The application of proxies for unobservable variables in regression analysis spans most areas of economics, with examples ranging from the use of Tobin's q to proxy for unobservable investment opportunities in empirical corporate finance (Fazzari et al. (1988), Erickson and Whited (2000)), to estimating energy savings from market transformation investments using shipments of energy efficient equipment Horowitz (2004). To assess how measurement error may affect the estimated net contract coefficient, I implement the minimum distance cumulant estimator from Erickson et al. (2014). The approach uses the measured data to identify a value for the true coefficient in cases where measurement error is suspected, and is based on a long history of work in the errors-in-variables literature (Geary (1942), Pakes (1982), Klepper and Leamer (1984)).

The analysis is implemented assuming that both the net contract and construction share variables may be measured with error.[12] The results are presented in Panel A of Table A1. Since the cumulant estimator is identified if the mismeasured regressors are non-normally distributed, Panel B shows the third to sixth higher standardized moments of the contract and construction share variables. The standardized moments are obtained by scaling each moment by the standard deviation raised to the corresponding power. As shown, while both variables show modest kurtosis, they are positively skewed and the fifth and sixth order moments deviate significantly from zero. Normality tests based on Jacque and Bera (1987), D'agostino et al. (1990), and Royston (1991) strongly reject the null for both variables.

Columns (1) and (2) in Table 5 report OLS results, and column (3) reports the cumulant estimator results. A fifth-order cumulant estimator was utilized as cumulants beyond the fourth-order attain the efficiency in finite samples (Dagenais and Dagenais (1997)).[13] A comparison of columns (2) and (3) indicates the cumulant adjustment results in very little change in the estimated coefficients. In the table, τ^1 and τ^2 measure the quality of the proxies used to measure the net

[12]Assuming that only the net contract share variable is mismeasured results in quite similar results, but since the estimated contract share variable is even larger (in absolute value), the more conservative estimates are reported here.

[13]A sixth-order cumulant estimator failed to minimize the objection function in the maximum likelihood estimation.

contract share and the share of buildings constructed under a code, respectively. According to these estimates, the net contract and construction shares are very high quality proxies.[14]

6. Conclusion

While it is well-known that market-based instruments are more cost-effective than standards at addressing excessive energy consumption due to negative environmental externalities, direct (or "command and control") regulatory actions aimed at reducing energy use in several sectors of the economy have continued to be pursued, and successfully enacted, across the United States and Canada.[15] The persistent popularity of direct regulatory instruments points to the importance of evaluating the realized effectiveness of the array of environmental regulations that are applied in practice.

While a few recent studies have assessed the impact of energy codes and demand-side management on residential and total energy demand (Aroonruengsawat et al. (2012), Arimura et al. (2012)), the commercial sector has generally not been a focus of energy code evaluations. This is problematic if policymakers care about crafting policies that differentiate among heterogeneous end-uses, particularly since recent evidence has shown that commercial energy users' demand is inelastic when faced with energy price changes, compared to residential users (Jessoe and Rapson (2013)). In addition, thus far no studies have assessed the realized impact of tenancy contract structures on national energy demand, despite evidence suggesting that an increase in the prevalence lease contracts in which tenants pay their own utilities is likely to mitigate energy use (Levinson and Niemann (2004), Kahn et al. (2014)).

Using plausibly exogenous variation in energy standard adoptions, as mandated by the 1992 Energy Policy Act (EPAct) in the U.S., I estimate the effectiveness of state-level energy codes and the share of tenant-paid utility bills at reducing commercial electricity consumption. I find that in states with a large fraction of post-EPAct new construction under a code, per capita commercial electricity consumption is lower by about 13%. These estimated savings are less than half of predicted simulated energy standard savings (Hadley and Halverson (1993); Department of Energy

[14] In empirical corporate finance applications, proxy quality estimates tend to range between 0.2-0.5 (Erickson et al. (2014)).

[15] Parry et al. (2010) argue that even if large informational market failures also affect energy use, market-based instruments are still the preferred policy option.

(2002); Department of Energy (2008)). The less than predicted savings from energy standard savings are consistent with previous work based on smaller samples sizes (Nadel and Keating (1991), Richman et al. (2008)) or for specific states (e.g. Levinson (2013) on California's residential energy standard savings). In addition, a one percentage point increase in the rate of tenancy contracts in which tenants pay directly for energy utilities is associated with a 1% decrease in per capita electricity demand. The results are robust to controlling for cumulative state-level demand side management spending and compliance heterogeneity.

References

A.B. 32, "California Global Warming Solutions Act of 2006," 2006.

Angrist, Joshua, Guido Imbens, and Donal Rubin, "Identification of Causal Effects Using Instrumental Variables," *Journal of the American Statistical Association*, 1996, *91(434)*, 444–455.

Arimura, Toshi H., Shanjun Li, Richard G. Newell, and Karen Palmer, "Cost-Effectiveness of Electricity Energy Efficiency Programs," *The Energy Journal*, 2012, *33* (2), 63–99.

Aroonruengsawat, Anin, Max Auffhammer, and Alan Sanstad, "The Impacts of State Level Building Codes on Residential Electricity Consumption," *The Energy Journal*, 2012, *33* (1), 31–52.

Auffhammer, Maximilian, Carl Blumstein, and Meredith Fowlie, "Demand Side Management and Energy Efficiency Revisited," *The Energy Journal*, 2008, *29* (3), 91–104.

Baltagi, Badi, Georges Bresson, and Alain Pirotte, "Comparison of forecast performance for homogeneous, heterogeneous and shrinkage estimators Some empirical evidence from US electricity and natural-gas consumption," *Economics Letters*, 2002, *76.*

BCAP, "Building Codes Assistance Project Newsletter," September/October 1997.

_ , "Building Codes Assistance Project Newsletter," September/October 1998.

_ , "Building Codes Assistance Project Newsletter," September/October 2000.

_ , "Building Codes Assistance Project Newsletter," September/October 2002.

_ , "Building Codes Assistance Project Newsletter," May/June 2003.

_ , "Building Codes Assistance Project Newsletter," January/February 2004.

_ , "Building Codes Assistance Project Newsletters, Online Code and Advocacy Network," 2013. http://energycodesocean.org/bcap-newsletters. Accessed May 9, 2013.

BEA, "State annual tables," 2013. Bureau of Economic Analysis, Washington, DC: Department of Commerce.

_ , “SA1-3 Personal income summary,” , Bureau of Economic Analysis, Washington, DC: Department of Commerce 2013b.

BLS, “Consumer Price Index, U.S. City Average,” , Bureau of Labor Statistics, Washington, DC: Department of Labor 2013.

Bound, John, David A. Jaegger, and Regina M. Baker, “Problems With Instrumental Variables Estimation When the Correlation Between the Instruments and the Endogenous Explanatory Variable is Weak,” *Journal of the American Statistical Association*, 1995, *90* (430), 443–450.

Cort, K.A. and D.B. Belzer, “Statewide savings projections from the adoption of a commercial building energy code in Illinois,” *Building Standards and Guidelines Program, US Department of Energy*, 2002.

_ , _ , D.W. Winiarski, and E.E. Richman, “Analysis of Potential Benefits and Costs of Updating the Commercial Building Energy Code in Iowa,” Report PNNL-14016, Pacific Northwest Laboratory, Department of Energy 2002.

_ , _ , _ , and _ , “Analysis of Potential Benefits and Costs of Adopting ASHRAE Standard 90.1-2001 as a Commercial Building Energy Code in Tennessee,” *Building Standards and Guidelines Program, US Department of Energy*, 2004.

_ , _ , M. Halvorsen, E.E. Richman, and D.W. Winiarski, “Analysis of Potential Benefits and Costs of Adopting ASHRAE Standard 90.1-1999 as a Commercial Building Energy Code in Michigan,” Report PNNL-14017, Pacific Northwest Laboratory, Department of Energy 2002.

Dagenais, M.G. and D.L. Dagenais, “Higher order moment estimators for linear regression models with errors in the variables,” *Journal of Econometrics*, 1997, *76* (2), 193–221.

D’agostino, R.B., A.J. Belanger, and R.B. D’agostino Jr., “A suggestion for using powerful and informative tests of normality,” *American Statistician*, 1990, *44*.

Department of Energy, “Office of Codes and Standards Resource Book: Energy Codes and Standards,” Pacific Northwest Laboratory Report 10392-2 1996.

_ , "Determination Regarding Energy Efficiency Improvements in the Energy Standard for Buildings, Except Low-Rise Residential Buildings, ASHRAE/IESNA Standard 90.1-1999," 2002.

_ , "Determination Regarding Energy Efficiency Improvements in the Energy Standard for Buildings, Except Low-Rise Residential Buildings, ASHRAE/IESNA Standard 90.1-2004," 2008.

_ , "Status of State Codes," 2013. http://www.energycodes.gov/adoption/states.

EPA, "2013 Proposed Carbon Pollution Standard for New Power Plants," 2013. Environmental Protection Agency, http://1.usa.gov/1dpRfV1.

Erickson, Timothy and Toni M. Whited, "Measurement error and the Relationship between Investment and q," *Journal of Political Economy*, 2000, *108* (5), 1027–1057.

_ , Colin Huan Jiang, and Toni M. Whited, "Minimum distance estimation of the errors-in-variables model using lainera cumulant equations," *Journal of Econometrics*, 2014, *183* (2), 211–221.

Fazzari, Steven, R. Glenn Hubbard, and Bruce C. Petersen, "Financing Constraints and Corporate Investment," *Brookings Papers Econ. Activity*, 1988.

Fickett, A.P., Clark W. Gellings, and Amory B. Lovins, "Efficient Use of Electricity," *Scientific American*, 1990, *263*, 64–74.

Geary, R. C., "Inherent relations between random variables," *Proceedings of the Royal Irish Academy. Section A: Mathematical and Physical Sciences*, 1942, *47*, 63–76.

Gillingham, Kenneth, Matthew Harding, and David Rapson, "Split Incentives in Household Energy Consumption," *Energy Journal*, 2012, *33(2)*, 37–62.

GOC, "National Energy Code of Canada for Buildings," 2011. National Research Council Canada, Government of Canada.

_ , "Canada's Action on Climate Change," 2013. Government of Canada, http://bit.ly/1bWCoV2.

Hadley, D.L. and M.A. Halverson, "Energy Conservation Potential of the U.S. Department of Energy Interim Commercial Building Standards," Report 7967, Pacific Northwest National Laboratory 1993.

Hatrup, M.P., "Office of Codes and Standards Resource Book," Report 7967, Pacific Northwest National Laboratory 1995.

Horowitz, Marvin J., "Electricity Intensity in the Commercial Sector: Market and Public Program Effects," *The Energy Journal*, 2004, *25*, 115–137.

H.R. 2454, "American Clean Energy and Security Act of 2009," 2009. 111th Congress.

HUD, "Energy Standards and State Energy Codes," 1997. U.S. Department of Housing and Urban Development Notice PIH 97-16.

Imbens, Guido and Jeffrey Wooldridge, "Recent Developments in the Econometrics of Program Evaluation," *Journal of Economic Literature*, 2009, *47* (1), 5–86.

Jacobsen, Grant D. and Matthew J. Kotchen, "Are Building Codes Effective at Saving Energy? Evidence from Residential Billing Data in Florida," *Review of Economics and Statistics*, 2013, *95* (1), 34–49.

Jacque, C.M. and A.K. Bera, "A test for normality of observations and regression residuals," *International Statistical Review*, 1987, *55.*

Jaffee, Dwight M., Richard Stanton, and Nancy E. Wallace, "Energy Factors, Leasing Structure and the Market Price of Office Buildings in the U.S.," Working Paper, AREUEA Annual Meeting, Chicago 2012.

Jessoe, Katrina and David Rapson, "Commercial and Industrial Demand Response Under Mandatory Time-of-Use Electricity Pricing," *Working Paper*, 2013.

Joskow, Paul and Donal Marron, "What Does a Negawatt Really Cost? Evidence from Utility Conservation Programs," *The Energy Journal*, 1992, *13*, 41–74.

Kahn, Matthew E., Nils Kok, and John M. Quigley, "Carbon emissions from the commercial building sector: The role of climate, quality, and incentives," *Journal of Public Economics*, 2014, *114*, 1–12.

Klepper, Steven and Edward E. Leamer, "Consistent Sets of Estimates for Regressions with Errors in All Variables," *Econometrica*, 1984, *52* (1), 163–184.

Levinson, A. and S. Niemann, "Energy Use by Apartment Tenants When Landlords Pay for Utilities," *Resource and Energy Economics*, 2004, *26*, 51–75.

Levinson, Arik, "California's Energy Efficiency: Lessons for the Rest of the World, Or Not?," Working Paper 19123, National Bureau of Economic Research 2013.

Nadel, Steve and Kenneth Keating, "Engineering Estimates vs. Impact Evaluation Results: How Do They Compare and Why?," 1991. Research Report, Americal Council for an Energy Efficient Economy, Washington, D.C.

Nadel, Steven, "Utility Demand-Side Management Experience and Potential: A Critical Review," *Annual Review of Energy and the Environment*, 1992, *17*, 507–535.

National Science and Technology Council, "Submetering Of Building Energy And Water Usage," , National Science and Technology Council Committee on Technology, Subcommittee on Buildings Technology Research and Development 2011.

NOAA, "Heating & Cooling Degree Day Data," , National Oceanic and Atmospheric Administration, Washington, DC: Department of Commerce 2013.

Ontario, "Building Code Act, 1992," 2012. Ruling of the Minister of Municipal Affairs and Housing, No. MR-11-S-17.

Pakes, A., "On the asymptotic bias of wald-type estimators of a straight line when both variables are subject to error," *International Economic Review*, 1982, *23.*

Papineau, Maya, "Energy Codes and the Landlord-Tenant Problem," Fisher Center Working Paper, Fisher Center for Real Estate and Urban Economics, Institute of Business and Economic Research, UC Berkeley 2013.

Parformak, Paul and Lester B. Lave, "How Many Kilowatts Are in a Negawatt? Verifying 'Ex-Post' Estimates of Utility Conservation Impacts at the Regional Level," *The Energy Journal*, 1996, *17*, 59–88.

Parry, Ian W.H., David Evans, and Wallace E. Oates, "Are Energy Efficiency Standards Justified?," Resources For the Future Working Paper DP 10-59 2010.

Richman, Eric, Emily Rauch, Jaclyn Phillips, Kimberly Petty, and Jessica Knappek, "National Commercial Construction Characteristics and Compliance with Building Energy Codes: 1999-2007," ACEEE Summer Study Report, American Council for an Energy Efficient Economy 2008.

Royston, P., "Comment on sg3.4 and an improved D'Agostino test," *Stata Technical Bulletin*, 1991, *3.*

Shankle, D.L., J.A. Merrick, and T.L. Gilbride, "A History of the Building Energy Standards Program," Report 9386, Pacific Northwest Laboratory, Department of Energy 1994.

Stock, James H., Jonathan H. Wright, and Motohiro Yogo, "A Survey of Weak Instruments and Weak Identification in Generalized Method of Moments," *Journal of Business Economics and Statistics*, 2002, *20*, 518–529.

Treitler, Marc, "Submetering: What You Don't Know Can Cost You," Technical Report July, Units Magazine, National Apartment Organization 2000.

U.S. Census, "Historical Value Put in Place," , Washington, D.C. 2013.

Utility Management and Conservation Association, "Research Database," 2014. http://www.utilitymca.org/.

Winiarski, D.W., D.B. Belzer, K.A. Cort, and E.E. Richman, "Energy Savings and Economic Analysis of Updating New Mexico?s Commercial Building Energy Code," Report PNNL-14073, Pacific Northwest Laboratory, Department of Energy 2003.

Figure 1: Regional Electricity Consumption

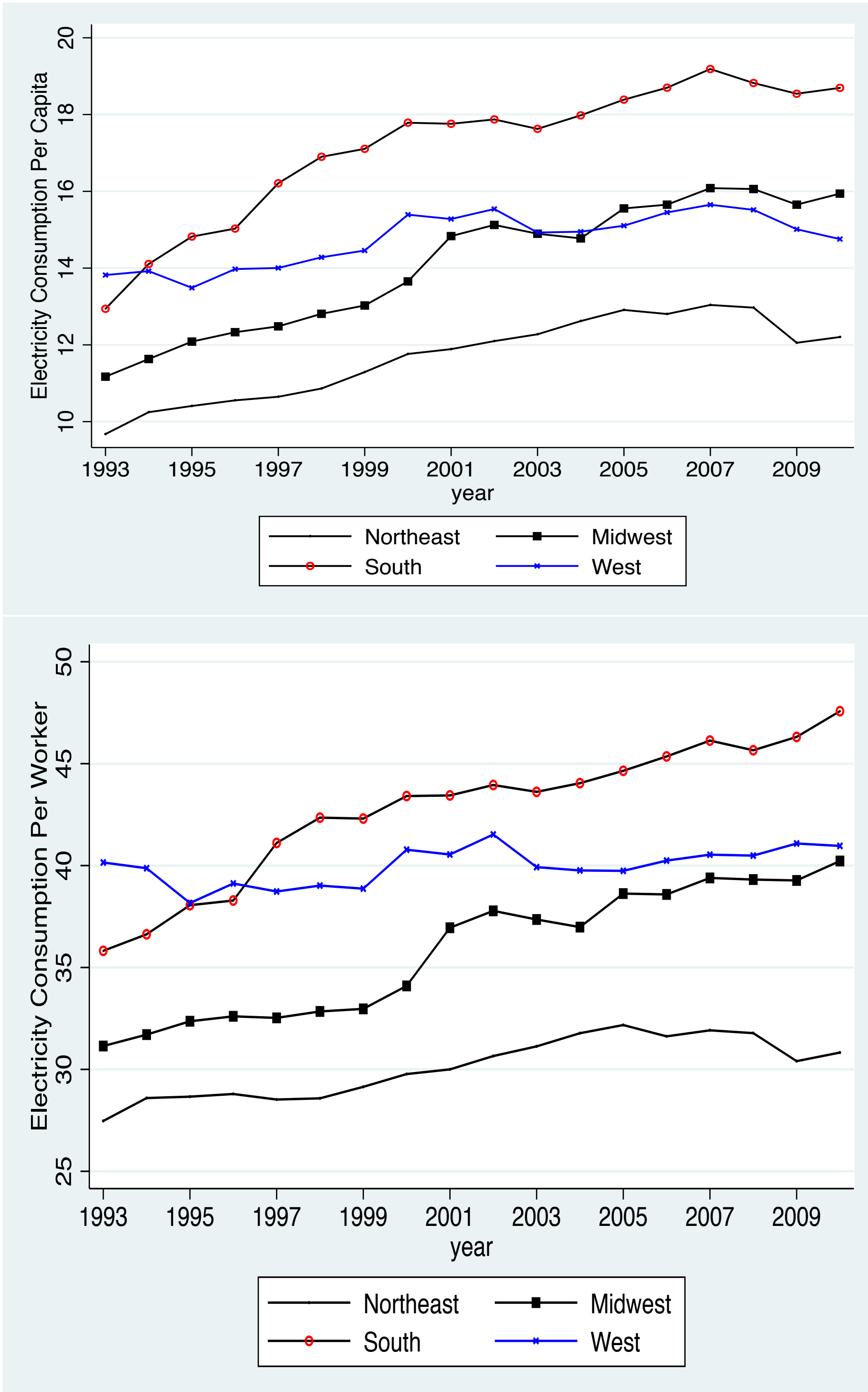

Figure 2: State-Level Adoptions

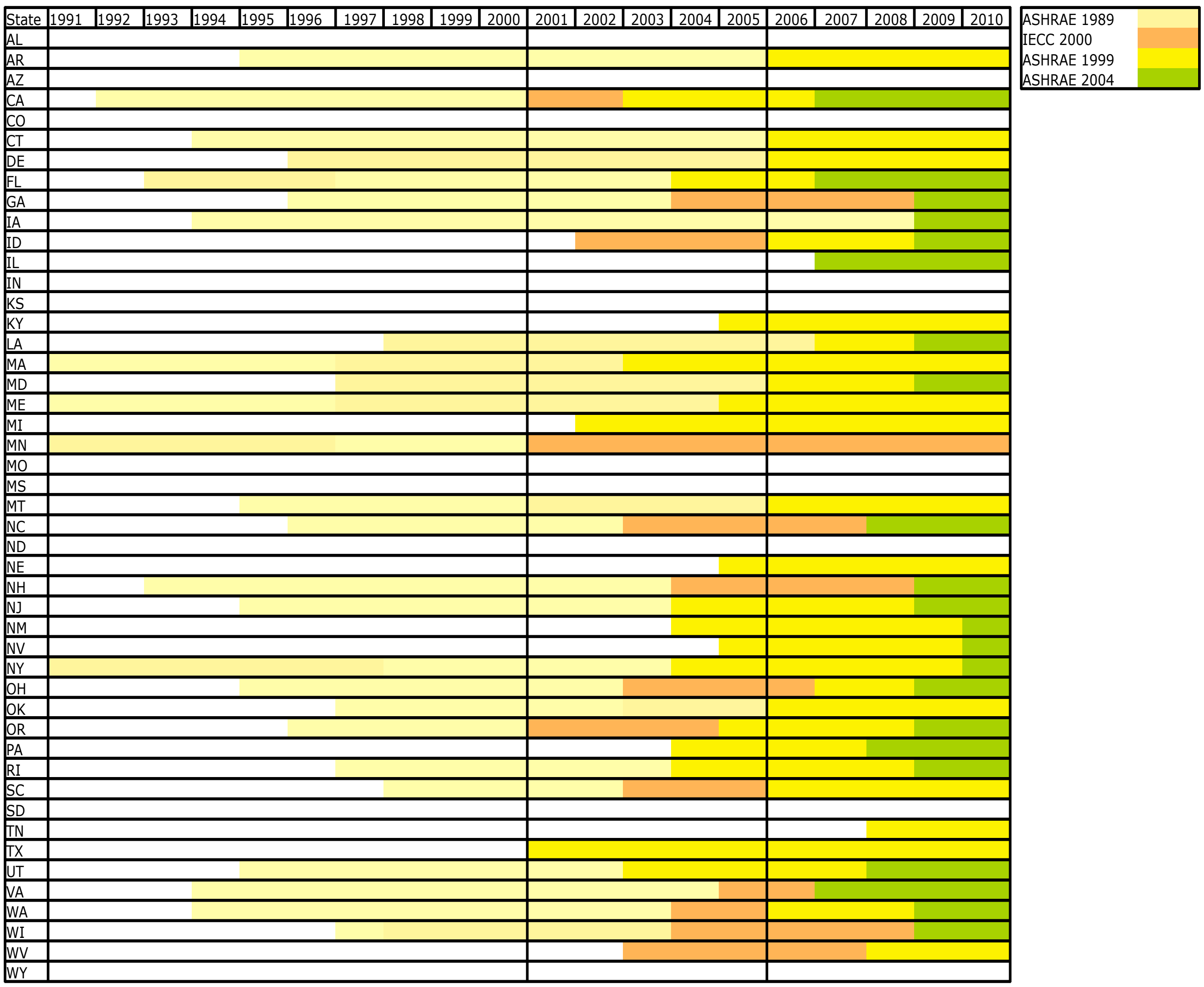

Figure 3: Variation in Value Share of Post-EPACT New Construction Value

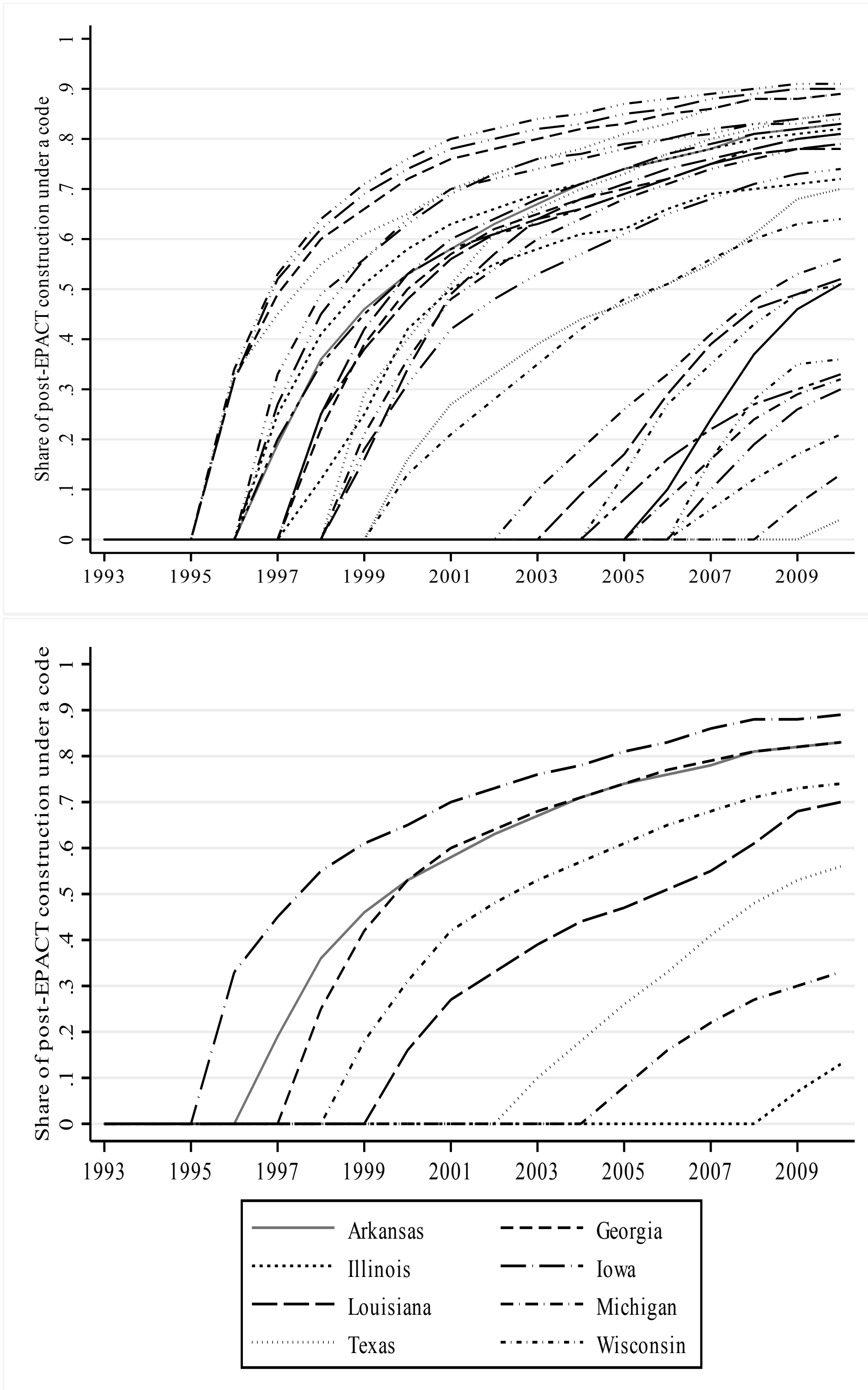

Figure 4: Variation in Value Share of Post-EPACT New Construction Value

Selected States, 2010

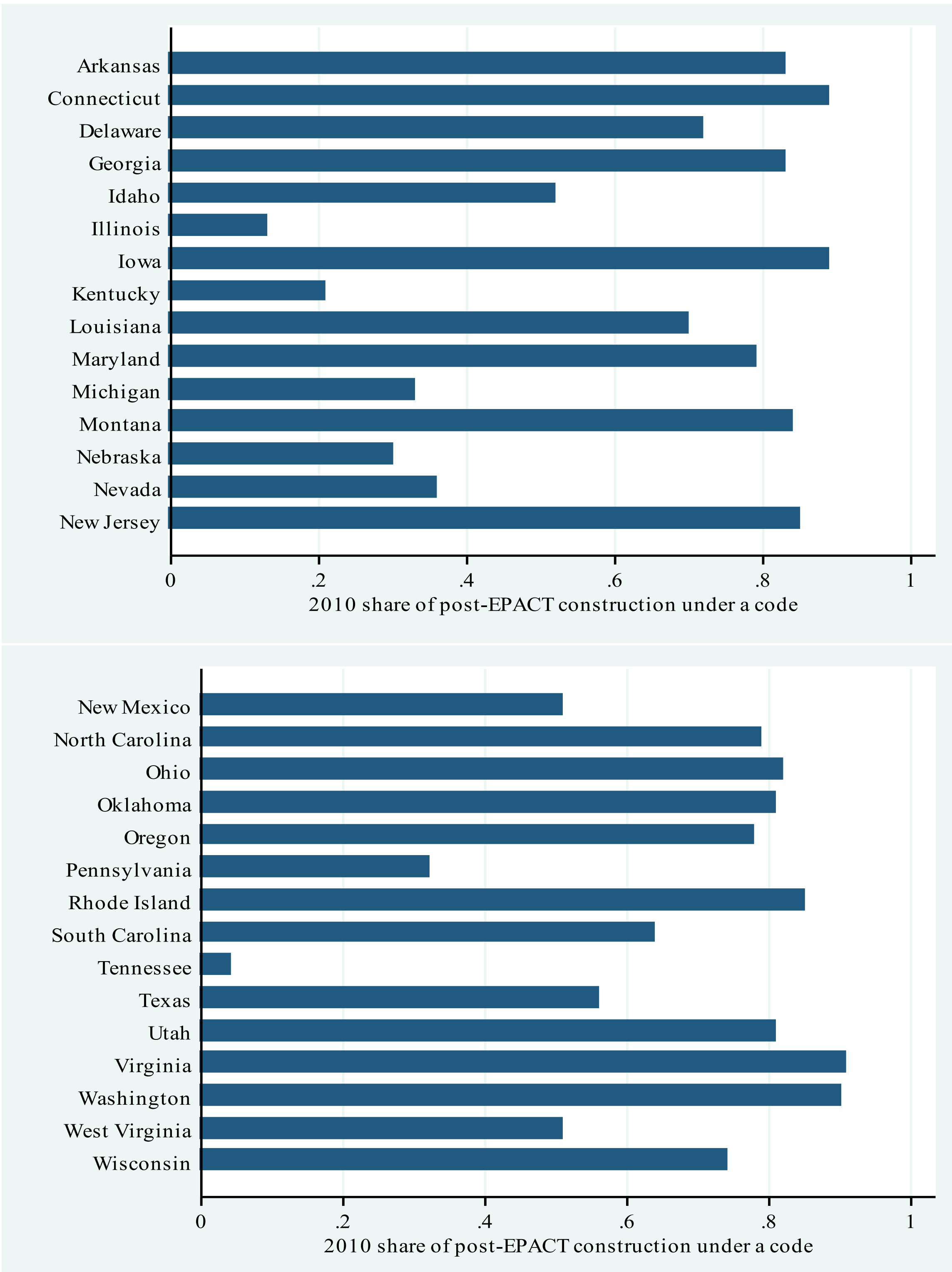

Figure 5: Variation in Intensity of Post-EPACT Energy Standards

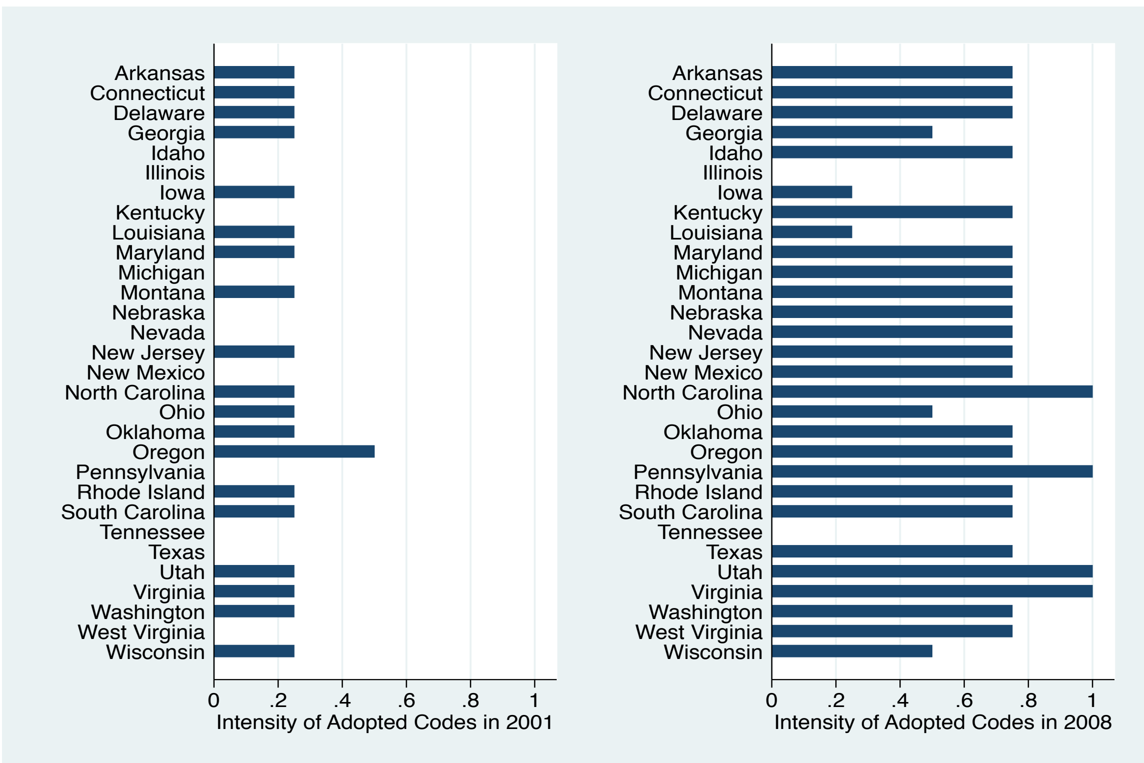

Figure 6: Variation in Net Contract Share

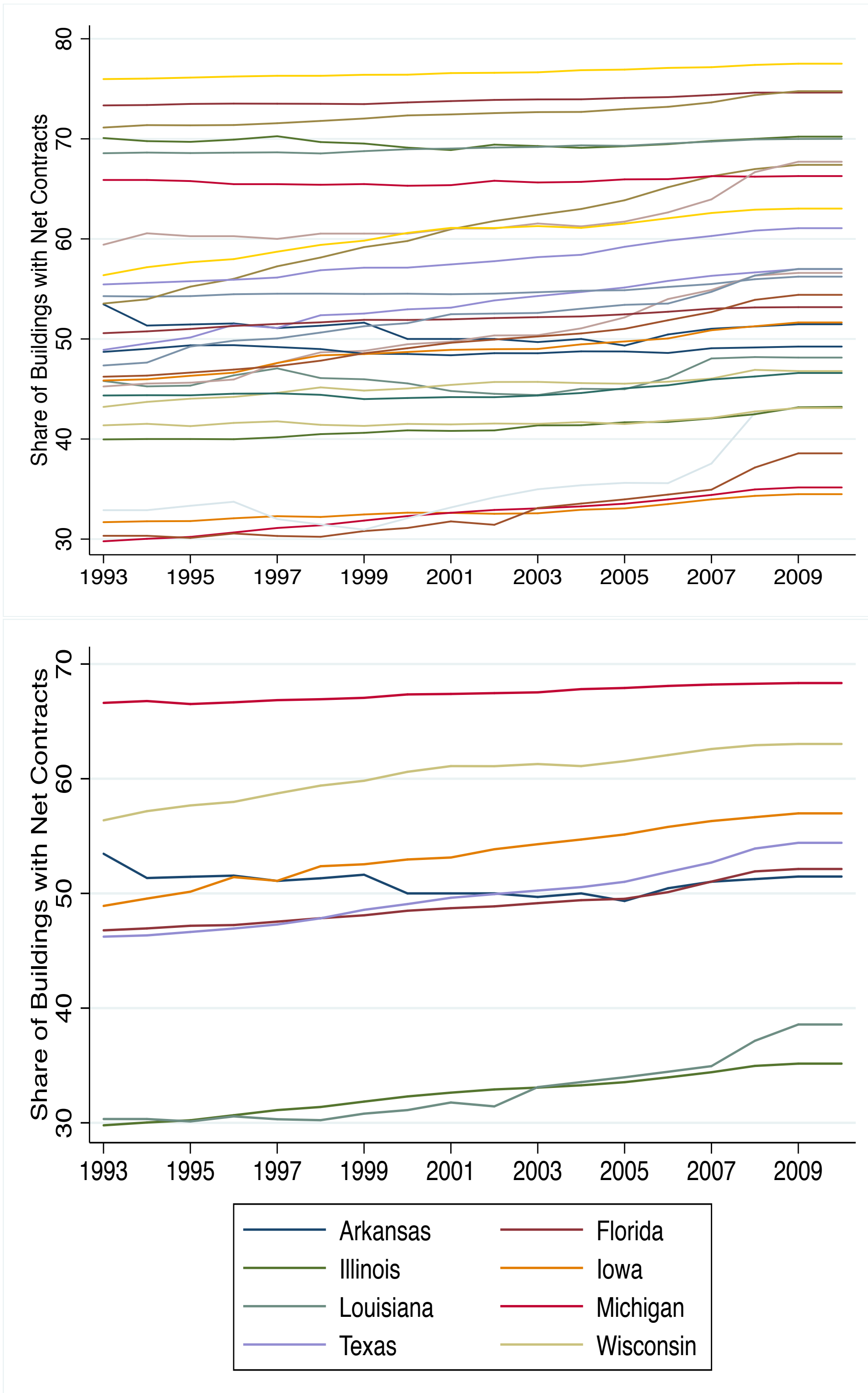

Table 1: EPAct States, Early Adopters and Never-Adopters

EPAct		Non-EPAct	
Arkansas	(HI)	Alabama	(NA)
Connecticut	(HI)	Arizona	(NA)
Delaware	(HI)	California	(EA)
Georgia	(HI)	Colorado	(NA)
Idaho	(LO)	Florida	(EA)
Illinois	(LO)	Indiana	(NA)
Iowa	(HI)	Kansas	(NA)
Kentucky	(LO)	Maine	(EA)
Louisiana	(HI)	Masschusetts	(EA)
Maryland	(HI)	Minnesota	(EA)
Michigan	(LO)	Mississippi	(NA)
Nebraska	(LO)	Missouri	(NA)
Nevada	(LO)	New Hampshire	(EA)
New Jersey	(HI)	New York	(EA)
New Mexico	(LO)	North Dakota	(NA)
North Carolina	(HI)	South Dakota	(NA)
Ohio	(HI)	Wyoming	(NA)
Oklahoma	(HI)		
Oregon	(HI)		
Pennsylvania	(LO)		
Rhode Island	(HI)		
South Carolina	(HI)		
Tennessee	(LO)		
Texas	(LO)		
Utah	(HI)		
Virginia	(HI)		
Washington	(HI)		
West Virginia	(LO)		
Wisconsin	(HI)		

Notes: HI = high intensity, denoting states that complied with EPAct before 2002. LO = low intensity, denoting states that complied in 2002 or later. NA = never-adopter, states that did not comply with EPAct. EA = early adopter, states that adopted an energy standard before the EPAct mandate came into effect.

Table 2: Summary Statistics, EPAct Sample

	High Intensity (n=324)				Low Intensity (n=198)				norm. diff.
	mean	s.d.	min	max	mean	s.d.	min	max	
Electricity Consumption (per capita)	14.37	2.35	8.24	20.68	13.83	2.47	3.99	19.48	0.16
Electricity Consumption (per service worker)	38.74	6.35	22.69	52.47	38.19	7.10	11.44	56.58	0.06
Electricity Price ($ per mmBTU)	22.30	6.36	13.19	50.17	21.02	4.64	12.22	40.77	0.16
Natural Gas Price ($ per mmBTU)	8.10	2.92	3.30	15.58	7.46	2.71	3.27	14.06	0.16
Per Capita Income (000s)	30.49	8.00	16.69	56.96	28.46	6.28	16.55	43.50	0.20
Cooling Degree Days (000s)	1.09	0.68	0.08	3.10	1.21	0.69	0.21	3.22	-0.11
Heating Degree Days (000s)	4.85	1.66	1.43	8.84	4.97	1.49	1.51	7.37	-0.05
Net Contract Share	55.0	12.8	30.1	77.5	51.0	12.2	29.8	70.0	0.23
New Construction Value Share	0.47	0.33	0	0.91	0.07	0.14	0	0.56	1.12
Building Code Stringency	0.35	0.32	0	1	0.19	0.34	0	1	0.34
Demand-Side Management	0.36	0.37	0.0	1.1	0.08	0.08	0.0	0.23	0.74

Notes: The normalized difference measures the degree of overlap for each covariate across the high and low intensity of treatment samples. It is defined as $\frac{\bar{X}_1 - \bar{X}_0}{\sqrt{S_1^2 + S_0^2}}$, where $\bar{X}_i$ denotes the mean of a given covariate for each treatment status $i = 0, 1$, and S_i^2 denotes the sample variance of X_i.

Table 3: Summary Statistics, Early Adopters and Never-Adopters

	Early Adopters (n=126)				Never-Adopters (n=180)				norm. diff.
	mean	s.d.	min	max	mean	s.d.	min	max	
Electricity Consumption (per capita)	11.96	2.58	6.77	17.45	15.74	3.51	9.20	27.57	-0.87
Electricity Consumption (per service worker)	31.02	6.91	17.34	48.30	41.97	7.63	25.14	65.22	-1.06
Electricity Price ($ per mmBTU)	30.79	8.04	17.23	49.35	19.91	3.15	14.71	29.83	1.25
Natural Gas Price ($ per mmBTU)	8.90	3.08	3.89	15.51	7.31	2.81	3.59	15.47	0.38
Per Capita Income (000s)	33.67	7.90	18.69	51.90	28.69	7.11	15.43	49.10	0.47
Cooling Degree Days (000s)	0.97	1.08	0.14	3.88	1.28	0.89	0.13	3.36	-0.22
Heating Degree Days (000s)	5.51	2.69	0.50	9.59	5.46	2.43	1.68	10.74	0.01
Net Contract Share	57.7	10.9	40.6	72.8	41.7	13.9	19.0	68.9	0.91
New Construction Value Share	0.90	0.22	0.0	1	0.0	0.0	0.0	0.04	4.09
Building Code Stringency	0.45	0.27	0.0	1	0.0	0.06	0.0	0.75	1.63
Demand-Side Management	0.64	0.36	0.13	1.3	0.09	0.09	0.0	0.28	1.48

Notes: The normalized difference measures the degree of overlap for each covariate across the high and low intensity of treatment samples. It is defined as $\frac{\bar{X}_1-\bar{X}_0}{\sqrt{S_1^2+S_0^2}}$, where $\bar{X}_i$ denotes the mean of a given covariate for each treatment status $i = 0, 1$, and S_i^2 denotes the sample variance of X_i. Three never-adopter states do not have data on the net contract share: North Dakota, South Dakota, and Wyoming. Net contract share values above are calculated by omitting these states.

Table 4: Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Electricity Price	-0.0026	-0.0030	-0.0031	-0.0036	-0.0036	-0.0043	-0.0043	-0.0046	-0.0018	-0.024***
	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)
Natural Gas Price	0.021**	0.021***	0.021***	0.024***	0.024***	0.019**	0.019**	0.018**	0.018**	0.007
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.007)
Cooling Degree Days	0.100**	0.101**	0.092**	0.095**	0.093**	0.088*	0.084*	0.080*	0.072	0.064
	(0.044)	(0.044)	(0.043)	(0.043)	(0.047)	(0.047)	(0.046)	(0.046)	(0.046)	(0.046)
Heating Degree Days	-0.023	-0.023	-0.014	-0.017	-0.017	-0.018	-0.014	-0.015	-0.017	0.016
	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.023)	(0.023)	(0.023)	(0.020)
Per Capita Income	0.003	0.003	0.002	0.007	0.007	0.007	0.006	0.005	0.007	-0.014
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.006)
Energy Code Dummy			-0.073***							
			(0.019)							
Contruction Share				-0.122***	-0.122***	-0.139***	-0.091**	-0.136**	-0.130**	-0.169***
				(0.040)	(0.040)	(0.040)	(0.044)	(0.062)	(0.062)	(0.052)
Net Contract Share						-0.012***	-0.011***	-0.010**	-0.011**	-0.024***
						(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Intensity							-0.100**	-0.088**	-0.089**	0.013
							(0.040)	(0.041)	(0.041)	(0.062)
DSM									-0.036**	0.065***
									(0.018)	(0.023)
Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Price Instruments	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES
Time Trend	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES
H/L Intensity Trend	NO	NO	NO	NO	NO	NO	NO	YES	YES	YES
Observations	522	522	522	522	522	522	522	522	522	252
R-squared (within)	0.36	0.36	0.38	0.38	0.38	0.39	0.39	0.40	0.40	0.69

Fixed effects refer to both state and time fixed effects. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 5: Robustness to Mismeasurement

Panel A	(1)	(2)	(3)	
Electricity Price	-0.006*	-0.005*	-0.006**	
	(0.003)	(0.003)	(0.002)	
Natural Gas Price	0.002	-0.002	-0.001	
	(0.003)	(0.003)	(0.003)	
Cooling Degree Days	0.067**	0.045**	0.044**	
	(0.027)	(0.019)	(0.021)	
Heating Degree Days	-0.023	-0.028*	-0.027*	
	(0.014)	(0.015)	(0.016)	
Per Capita Income	0.022**	0.010**	0.011**	
	(0.009)	(0.004)	(0.005)	
DSM	-0.035*	-0.029*	-0.023	
	(0.020)	(0.017)	(0.021)	
Intensity	-0.067	-0.115*	-0.095	
	(0.055)	(0.066)	(0.090)	
Net Contract Share	-0.011	-0.014	-0.015***	
	(0.008)	(0.010)	(0.003)	
Contruction Share	-0.046	-0.051	-0.114**	
	(0.125)	(0.122)	(0.054)	
τ_1^2			1.00***	
			(0.205)	
τ_2^2			0.87***	
			(0.221)	
Fixed Effects	YES	YES	YES	
Time Trend	NO	YES	YES	
Cumulant Estimator	NO	NO	YES	
Observations	522	522	522	
R-squared (within)	0.34	0.36	0.36	
Panel B				
Standardized Moments	Third	Fourth	Fifth	Sixth
Net Contract Share	0.54	6.05	7.10	60.02
Contruction Share	-0.63	2.67	-3.87	10.62

Standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. τ_1^2 and τ_2^2 refer to indices of measurement for the proxies of the net contract share and construction share, respectively. These values lie between 0 and 1, with 0 indicating a worthless proxy and 1 indicating a perfect proxy.