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Even for the environment, context matters! States, households, and residential energy consumption

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Abstract

This study adopts a multi-level approach to examine the extent to which state- and household-level factors shape residential energy consumption in the United States, focusing on efficiency improvement and affluence. Analyzing the 2009 Residential Energy Consumption Survey, state-level energy efficiency data from the American Council for an Energy-Efficient Economy (ACEEE), and other sources, we find that state context significantly influences energy consumption at the household level. Households in states scoring high on energy efficiency consume significantly less residential energy than those in states scoring low on the measure. At the household level, the analysis reveals mixed relationships between investment in energy efficiency technologies and residential energy consumption, as some measures of efficiency technology are negatively related to residential energy consumption, others are positively related to it. In regard to affluence, state-level measures do not emerge as significant predictors of residential energy consumption. At the household level, however, affluence drives residential energy consumption, which, in turn, is a significant driver of carbon dioxide emissions. Our study makes an important contribution to the social scientific literature on energy consumption, illuminating distinct relationships at different levels. To the best of our knowledge, this is the first study that simultaneously examines the impacts of factors measured at both the household (micro) and state (meso) levels.

1. Introduction

Energy consumption is one of the leading contributors to the increasing atmospheric concentration of greenhouse gases, a proximate cause of global warming. It is estimated that residential energy consumption directly and indirectly accounted for 17% of global carbon emissions in 2011 (Nejat et al 2014). In 2010 in the United States, buildings-related energy consumption generated 5634 million metric tons of carbon dioxide, with the residential sector accounting for 22% of this estimate (US Department of Energy 2012). Given that carbon dioxide is the leading greenhouse gas, efforts to address climate change have focused, to a very large extent, on improving efficiency in energy utilization across all economic sectors, in the belief that this will decrease overall emissions. Yet, whether or not energy efficiency actually leads to the expected results remains inconclusive. Substantial research, including William Stanley Jevons’s groundbreaking work on coal in the 1860s, suggests that efficiency gains in the use of a resource often paradoxically lead to increased consumption (Jevons 1906, Brookes 1990, 2000, Greening et al 2000, Clark and Foster 2001, Alcott 2005, Brannlund et al 2007, York et al 2005, 2009, Adua et al 2016, Wei and Liu 2017). Jevons (1906, p 140) stressed that ‘it is wholly a confusion of ideas to suppose that the economical (efficient) use of fuel is equivalent to diminished consumption. The very contrary is the truth.’ Thus, improving energy efficiency can correspond with an expansion in energy consumption and more carbon dioxide emissions. Given that energy

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efficiency remains the preferred approach to curtail carbon dioxide emissions, it is important to empirically test these relationships and to consider how context may influence energy consumption patterns.

We adopt a unique approach to examining the relationship between energy efficiency and residential energy consumption by considering the influence of state context. This is especially important within the evolving national political climate, which impacts environmental management one way or the other. For example, while the United States under President Donald Trump has retreated from addressing climate change (or actively acted to reverse prior climate change mitigation efforts), several states and local governments have enacted policies to try to more aggressively address this issue (Bromley-Trujillo 2017, Tabuchi and Fountain 2017). Thus, we examine whether or not the state context matters by conducting multi-level (state- and household-level) analysis of residential energy consumption. We specifically address the following questions: (1) Does state context influence residential energy consumption? (2) To what extent do energy efficiency innovations and affluence at the state- and household-level influence residential energy consumption? While controlling for the broader context, we analyze an important state-level predictor of residential energy consumption—state energy efficiency scores. We also examine the relative impacts of efficiency improvement in energy utilization and affluence. In our analyses, we assess the influence of affluence, given that social science research has indicated that it is a major driver of environmental change and an important correlate of residential energy consumption.

To what extent is this study justified? The study addresses two limitations in the extant literature, especially those focused on the United States. First, while several studies have examined factors influencing energy consumption at the household level (see Cramer et al 1984, Schipper et al 1989, Lutzenhiser 1993, Lutzenhiser and Hackett 1993, Adua 2010, Adua and Sharp 2011, Adua et al 2016), none, to the best of our knowledge, has considered the influence of state context. This is a major limitation, as state governments across the United States frequently make significant environment-related decisions. Second, while studies have investigated the relationships between efficiency technologies and energy consumption, few have included an assessment of the broad set of efficiency technology measures widely adopted by US households. We address this limitation by relying on a large sample of US households (nested within several states) to examine the influence of insulation, programmable thermostats, efficient light bulbs, multiple-pane windows, and efficient appliances on energy consumption, while accounting for the effects of state context and other factors. More broadly, consideration of the questions posed in this study is necessary, given that efficiency improvement is seen as a panacea for reining in energy consumption and decreasing carbon dioxide emissions. For the United States, this strategy has been a less risky approach to dealing with climate change, as political gimmicks and concerted disinformation campaigns have been used to dissuade a critical mass of politicians from considering an effective policy response to the challenge (see McCright and Dunlap 2011, Farrell 2018).

This study addresses key concerns related to the ecological-modernization and political-economy perspectives regarding society-environment interrelationships. The ecological-modernization perspective is generally optimistic about how affluence, technological innovations, and state policies can help address environmental problems, which are generally associated with resource consumption. The political-economy perspective, in contrast, proposes that affluence often increases demands for resources. It is more cautious about the impacts of efficiency innovations and state policies, noting that these often lead to more resource consumption. A longer discussion of these perspectives can be found in the supplementary material, along with an engagement with the associated empirical literature.

In what follows, we describe the data, along with the analytical approach. Following this, we present and discuss the findings, offering concluding comments at the end. In a nutshell, the findings show mixed relationships between energy efficiency measures and residential energy consumption. They reveal positive relationships between the measures of affluence and energy consumption. Importantly, they indicate state context and factors do influence residential energy consumption.

2. Data and methods

The data used in this study is a subsample of the 2009 Residential Energy Consumption Survey (RECS) (N = 12 083). This survey is one of several cross-sectional studies conducted by the Energy Information Administration (EIA) since 1978, which are collectively known as the RECS. In addition to other variables, the surveys gather environment and energy-related data from occupied housing units in the United States. Several strategies are employed to ensure the accuracy of the RECS data: employment of trained interviewers in data collection; use of help screens or cards to offer respondents standardized definitions or examples; hot-deck imputation; and comparing research subjects’ responses to certain questions to interviewers’ field notes, and recontacting them if necessary. Additional information about the RECS is available at the EIA’s website.

5 One of these active efforts to reverse climate mitigation actions includes Trump rolling back an Obama-era rule that required automakers to build vehicles achieving substantially higher gas mileage (54.5 miles per gallon) by 2025.

6 Adua et al (2016) is one of the few studies that have analyzed the wider set of measures of energy efficiency technologies.

7 Information about the RECS data is available at this website: http://eia.gov/consumption/residential/index.cfm.
To model state contextual influence, we use a subsample of respondents linked to states \((N = 8315)\). For the 2009 RECS, the EIA reported the states of residence for this large subsample of respondents. This subgroup of respondents, nested in 16 states, constitutes a large proportion of the original sample \(\text{i.e. about 70\%}\). The states included in the subsample are quite representative of all US states: it includes blue \(\text{i.e. Democratic-leaning}\), red \(\text{i.e. Republic-leaning}\), and purple \(\text{swing}\) states; small and large states; historical confederate and non-confederate states; rustbelt and non-rustbelt states; and at least one state from each of the nation’s census regions and divisions. The states included in the study are reported in table 1, along with some characteristics. The earlier waves of the RECS \(\text{i.e. those before 2009}\) and the most recent one \(\text{i.e. 2015 RECS}\) do not provide state of residence information for respondents.

### Table 1. States included in the study.

| State         | \(N\) (From 2009 RECS) | Population (2009) | Confederate state? | Rustbelt state? | Census region | Census division  |
|---------------|-------------------------|-------------------|-------------------|----------------|---------------|-----------------|
| Arizona      | 226                     | 6343 154          | Yes\(^c\)        | No             | West          | Mountain South  |
| California   | 1606                    | 36 961 229        | No                | No             | West          | Pacific         |
| Colorado     | 295                     | 4972 195          | No, mostly\(^d\) | No             | West          | Mountain North  |
| Florida      | 948                     | 18 652 644        | Yes               | No             | South         | South Atlantic  |
| Georgia      | 440                     | 9620 846          | Yes               | No             | South         | South Atlantic  |
| Illinois     | 248                     | 12 796 778        | No                | Yes            | Midwest       | East North Central |
| Massachusetts| 501                     | 6517 613          | No                | No             | North East    | New England     |
| Michigan     | 274                     | 9901 591          | No                | Yes            | Midwest       | East North Central |
| Missouri     | 686                     | 5961 088          | No\(^e\)          | No             | Midwest       | West North Central |
| New Jersey   | 204                     | 8755 602          | No                | No             | North East    | Mid Atlantic    |
| New York     | 839                     | 19 307 066        | No                | No             | North East    | Mid Atlantic    |
| Pennsylvania | 285                     | 12 666 858        | No                | Yes            | Midwest       | South Atlantic  |
| Tennessee    | 249                     | 6306 019          | Yes               | No             | South         | East South Central |
| Texas        | 991                     | 24 801 761        | Yes               | No             | South         | West South Central |
| Virginia     | 281                     | 7925 937          | Yes               | No             | South         | South Atlantic  |
| Wisconsin    | 242                     | 5669 264          | No                | Yes            | Midwest       | East North Central |

\(^a\) Sourced from the US Census Bureau, Population Division (https://census.gov/data/tables/time-series/demo/popest/intercensal-2000-2010-state.html).

\(^b\) Source of information: https://nps.gov/civilwar/facts.htm.

\(^c\) Arizona was a territory that voted to join the Confederacy, but was quickly captured by union fighters and later split into two territories, Arizona and New Mexico (https://history.com/topics/american-civil-war/confederate-states-of-america).

\(^d\) Smith (1961).

\(^e\) Border state.

To model state contextual influence, we use a subsample of respondents linked to states \((N = 8315)\). For the 2009 RECS, the EIA reported the states of residence for this large subsample of respondents. This subgroup of respondents, nested in 16 states, constitutes a large proportion of the original sample \(\text{i.e. about 70\%}\). The states included in the subsample are quite representative of all US states: it includes blue \(\text{i.e. Democratic-leaning}\), red \(\text{i.e. Republic-leaning}\), and purple \(\text{swing}\) states; small and large states; historical confederate and non-confederate states; rustbelt and non-rustbelt states; and at least one state from each of the nation’s census regions and divisions. The states included in the study are reported in table 1, along with some characteristics. The earlier waves of the RECS \(\text{i.e. those before 2009}\) and the most recent one \(\text{i.e. 2015 RECS}\) do not provide state of residence information for respondents.

### 2.1. Dependent variable

The main dependent variable analyzed in this study is residential energy (electricity and natural gas) consumption estimates for the households included in the study. Residential energy consumption is measured with annualized estimates of respondents’ electricity and natural gas consumption. To obtain energy consumption estimates, the appropriate utility service providers were contacted for respondents’ actual monthly energy consumption figures, which were subsequently annualized to create annual estimates. The estimates are available in KWH \(\text{(electricity)}\) and cubic feet \(\text{(natural gas)}\), but we use the BTUs \(\text{(i.e. British Thermal Units)}\) estimates, which are available for both fuels\(^8\). We focus on electricity and natural gas because they are the most widely used fuels in residential buildings in the United States. For the multivariate analysis, we estimate separate models for electricity and natural gas consumption, and a third for combined electricity and natural gas consumption. Summary statistics for all the variables are reported in table 2.

### 2.2. Independent variables

Several sets of independent variables are included in the analysis. These broadly include measures of efficiency innovations, affluence, and statistical controls. We include independent variables at both the household and state levels. Below, we discuss how these variables are measured.

\(^8\) British thermal unit (BTU) is a measure of the heat content of an energy source.
Table 2. Descriptive statistics of dependent and independent variables.

| Variable | Mean/proportion | Linearized std. errors | 95% confidence interval |
|----------|-----------------|-------------------------|-------------------------|
| Energy consumptiona | | | |
| Electricity | 3.64e + 07 | 315 937,000 | 3.58e + 07–3.71e + 07 |
| Natural gas | 4.31e + 07 | 678 207,400 | 4.18e + 07–4.46e + 07 |
| Total, electricity + natural gas | 7.96e + 07 | 745 156,700 | 7.81e + 07–8.10e + 07 |
| Efficiency innovations | | | |
| Adequacy of insulation: | | | |
| Well-insulated | 0.345 | 0.006 | 0.33–0.36 |
| Adequately insulated | 0.443 | 0.006 | 0.43–0.46 |
| Poorly/no insulation | 0.212 | 0.005 | 0.20–0.22 |
| Household had added insulation (yes = 1)c | 0.212 | 0.005 | 0.20–0.22 |
| Heating equipment with programmable thermostat?c | | | |
| No | 0.437 | 0.006 | 0.42–0.45 |
| Yes | 0.395 | 0.006 | 0.38–0.41 |
| Not applicabled | 0.168 | 0.005 | 0.16–0.18 |
| Type of gas in windows (ref. = single pane)c | | | |
| Single pane | 0.457 | 0.006 | 0.44–0.47 |
| Double pane | 0.530 | 0.006 | 0.52–0.54 |
| Triple pane | 0.014 | 0.002 | 0.01–0.02 |
| Ratio of efficient to inefficient light bulbs:c | | | |
| Ratio > 0 (No efficient bulbs) | 0.344 | 0.006 | 0.33–0.36 |
| Ratio > 0, but < 1 | 0.137 | 0.004 | 0.13–0.15 |
| Ratio = 1 | 0.348 | 0.006 | 0.34–0.37 |
| Not applicable/did not answerd | 0.171 | 0.005 | 0.16–0.18 |
| Insulated hot water heater (yes = 1)c | 0.140 | 0.004 | 0.13–0.15 |
| Caulked/weather stripped home? (yes = 1)c | 0.338 | 0.006 | 0.33–0.35 |
| Energy star-rated dish washer? (Yes = 1)c | | | |
| No | 0.126 | 0.004 | 0.12–0.13 |
| Yes | 0.245 | 0.005 | 0.23–0.26 |
| Not applicabled | 0.629 | 0.006 | 0.62–0.64 |
| State energy efficiency scorec | 17.267 | 0.109 | 17.06–17.48 |
| Affluence | | | |
| Household incomeb | 55 418,770 | 475,769 | 54 486,15–56 351,40 |
| Home ownership (own = 1)c | 0.656 | 0.006 | 0.64–0.67 |
| Home size (sq. ft.)b | 2085.719 | 18.178 | 2050.09–2121.35 |
| State level personal income per capita, 2004b | 35 383,830 | 46.465 | 35 292,74–35 474,91 |
| Statistical Controls: demogr. factors, location characteristic, educ. and pol. orientation | | | |
| Household size, number of membersb | 2.603 | 0.019 | 2.57–2.64 |
| Femalec | 0.530 | 0.006 | 0.52–0.54 |
| Whitec | 0.777 | 0.005 | 0.76–0.79 |
| Member at home, typical week day (yes = 1)c | 0.564 | 0.006 | 0.55–0.58 |
| Heating degree days, 30-year averagec | 3822.872 | 26.720 | 3770.49–3875.25 |
| Cooling degree days, 30-year averageb | 1331.336 | 12.356 | 1507.11–1555.57 |
| Presence of tree coverc | 0.440 | 0.006 | 0.43–0.45 |
| Home agec | 38.928 | 0.318 | 38.30–39.55 |
| Education, household headb | 3.378 | 0.021 | 3.34–3.42 |
| State pol. orientation, 2004 Elect. Col. winner (Bush = 1)c | 0.435 | 0.006 | 0.42 v 0.45 |

a Linearization (Taylor) corrects for the design characteristics of the sample (area probability sampling). The survey was not based on a simple random sample. Computing these descriptive statistics involved use of the sampling weights provided.
b Continuous variables.
c Ordinal or dichotomous variables.
d The ‘Not applicable’ categories are included in our regression analyses as dummy variables so as not to lose too many observations. While we are not reporting them in the regression table (table 3), we thought it necessary to report their descriptive statistics here.

2.2.1. Efficiency innovations

At the household level, efficiency innovations is measured with several items from the survey, which include adequacy of insulation, presence of a programmable thermostat in a home, type of glass in a home’s windows, ratio of energy efficient to non-efficient bulbs used, insulation of water heater, caulking and weather-stripping, and use of an Energy Star-rated dishwasher. Adequacy of insulation, the first indicator of efficiency innovations, is measured with a survey item that requested respondents to indicate whether their homes/apartments are (1) well insulated,
(2) adequately insulated, or (3) poorly insulated. A fourth option—no insulation—was volunteered by a few residents. For our analysis, this option is added to response option 3 (poorly insulated). The second measure is an item that asked respondents to indicate whether or not (yes = 1; no = 0) the household had added insulation to the home since taking possession of it. Third, efficiency innovations is measured with an item requesting respondents to report on whether or not (yes/no) their homes’ central heating systems are equipped with programmable thermostats. The fourth measure is an item that requested respondents to report on the type of glass in the windows of their homes, with the following response options: single pane; double pane; and triple pane. The assumption is that energy efficiency improves as the number of panes in a glass window increases, given that there is space between the panes. The fifth indicator is households’ use of energy efficient light bulbs. Respondents reported on the number of energy efficient light bulbs used between 1 and 4 hours per day. For our analysis, we computed the ratio of these bulbs to all others used in the home for the same length of time. Due to extreme skewness in the resulting variable, it was recoded into a categorical variable: 0 = zero ratio (basically no energy efficient bulbs); 1 = ratio greater than 0, but less than 1; and 2 = ratio is exactly 1. The sixth measure of efficiency innovations is whether a home’s hot water heater is insulated (i.e. covered with heat-conserving blankets)—yes (1), no (0), not applicable. Caulking or weather-stripping is the seventh indicator of efficiency innovations used in the study. Respondents were asked if they had caulked or weather-stripped their homes, with the following response options: yes (1), no (0), not applicable. The final measure of household efficiency innovations is whether respondents’ main dish washer is Energy Star-rated, with the response options: yes (1), no (0), and not applicable. Energy Star-rating is a well-known industry standard for gauging the efficiency of electronic gadgets and appliances. For the analysis conducted in this study, each of these variables was dummy-coded.

At the state level, one composite measure of energy efficiency is included in the analysis—states’ 2006 energy efficiency scores from the American Council for an Energy-Efficient Economy (ACEEE). The scores are based on states’ progress in eight energy efficiency policy categories: spending on utility and public benefits energy efficiency programs; energy efficiency resource standards; combined heat and power; building energy codes; transportation policies; appliance and equipment efficiency standards; tax incentives; and state lead by example and research and development (Eldridge et al 2007). This variable ranges in value from a minimum of 2 to a maximum of 33.

The ecological-modernization position anticipates negative relationships between indicators of efficiency innovations and energy consumption, while the political-economy perspective proposes the opposite or the absence of any environmentally beneficial relationships.

2.2.2. Affluence
At the household level, affluence is based on several items from the survey. Following Adua et al (2016), Adua (2010), and Lutzenhiser and Hackett (1993), we measure affluence in terms of household income, which is based on annual pre-tax income for all household members from all sources (wages, interest, alimony, social security, and so forth). The response options were reported in income ranges. For the analysis conducted in this study, each income range was recoded to its category midpoints. Two additional measures of affluence used in this study are home ownership and home size (square feet). Home ownership is measured, simply, by whether or not a respondent owns his/her current place of residence (1 = own; 0 = other arrangement). Home size is measured by the total square footage of a respondent’s place of residence. While these measures communicate nothing about market value, homes represent one of the most important physical assets US households can possess. Additionally, home prices are generally associated with size (square footage), all things being equal. A visible symbol of affluence in many societies is home ownership and home size (see Adua et al 2016).

At the state level, affluence is measured by personal income per capita in 2004; in terms of causality, the 2004 measure of personal income sufficiently precedes the dependent variable. This information is sourced from the Bureau of Economic Analysis.

While the ecological-modernization perspective anticipates an inverted U-shaped relationship between affluence and energy consumption, the political-economy perspective expects affluence to continue to drive more consumption, which will in turn increase resource demands.

2.2.3. Statistical controls
Several statistical control variables are included in the analysis. These include several demographic variables (number of household members, gender, race, and whether there is always someone at home) and locational and physical characteristics of respondents dwelling places (heating and cooling degree days, presence of tree cover, and home age). The inclusion of these variables is informed by the human ecology perspective and prior empirical findings (see Lutzhenhiser and Hackett 1993, Dietz and Rosa 1994, O’Neill and Chen 2002, York et al 2003, York 2007, Adua et al 2016). Number of household members is measured with an item asking respondents to report on the number of people in the household. For gender, we use sex as a proxy (female = 1; male = 0). Race is measured by the race of the household head (white = 1; all others = 0). To measure the last demographic
variable, someone always at home, respondents were asked to indicate whether there is a household member at home on a typical week day (yes = 1; no = 0).

Heating and cooling degree days are two measures used to tap the locational and physical characteristics of respondents’ place of residence. Heating degree days is measured by the number of degrees per day that the average temperature of a place is lower than 65 °F, a base temperature level adopted by the Department of Energy. Cooling degree days, in contrast, is the number of degrees per day that the average temperature exceeds 65 °F. For the analyses, we use 30-year averages of cooling and heating degree days, which allows us to capture the impacts of climatic conditions. Another measure is presence of tree cover, which is measured by whether or not a respondent’s home is covered by large trees (yes = 1; no = 0). This variable taps homes’ micro-climate (see Adua et al. 2016). The final measure for this category is home age, which is calculated based on the year a respondent’s home was built.

The last individual-level control variable included in the analysis is education, which is measured by the highest level of education completed by household head.

At the state level, the analysis controls for the influence of states’ political orientation. State political orientation is measured by the candidate who won a state’s Electoral College votes in the 2004 presidential elections (George Bush = 1; John Kerry = 0). This information is sourced from the National Archives and Records Administration. There is evidence that state-level politics can influence environmentally significant decisions (Dietz et al. 2015).

2.3. Estimation

The hierarchical linear modeling approach (see Raudenbush and Bryk 2002) is adopted to examine the extent to which state- and household-level factors shape residential energy consumption in the United States. This approach is necessitated, first, by the structure of the data used: the data have a hierarchical structure with households nested within states. As a result of this structure, state-level influence on the outcome variable is to be expected, and, indeed, our diagnostics confirm that to be the case. An initial unconditional model (i.e. intercept only model) shows a significant state-level random effect of 0.103 (std. error = 0.037)⁹. Secondly, the approach allows us to model the effects of predictors at both the household and state levels. While most of the predictors analyzed pertain to the household level (Level 1), we do model the impacts of three state-level (level 2) predictors. With this approach, we are able to analyze the impacts of state level factors and contexts on residential energy consumption.

We adopt a stepwise approach in the model estimation. In the first iteration of the estimation, we include only Level 1 predictors, that is, predictors measured at the household level. In the second iteration, we introduce predictors measured at the state level (i.e. Level 2 predictors). The goal here is to determine whether the introduction of the Level 2 predictors will influence the impacts of the Level 1 predictors in anyway. In the results reported, home size, a measure of affluence, is modeled as a random slope. This is because our diagnostics show that its impacts on residential energy consumption vary significantly both within and across states; intuitively, this means the impacts of home size on residential energy consumption in one state will differ from its impacts in another.

3. Results

In response to the first research question, our analysis shows state context does, indeed, influence residential energy consumption. State random effects for the models estimated are reported under Model Statistics of table 3. The final regression results from the data analyzed are reported in table 3. Under Model 1, we report the results of the regression of residential electricity consumption on the predictors (measures of efficiency innovations, affluence, and several statistical controls), while under Model 2, we report results for the regression of residential natural gas consumption on these predictors. Results for the regression of combined residential electricity and natural gas consumption (hereinafter referred to as total energy consumption) are reported under Model 3.

Across the three models, we find mixed relationships between the indicators of efficiency innovations and residential energy consumption. In the first model, the results show that homes without insulation or poorly insulated are associated with more electricity consumption than homes that are well-insulated (Model 1). In Model 2, we find that households’ use of energy-efficient bulbs (measured by ratio of efficient to inefficient light bulbs) is negatively related to natural gas consumption. Caulking or weather-stripping is also negatively related to natural gas consumption (b = −0.41). In the final model (Model 3), a few household-level energy efficiency innovations are further shown to be negatively related to energy consumption. Homes that are just adequately insulated are associated with about 5% more total energy consumption (combined electricity and natural gas) than those that are well-insulate, while those that are poorly or not insulated are associated with about 10% more energy consumption. Use of energy efficient light bulbs is also associated negatively with energy consumption (b = −0.034). Concerning state-level
Table 3. The effects of technology, affluence, and other factors on residential energy consumption, 2009.

|                      | Model 1: Electricity consumption | Model 2: Natural gas consumption | Model 3: Total energy consumption |
|----------------------|----------------------------------|----------------------------------|----------------------------------|
|                      | 1A: b (Std. Error)               | 1B: b (Std. Error)               | 2A: b (Std. Error)               |
| Efficiency innovations | 2B: b (Std. Error)               | 2B: b (Std. Error)               | 3A: b (Std. Error)               |
|                      | 3B: b (Std. Error)               |                                  |                                  |
| Adequately insulated (ref. = Well-insulated) | 0.013 (0.013) | 0.013 (0.013) | 0.309 (0.183) | 0.314 (0.183) | 0.051 (0.014)*** | 0.051 (0.014)*** |       |
| Poorly or not insulated (ref. = Well-insulated) | 0.059 (0.016)*** | 0.058 (0.016)*** | 0.321 (0.236) | 0.329 (0.236) | 0.100 (0.018)*** | 0.101 (0.018)*** |       |
| Household had added insulation (yes = 1) | 0.054 (0.015)** | 0.040 (0.015)** | −0.220 (0.220) | −0.215 (0.220) | 0.026 (0.017) | 0.026 (0.017) |       |
| Programmable thermostat (yes = 1)** | 0.008 (0.013) | −0.008 (0.013) | 1.707 (0.185)*** | 1.700 (0.185)*** | 0.077 (0.014)*** | 0.077 (0.014)*** |       |
| Type of window: Double pane (ref. = single pane) | −0.010 (0.013) | −0.010 (0.013) | 0.213 (0.182) | 0.215 (0.182) | −0.024 (0.014) | −0.024 (0.014) |       |
| Type of window: Triple pane (ref. = single pane) | 0.029 (0.050) | 0.029 (0.050) | 0.660 (0.722) | 0.675 (0.722) | 0.006 (0.056) | 0.008 (0.056) |       |
| Efficient to inefficient bulb: ratio > 0, but < 1 (ref. = ratio = 0) | 0.033 (0.018) | 0.033 (0.018) | −0.578 (0.254)* | −0.579 (0.254)* | −0.004 (0.020) | −0.004 (0.020) |       |
| Efficient to inefficient bulb: ratio = 1 (ref. = ratio = 0)** | −0.001 (0.013) | −0.001 (0.013) | −0.464 (0.192)* | −0.468 (0.192)* | −0.033 (0.015)* | −0.034 (0.015)* |       |
| Insulated hot water heater (yes = 1)** | 0.051 (0.016)** | 0.052 (0.016)** | −0.333 (0.231) | −0.335 (0.231) | −0.009 (0.018) | −0.009 (0.018) |       |
| Caulked/weather stripped home? (yes = 1)** | 0.053 (0.013)*** | 0.053 (0.013)*** | −0.415 (0.188)* | −0.411 (0.188)* | 0.005 (0.015) | 0.006 (0.015) |       |
| Energy Star-rated dish washer? (Yes = 1)** | 0.011 (0.019) | 0.012 (0.019) | 0.351 (0.275) | 0.334 (0.275) | 0.027 (0.021) | 0.026 (0.021) |       |
| State energy efficiency score, ACEEE** | −0.042 (0.017)* | — | 0.258 (0.354) | — | −0.038 (0.018)* |       |       |
| Affluence |                                  |                                  |                                  | | | | |
| Household income | 0.000 (0.000) | 0.000 (0.000) | 0.000 (0.000)*** | 0.000 (0.000)*** | 0.000 (0.000)*** | 0.000 (0.000)*** |       |
| Household income household income** | 0.000 (0.000)* | 0.000 (0.000)* | — | — | — | — |       |
| Home ownership (own = 1) | 0.094 (0.015)*** | 0.093 (0.015)*** | −0.266 (0.218) | −0.257 (0.218) | 0.064 (0.017)*** | 0.064 (0.017)*** |       |
| Home size (sq. ft.) | 0.287 (0.021)*** | 0.285 (0.020)*** | 1.647 (0.503)*** | 1.663 (0.493)*** | 0.373 (0.024)*** | 0.372 (0.024)*** |       |
| State personal income per capita** | −0.000 (0.000) | — | 0.001 (0.001) | — | 0.000 (0.000) |       |       |
| Statistical Controls: Demogr. factors, location characteristic, educ. and pol. orientation | | | | | | | |
| Household size, number of members | 0.094 (0.004)*** | 0.094 (0.004)*** | −0.006 (0.055) | −0.003 (0.055) | 0.078 (0.004)*** | 0.078 (0.004)*** |       |
| Female | 0.011 (0.011) | 0.011 (0.011) | −0.071 (0.160) | −0.073 (0.160) | 0.012 (0.012) | 0.012 (0.012) |       |
| White | 0.032 (0.014)** | 0.032 (0.014)** | −1.254 (0.190)*** | −1.244 (0.190)*** | −0.084 (0.015)*** | −0.083 (0.015)*** |       |
| Member at home, typical week day (yes = 1) | 0.065 (0.012)** | 0.066 (0.012)** | 0.271 (0.166) | 0.265 (0.166) | 0.074 (0.013)** | 0.073 (0.013)** |       |
| Heating degree days, 30-year average** | 0.041 (0.017)** | 0.043 (0.017)** | 0.760 (0.244)** | 0.736 (0.243)** | 0.079 (0.019)*** | 0.078 (0.019)*** |       |
| Cooling degree days, 30 year average** | 0.110 (0.012)** | 0.111 (0.012)** | 0.861 (0.176)** | 0.856 (0.176)** | 0.100 (0.014)** | 0.100 (0.014)** |       |
| Presence of tree cover | 0.029 (0.012)*** | 0.029 (0.012)*** | −0.506 (0.166)** | −0.501 (0.166)** | −0.012 (0.013) | −0.012 (0.013) |       |
| Home age | −0.003 (0.000)*** | −0.003 (0.000)*** | 0.056 (0.004)*** | 0.056 (0.004)*** | 0.003 (0.000)*** | 0.003 (0.000)*** |       |
| Education, household head | −0.010 (0.004)** | −0.010 (0.004)** | 0.066 (0.054) | 0.066 (0.054) | −0.009 (0.004)*** | −0.009 (0.004)*** |       |
| State pol. orient., 2004 Elect. Col. winner (Bush = 1)** | −0.044 (0.300) | — | −16.436 (6.084)*** | — | −1.137 (0.320)*** |       |       |
| Model statistics | | | | | | | |
| Intercept, overall (grand) mean | 13.647 | 15.874 | −15.38 | −48.320 | 13.461 | 13.569 |       |
| Log-likelihood | −5668.351 | −5661.877 | −26 925.049 | −26 916.148 | −6521.235 | −6515.308 |       |
| State random effect | 0.489 | 0.361 | 15.526 | 7.947 | 0.595 | 0.366 |       |
Table 3. (Continued.)

|                   | Model 1: Electricity consumption | Model 2: Natural gas consumption | Model 3: Total energy consumption |
|-------------------|----------------------------------|----------------------------------|----------------------------------|
|                   | 1A: b (Std. Error) | 1B: b (Std. Error) | 2A: b (Std. Error) | 2B: b (Std. Error) | 3A: b (Std. Error) | 3B: b (Std. Error) |
| N                 | 7974 | 7974 | 7974 | 7974 | 7974 | 7974 |

Note: Models 1A, 2A, and 3A exclude the three state level predictors considered in the study. We conducted stepwise analysis to help determine whether the introduction of the Level 2 (state level) predictors will influence the impacts of the Level 1 (household level) predictors in anyway.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

* Not applicable options have been included as a dummy variable in the analysis so as to not lose cases, although they are not reported here.

* The effects of household income are modest (very low), but not zero. They appear to be zero in this table because the coefficients are rounded to three decimal places.

* Log-transformed.

* State level measure.
influence, households in states scoring high on the ACEEE energy efficiency ranking consume significantly less residential electricity \((b = -0.042)\) and total residential energy \((b = -0.038)\) than households in states scoring low on the ranking. States’ scores on the ACEEE efficiency ranking is unrelated to households’ natural gas consumption. These findings are consistent with certain positions associated with the ecological-modernization perspective, such as the contention that technological innovations serve as a way to manage human impacts on the environment in the modern society. This expectation applies to energy consumption, given that energy production and consumption is one of the leading drivers of environmental degradation.

We, however, also find positive relationships between several other measures of efficiency innovations and energy consumption, which is consistent with the caution raised by researchers from the political-economic perspective about reliance on technology to address environmental problems. The analysis shows that households that reported adding insulation during ownership of their homes consumed 4% more electricity than those not reporting the addition of insulation. Households reporting that their main water heater is insulated (i.e. covered with a heat-conserving blanket) consumed about 5.2% more electricity than households reporting no such insulation (Model 1). Households that reported caulking/weather-stripping their homes also consumed 5.3% more electricity (Model 1). That caulking/weather-stripping is negatively related to natural gas consumption, but positively related to electricity consumption suggests some cancelling dynamic: as households reduce their natural gas consumption, they somehow increase their use of electricity. In Model 2, we find that households with central heating systems equipped with programmable thermostats, a technical approach to managing residential energy consumption, consume 170% more natural gas than those without this type of equipment. This result, which is consistent with earlier findings by Adua et al. (2016) and other studies documenting rebound effects (Brookes 1990, Brännlund et al. 2007, Greening et al. 2000, Wei and Liu 2017), pertain to Model 3 too: homes with central heating systems equipped with programmable thermostats consume about 8% more total residential energy (electricity and natural gas) than homes without this type of equipment. Several other indicators of efficiency innovations are not related to energy consumption, which, in itself, is anticipated under the political-economic perspective. Without denying the potential for efficiency innovations to generate environmentally beneficial impacts, political-economy researchers indicate that savings accruing from efficiency innovations are often ferreted into more consumption, effectively cancelling out these potential benefits (see Schor 2005, Polimeni et al. 2008, Cohen 2010). In terms of affluence, the evidence in this study solidly supports arguments from the political-economy perspective. We find a weak, but positive relationship between household income and residential electricity consumption. This relationship is curvilinear: the slope gets steeper (positively) as income grows (Model 1)\(^{10}\). In Models 2 and 3, the results also show weak, but positive linear relationships between household income and energy (natural gas and total) consumption. See Adua et al. (2016) and Lutzenhiser and Hackett (1993) for similar findings. Home ownership, another measure of affluence, is positively related to residential energy consumption: the data indicate that households owning their homes consume 9.3% more electricity and 6.4% more total energy than those not owning their homes. Across all three models, we find strong relationships between home size (in square feet) and residential energy consumption: a square foot increase in home size results in 0.285%, 1.663%, and 0.372% increases in electricity, natural gas, and total energy consumption respectively. Here, more affluence leads to more energy consumption, as suggested by the political-economic perspective.

An important finding in relation to home size is that its impacts on residential energy consumption varies across states. Across all three models reported, we find this to be the case. This makes substantive sense. Homes in relatively urbanized states are more likely to be in dense urban locations: households in such locations are more likely to experience the so-called heat island effect (i.e. the tendency for built up areas to be hotter than the nearby countryside) than those in less urban states. Thus, households in more urbanized states may need more energy for cooling in the hotter seasons and less energy for heating in the colder seasons. Another important observation from the data is that the inclusion of state-level (Level 2) predictors had essentially no impacts on the effects of the household-level measures of efficiency innovations and affluence (table 3, Models 1B, 2B, and 3B). This suggests state-level context and factors help explain household-level energy consumption, but do not moderate the impacts of household-level predictors on consumption.

### 4. Conclusions

In this study, we examined the impacts of energy efficiency innovations and affluence on residential energy consumption, while considering the influence of state context, state-level predictors, and other factors. We drew upon and reflected on two of the prominent social-scientific perspectives regarding society-environment relationships—ecological-modernization and political-economy (see supplementary

\(^{10}\) Note that the effects of household income are modest (very low), but not zero. They appear to be zero in the results table (table 3) because the coefficients are rounded to three decimal points.
material). Discernable from the ecological-modernization perspective is the proposition that technological innovations will help mitigate human impacts on the environment, such as reducing energy consumption at the household level. It also suggests that affluence will have an inverted U-shaped relationship (indicative of the environmental Kuznets curve) with regard to environmental degradation (Mol et al 2009, Murphy and Gouldson 2009). According to political-economy arguments, efficiency gains are possible through technological innovations, but they often lead to more resource consumption, potentially cancelling out any benefits of efficiency (Schnaiberg 1980, Polimeni et al 2008, Foster et al 2010).

Our study makes a significant contribution to the literature, providing robust analysis of the relationship between measures of efficiency innovations and affluence on the one hand and residential energy consumption on the other. Our study addresses the impacts of a wider set of energy efficiency innovations used by US households than most previous studies. We do this while controlling for the impacts of several other variables. Furthermore, this study is the first, to the best of our knowledge, to interrogate these relationships (the impacts of the indicators of efficiency innovations, affluence, and statistical control), while accounting for state context and factors. We used the technique of hierarchical linear modeling to investigate these relationships, which allowed us to examine variables measured at the household level (Level 1) and state level (Level 2). In consonant with a broad set of studies examining anthropogenic environmental impacts, our empirical model fully complies with the classical IPAT model, which posits that environmental impact (I) is a product of population (P), Affluence (A), and Technology (T) (Commoner 1971, Ehrlich andHoldren 1970, 1972). The models we estimated include measures of population, affluence, and technology.\(^\text{11}\)

With respect to the impacts of technological innovations, the findings reported here provide support for aspects of both the ecological-modernization and political-economy perspectives. As suggested by ecological-modernization scholars, we find several measures of energy efficiency innovations associating negatively with one or more measures of residential energy consumption (electricity, natural gas, and combined electricity-natural gas). These measures of energy efficiency innovations include insulation, use of energy efficient bulbs, caulking/weather-stripping, and states' score on the ACEEE energy efficiency ranking (a state level predictor). Use of efficiency technologies is considered by ecological-modernization proponents as one of the strategies that modern economies would (or could) use to mitigate human impacts on the environment, and by extension as a basis for decreasing energy consumption. However, in our study, several other measures of efficiency innovations are either positively related to residential energy consumption or exert no influence at all. The addition of insulation, insulating a home’s main water heater, caulking/weather-stripping, and owning a central heating system equipped with a programmable thermostat are each positively related to one or more of our measures of residential energy consumption, while the use of multiple-pane glass windows (instead of single pane) and an Energy Star-rated dishwasher are unrelated to any of the measures. These findings are consistent with the political-economy perspective, which expects technological innovations to generate insubstantial environmental benefits or even result in negative impacts. They suggest technological innovations may help, but only marginally. The marginality of these impacts may be a function of the well-documented rebound effect that often accompanies efficiency improvement in resource utilization (see Brookes 1990, Alcott 2005, Brannlund et al 2007, Greening et al 2000, Wei and Liu 2017).

In terms of the impacts of affluence, the evidence in this study clearly supports the political-economy perspective. This perspective expects affluence to drive more resource consumption as well as the associated environmental problems (Schnaiberg 1980, Schor 2005, Polimeni et al 2008). Household income and home size, two of our indicators of affluence, are each positively related to all three measures of energy consumption analyzed in this study. The slope of the relationship between income and residential electricity consumption gets steeper (positively) as household income rises. Home ownership, the third measure of affluence, is positively related to both residential electricity and total energy (i.e. combined electricity-natural gas) consumption. These findings essentially counter what is projected by the ecological-modernization and the environmental Kuznets curve perspectives. To reiterate, these perspectives expect an inverted U-shaped relationship between affluence and consumption. Our findings here are consistent with several other prior studies (see Stern et al 1986, Lutzenhiser and Hackett 1993, Adua 2010, Adua et al 2016).

In conclusion, we observe overall that efficiency innovations do exert some influence on residential energy consumption, but the relationships are mixed. While some measures of efficiency innovations are shown to be effective in curbing residential energy consumption, others are shown to spur more consumption. Furthermore, we find that context, as exemplified by state-level traits and factors, do matter, as they create significant variations in energy consumption. Finally, we conclude, that affluence drives

\(^{11}\) For population, we use household size, which is analogous to population size in macro- and meso-level analyses (see Adua et al 2016). We did not think it makes substantive and intuitive sense to include state population as a predictor of household-level energy consumption. It is difficult to consider any process(es) linking these two variables. Indeed, empirical checks returned statistically non-significant relationship between state population and households’ residential energy consumption.
resource utilization, and this influence, in some instances, strengthens as level of affluence increases.

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