Journal of Economic Behavior & Organization 107 (2014) 269–289

Contents lists available at ScienceDirect

Journal of Economic Behavior & Organization

journal homepage: www.elsevier.com/locate/jebo

California energy efficiency: Lessons for the rest of the world, or not?

Arik Levinson[a,b,*]

[a] Georgetown Economics Department, United States
[b] NBER, United States

ARTICLE INFO

Article history:
Received 17 October 2013
Received in revised form 26 March 2014
Accepted 9 April 2014
Available online 26 April 2014

Keywords:
Energy efficiency
Regulations
Decomposition

ABSTRACT

Since the 1970s California's residential electricity consumption per capita has stopped increasing while other states' electricity use continued to grow steadily. What accounts for California's apparent savings? Some credit the strict energy efficiency standards for buildings and appliances enacted by California in the mid-1970s. They argue that the growing gap between California and other states demonstrates that other states and countries could replicate California's gains by adopting California-style regulations, and that California should build on its own success by tightening its standards further. Skeptics might point to three long-run trends that differentiate California's electricity demand from other states: (1) shifting of the U.S. population toward warmer climates of the South and West; (2) relatively small income elasticity of energy demand in California's temperate climate; and (3) evolving differences between the demographics of households in California and other states. Today, differences in climate and demographics account for almost 90 percent of the difference between California's and other states' residential electricity use. That difference thus provides no lessons for other states or countries considering adopting or tightening their own energy efficiency standards.

1. Introduction

For the past 40 years, residential electricity consumption per capita has remained nearly constant in California while growing by 75 percent in the rest of the United States. These starkly different trends, plotted in Fig. 1, serve as a key piece of evidence supporting the types of government-mandated energy-efficiency policies California implemented in the 1970s. Yet the figure by itself does not reveal the reason for California's slower-growing electricity consumption or whether that slowdown could be replicated by other states or countries adopting California-style regulations.

Proponents of regulations give credit for California's apparent savings to the California Energy Commission (CEC), which set the nation's first energy efficiency standards for appliances and buildings, and to the California Public Utility Commission (CPUC), which led the country in decoupling utility profits from sales of electricity and natural gas (Rosenfeld and Poskanzer, 2009). In addition to being the first state to set energy standards, California has maintained its lead. The most recent "State Energy Efficiency Scorecard" (ACEEE, 2012) ranks California as the best in the nation for its appliance standards and tied for first place with five other states in its building codes. And Palmer et al. (2012) ranks California's energy efficiency resource standard as the ninth most comprehensive among the 19 states with such standards. So there's no doubt that California

* Correspondence to: Georgetown Economics Department, United States. Tel.: +1 2026875571.
E-mail address: aml6@georgetown.edu

http://dx.doi.org/10.1016/j.jebo.2014.04.014

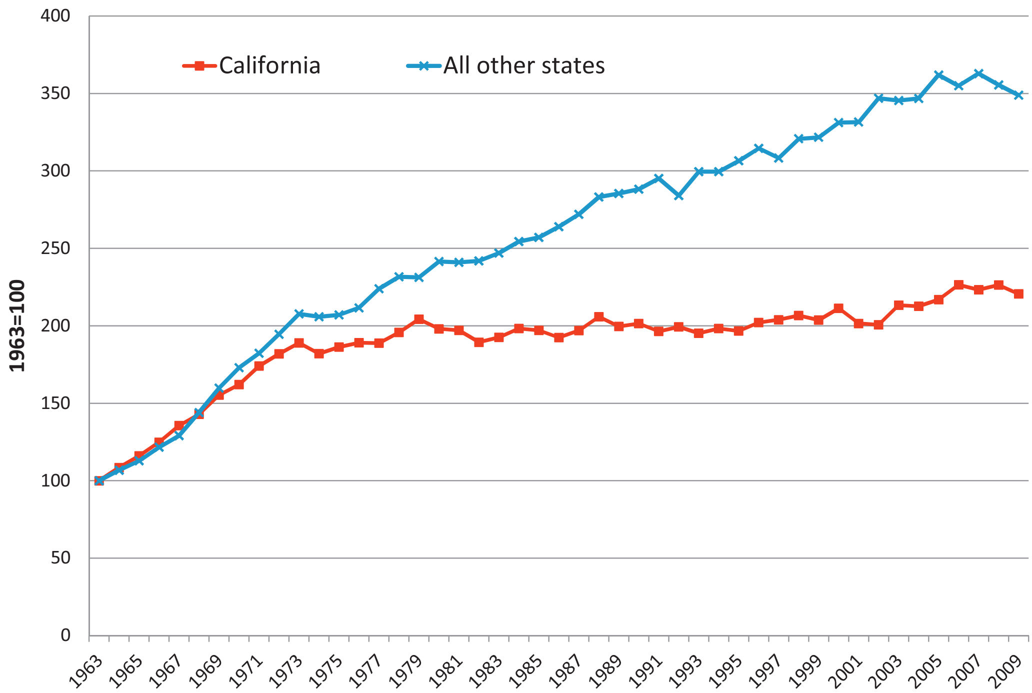

Fig. 1. Residential electricity use per capita 1963–2009.

has some of the longest-standing and most stringent energy efficiency policies. What we do not know, however, is what California has gained from those policies.

Unfortunately, the highest-profile piece of evidence for the efficacy of California's energy policy is Fig. 1, a simple comparison of residential electricity consumption per capita in California and other states. California regulators claim that "because of its energy efficiency standards and program investments, electricity use per person in California has remained relatively stable over the past 30 years, while nationwide electricity use has increased."[1] U.S. Energy Secretary Steven Chu attributes California's savings to its "progressive energy policies."[2] The Natural Resources Defense Council asserts that California's policies "offer lessons to states and utilities outside California" (Ettenson, 2011). And the World Bank devoted an entire page of its 2010 *World Development Report* to California and a reproduction of Fig. 1 as a lesson for the rest of the world. In this view, other states and countries could achieve California-sized energy savings by adopting California-style regulations.

There are, however, reasons to be skeptical about attributing California's apparent residential electricity savings in Fig. 1 to regulatory changes. First, appliance manufacturers quickly began meeting California's energy efficiency standards nationwide, rather than designing and producing two sets of products. Second, other states and the federal government soon followed California's lead, in some cases mimicking or adopting California's standards outright. Third, California's relative savings, depicted by the bottom line in Fig. 2, appear as a trend that began before 1970, long before the state's regulations took effect, and continued steadily through periods of high and low energy prices. And fourth, the five other states with the lowest per-capita growth in residential electricity use, also depicted in Fig. 2, are California's western neighbors: Nevada, Oregon, Washington, Idaho, and Hawaii.[3] All of this suggests the high-profile Fig. 1 may be the result of geographic and demographic trends unrelated to regulations.

If regulations do not deserve credit for California's declining relative electricity consumption, what can? This paper investigates three hypotheses: population migration, climate, and demographics.[4] First: migration. Over the past fifty years, the United States population has shifted from the North and East to the warmer and more air-conditioned South and Southwest, leading to higher electricity consumption in the comparison group, "other states." Second: climate. California's mild climate means that five decades of income and home size growth nationwide has translated into less increased heating and cooling in California than in other states. And third: demographics. Household sizes have shrunk less in California than in the rest of the country, so that California households have gained on average 0.6 members relative to households in other states. Since energy use per capita declines with household size, Californians' electricity use has increased less than that in

[1] California Public Utilities Commission and California Energy Commission, "Energy Efficiency: California's Highest-Priority Resource" June 2006.
[2] Steven Chu interviewed by Larry Klein and published in NOVA Online January 20, 2009. (www.pbs.org/wgbh/nova/tech/energy-secretary-chu.html).
[3] Chong (2012) makes a similar point.
[4] These have been proposed by others. See Tanton (2008), Clemente (2011), Mitchell et al. (2009), and Sudarshan (2013).

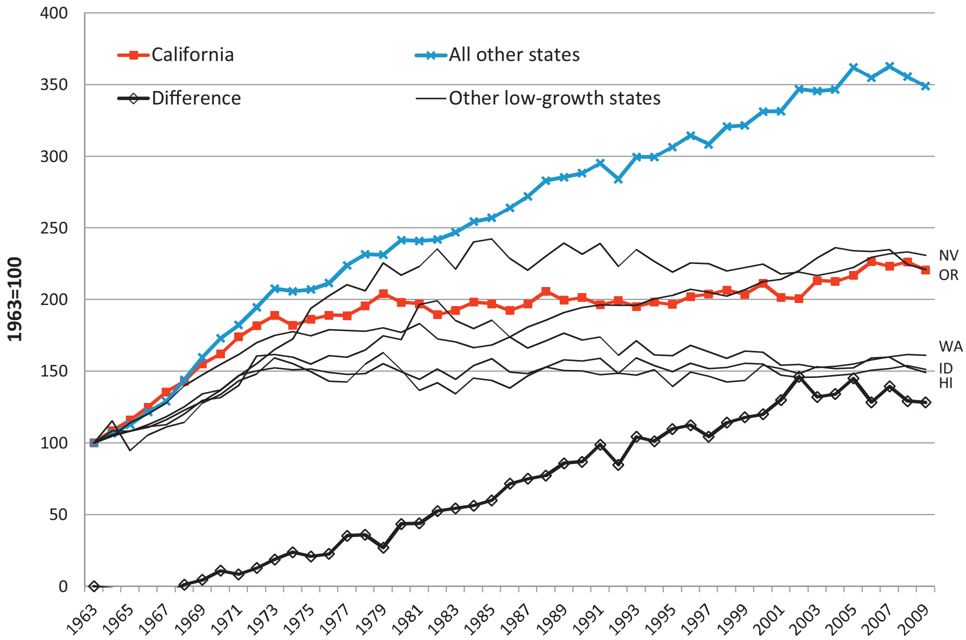

Fig. 2. Reasons to be suspicious.

other states. In this skeptical view, California's declining relative energy consumption has been coincidental, has little to do with regulatory decisions the state made in the 1970s, and cannot be replicated by other states or nations.

In the end, the widely cited Fig. 1 turns out to be uninformative. Fifteen percent of the gap between California's and other states' residential electricity growth, depicted in Fig. 1, can be explained entirely by migration of the U.S. population to the South and West where electricity use is higher, ignoring all other simultaneous trends. Twenty percent can be explained by growth in average household income, combined with the fact that income growth translates into a smaller increase in electricity use where the climate is milder as in California, again ignoring all other trends. And 40 percent can be explained solely by the fact the California household sizes shrank less than those in other states. Combining these factors and others, and accounting for interactions among them, nearly 90 percent of the gap between residential electricity consumption in California and other states in 2009 can be explained by the differences that are unrelated to California's regulations.

The question posed here, how much of California's relative energy savings can be explained by coincidental trends rather than regulations, takes on increasing importance as both California and federal regulators propose tightening energy efficiency standards even further. California's Global Warming Solutions Act of 2006 aims to reduce greenhouse gas emissions in the state to 1990 levels by 2020; 18 percent of those reductions are expected to come from new, stricter energy efficiency standards for buildings and utilities, and another 26 percent from stricter standards for vehicles (CARB, 2008, p.17). Massachusetts's Global Warming Solutions Act of 2008 proposes to reduce GHG emissions in that state by 27 percent below its 1990 levels; 36 percent of those gains are projected to come from energy efficiency improvements to buildings and appliances.[5] And similarly the climate bill that passed the U.S. House of Representatives in 2009 would have required substantially increased energy efficiency from new buildings, appliances, and vehicles.

This paper is not the first to attempt to assess the cause of California's energy efficiency gains, but the approach I take is somewhat new. I do not take a bottom-up engineering approach typical of regulatory impact analyses conducted by government agencies proposing efficiency standards. Those analyses typically disregard consumers' reactions to changes in energy efficiency. One potentially important reaction would be to use more energy – the Jevons paradox or "rebound effect." Standards that make appliances and buildings more energy efficient lower the cost of energy services, which may in turn increase energy consumption and offset some of the mandated efficiency gains. If bottom-up analyses assume that a regulation requiring air conditioners to be 30 percent more energy efficient will result in 30 percent less energy consumption, those analyses will overstate the energy-per-capita savings resulting from the regulation.

Nor do I take a completely top-down approach and try to work all of the explanations into one comprehensive model, such as a regression framework where multiple state characteristics explain state energy consumption. Mitchell et al. (2009), for example, discusses a regression of per capita energy use on energy efficiency standards and other state characteristics, finding that only 20 percent of California's per capita energy savings come from the standards. But that type of approach is sensitive to the choice of functional form and complicated by interaction effects among the various external factors. An increasingly less energy intensive industrial base might drive down the relative price of electricity and increase consumer demand. An

[5] Massachusetts Secretary of Energy and Environmental Affairs, 2010, p. ES-6.

increasing share of immigrants in the population has changed California's household size and income distribution, with different effects on energy consumption. Costa and Kahn (2010) regresses electricity consumption on house and household characteristics for customers of a California utility from 2000 to 2009. That approach provides an excellent characterization of California households' current electricity consumption, but less information about how that consumption compares to other states or has changed since the 1960s.

Instead of a bottom-up or top-down model, this paper has a somewhat unusual structure. Sections 2 and 3 explore the individual explanations separately – migration, climate and demographics – ignoring their interactions with one another. I recognize that each separate analysis therefore omits correlated trends: states with higher per capita electricity use experienced disproportionate population growth as well as differential changes in income and other household characteristics. But the power of Fig. 1 derives from its simplicity. To confront that appealingly simple figure, I have found it worthwhile to use correspondingly simple analyses, demonstrating the fraction of the gap in Fig. 1 that can be explained by migration, climate, and demographics in turn and alone, while recognizing that the separate analyses cannot be summed without considering their interactions. Section 4 then combines them all in a Oaxaca–Blinder decomposition that does account for the interactions, and there I find that nearly 90 percent of the difference between residential electricity consumption per capita in California and other states in 2009 can be explained by household characteristics not targeted by California's regulations. In the final section I briefly discuss two other major energy-using sectors, manufacturing and transportation, with smaller apparent percentage savings but larger shares of states' overall energy budgets. But mainly I focus on the sector featured in Fig. 1 and numerous campaigns to promote mandated efficiency standards: residential electricity.

1.1. An aside: electricity prices

Many readers of early versions of this paper noted that I ignore prices, an odd omission for an economist. Those readers are correct but the omission is intentional. If the goal of this paper were to demonstrate the efficacy of California's energy efficiency *standards*, holding all else equal, controlling for prices would be essential . . . and conceptually difficult. California has both tighter standards and higher prices than other states, and sorting out which is responsible for California's slower electricity growth would be tricky. We cannot simply regress energy demand on household characteristics and prices, because energy demand presumably affects the choice of those household characteristics.[6] In this project I have tackled a far simpler goal, showing that Fig. 1 does *not* demonstrate the efficacy of California's standards. To do that I merely provide alternative explanations for California's relative decline in residential electricity consumption – population shifts, climate, and demographics. Demonstrating those alternative explanations' contribution to California's energy demand is comparatively easy, because they are plausibly exogenous – not themselves determined by California's policies.

If California's apparent savings come from its high electricity prices, that outcome would appeal to economists. For one, high prices would more cost-effectively target efficiency savings. A homeowner remodeling a basement room would be inclined to spend more on energy efficiency the more frequently that room is used and the harsher the local climate. And furthermore, those price policies would be replicable by other states and countries. Any jurisdiction could tax energy and reproduce California's savings. So while some have dismissed Fig. 1 as being merely the result of California's energy prices, I would argue that (a) that would be a positive finding rather than a negative, but (b) most of Fig. 1 is explained by geographic and demographic differences unrelated to either efficiency standards or prices.

To satisfy the curious, since 1970 retail electricity prices have grown by 14 percent in real terms in California, while falling by 9 percent in the U.S. overall (DOE/EIA, 2011). That may well result in Californians using relatively less electricity, because Californians respond to the price either by purchasing more efficient homes and appliances or by purchasing smaller homes and using those appliances less. Either outcome could be described as a successful and replicable policy achieving a goal of reducing energy consumption through higher prices. Nothing in this paper supports or refutes that claim. I return to this issue briefly in the conclusion.

1.2. Another aside: energy savings in other sectors

Although residential electricity has been the focus of claims about the success of regulatory policy, figures similar to Fig. 1 drawn for other energy uses show similar patterns. Table 1 makes this point. The top row of Table 1 displays the data for California's total energy consumption, which was 217 Million BTU (MBTU) per capita in 2009. If California energy use had grown at the same rate as other states in *percentage terms*, it would have been 269 MBTU per capita in 2009; if California energy use had grown at the same rate in *absolute terms*, it would have been 283 MBTU.[7] The difference, 52 or 66 MBTU in columns (5) and (6) of Table 1, means that total energy consumption in California fell 19 or 23 percent relative to those other states. Had the rest of the country mimicked California's trajectory, total national energy consumption by 2009 would have

[6] Jacobsen and Kotchen (2013) and Aroonruengsawat et al. (2012) have made recent attempts at answering this more difficult question.

[7] Since California had lower per-capita energy consumption than other states in 1963, an equal proportional increase in California's energy use would result in a smaller absolute increase.

Table 1
California per capita energy savings relative to other US states 1963–2009.

	Actual 2009 CA consumption		Predicted 2009 consumption based on other states' energy growth		Apparent savings 1963–2009	
	MBTU	Share of total	From % growth MBTU	From absolute growth MBTU	From % growth MBTU	From absolute growth MBTU
	(1)	(2)	(3)	(4)	(5) [(3) − (1)]	(6) [(4) − (1)]
All energy	216.6	1.00	268.7	282.5	52.1 (19%)	65.9 (23%)
Retail electricity	24.0	0.11	38.1	43.8	14.1 (37%)	19.9 (45%)
Residential	8.3	0.04	13.0	16.0	4.7 (36%)	7.7 (48%)
Commercial	11.2	0.05	23.5	18.2	12.3 (52%)	7.0 (39%)
Industrial	4.4	0.02	6.1	8.0	1.7 (27%)	3.6 (45%)
All other energy	192.6	0.89	231.8	238.7	39.2 (17%)	46.1 (19%)
Residential	33.0	0.15	41.7	44.0	8.6 (21%)	11.0 (25%)
Commercial	31.5	0.15	45.7	47.5	14.2 (31%)	16.0 (34%)
Industrial	43.5	0.20	53.6	40.3	10.2 (19%)	−3.2 (−8%)
Transport	84.6	0.39	112.6	108.5	28.0 (25%)	23.9 (22%)

Source: Calculations using data from US Energy Information Administration (EIA).
Note: Shares of savings do not sum to totals because the shares of consumption in California changed relative to other states. From 1963 to 2009, retail electricity grew from 6 to 11 percent of total energy consumption in California, and from 6 to 13 percent in other states.

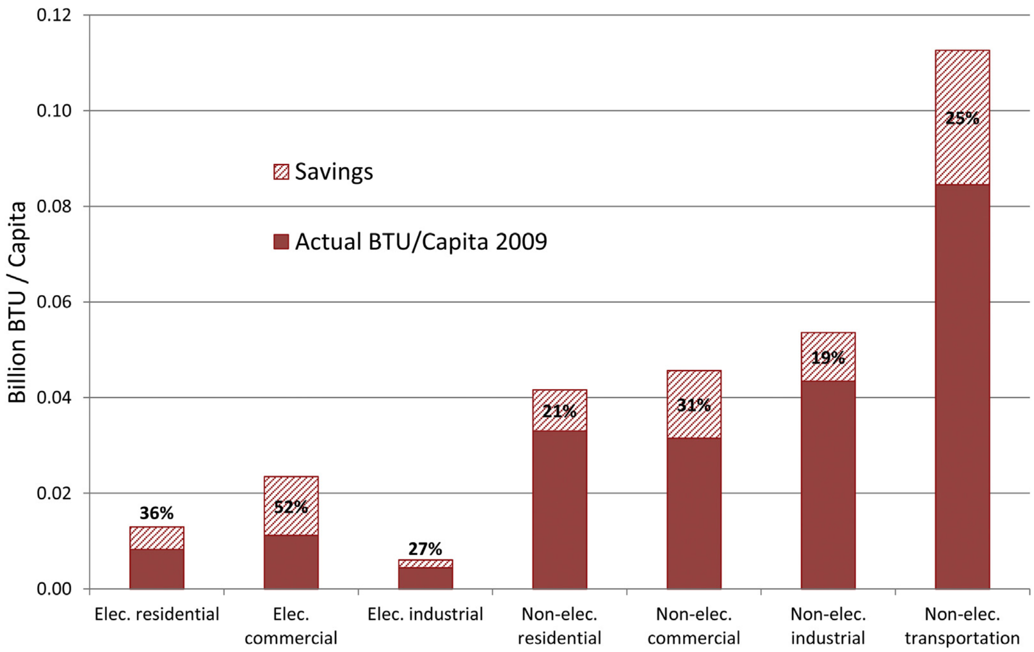

Fig. 3. California energy savings 1963–2009.

been lower by an amount sufficient to achieve the Obama Administration's goal of reducing U.S. greenhouse gas emissions to 17 percent below 2005 levels by 2020.[8]

Fig. 3 graphs these calculations, using the data from columns (1) and (5) of Table 1. The height of each column represents what each sector's per capita energy consumption would have been in 2009 in California had it changed by the same percentage as in other states since 1963. The height of the solid portion of each column represents California's actual consumption in 2009. The difference, cross-hatched in the figure, represents California's per capita savings from each sector relative to national energy use.

Table 1 and Fig. 3 make two important points. First, all sectors contributed to the relative decline in California's energy consumption per capita. Even sectors where per capita consumption grew substantially in California, such as transportation

[8] Energy use accounted for 87 percent of U.S. greenhouse gas emissions in 2009 (EPA, 2011, p. 3-1), and 20 percent reduction of 87 is just over 17 percent.

Table 2
Population shifts and energy consumption per capita 1963–2009.

	Other states' energy growth		Difference without migration	Share of Savings from Columns (5) and (6) of Table 1 [a]		Correlation (state population growth, average energy per capita)
	MBTU	%	MBTU	From % change	From absolute difference	
	(1)	(2)	(3)	(4)	(5)	(6)
Residential						
Electricity	11.5	248.9	0.70	0.15	0.09	0.093
Other energy	6.4	12.9	−1.28	−0.15	−0.12	−0.418
Commercial						
Electricity	11.6	336.7	0.21	0.02	0.03	0.039
Other energy	21.3	88.1	−1.00	−0.07	−0.06	−0.205

Source: Calculations based on US Energy Information Administration (EIA), State Energy Data Systems. (www.eia.gov/state/seds).
[a] Applies the share in columns (5) and (6) to the savings in Table 1.

and commercial energy, consumption grew faster in other states. Second, sectors with the most dramatic apparent savings – residential and commercial electricity – account for a relatively small fraction of overall savings because they represent a small part of states' energy budgets. In the end, how much each sector *really* contributes to energy efficiency savings depends on how much of those savings comes from energy efficiency and how much comes from other factors driving energy consumption, including geography and climate, household demographics, industrial composition, and transportation patterns.

2. Residential electricity: population shifts, climate, and the income elasticity of heating and cooling

Fig. 1 shows that from 1963 to 2009, residential electricity consumption per capita grew by 120 percent in California and 245 percent in other states. Skeptics of regulations as an explanation for the difference offer three main alternatives. First, the U.S. population shifted from the North and East to the South and West, driving up per-capita demand for air conditioning and electricity in states other than California. Second, even if the population had not moved, household incomes grew. Because California has a mild climate, the income elasticity of demand for space heating and cooling is lower there and energy consumption grew less. In this section, I discuss these first two explanations in turn. In the following section I discuss a third explanation; California household characteristics changed relative to other states, and with those changes came declines in energy consumption per capita.

2.1. Population shifts

Since 1963 the population of the Northeast and Midwest grew by 23 percent, while the South grew 96 percent, the West 130 percent, and the Mountain West 190 percent. This disproportionate growth in regions with different patterns of energy use could be one reason why California's energy consumption per capita fell behind that of other states.

The simplest way of assessing how population shifts contributed to California's apparent energy savings is to create a version of Fig. 1 that holds the populations of the other states fixed. Fig. 1 compares California's energy consumption per capita to energy consumption per capita in all other states combined:

$$\theta_t = \frac{1}{P'_t} \sum_{s \neq CA} \theta_{st} P_{st}$$

where θ_t is the energy use per capita in year t in states other than California, P'_t is the total population of the other, non-California, states, and θ_{st} represents the energy consumption per capita of state s in year t, or $\theta_{st} = E_{st}/P_{st}$. This measure, θ_t, is simply the weighted average of other states' energy use per capita, where the weights are the other states' populations. It is plotted as the top line in Fig. 1 and changes over time because of changes in various states' energy intensities (θ_{st}) *and* state populations (P_{st}).

Instead consider holding population fixed. Compare California's energy intensity to a weighted average of other states' individual energy consumption per capita each year, where the weights are each state's population *in 1963*:

$$\hat{\theta}_t = \frac{1}{P'_{63} \sum_{s \neq CA} \theta_{st} P_{s,63}} \qquad (1)$$

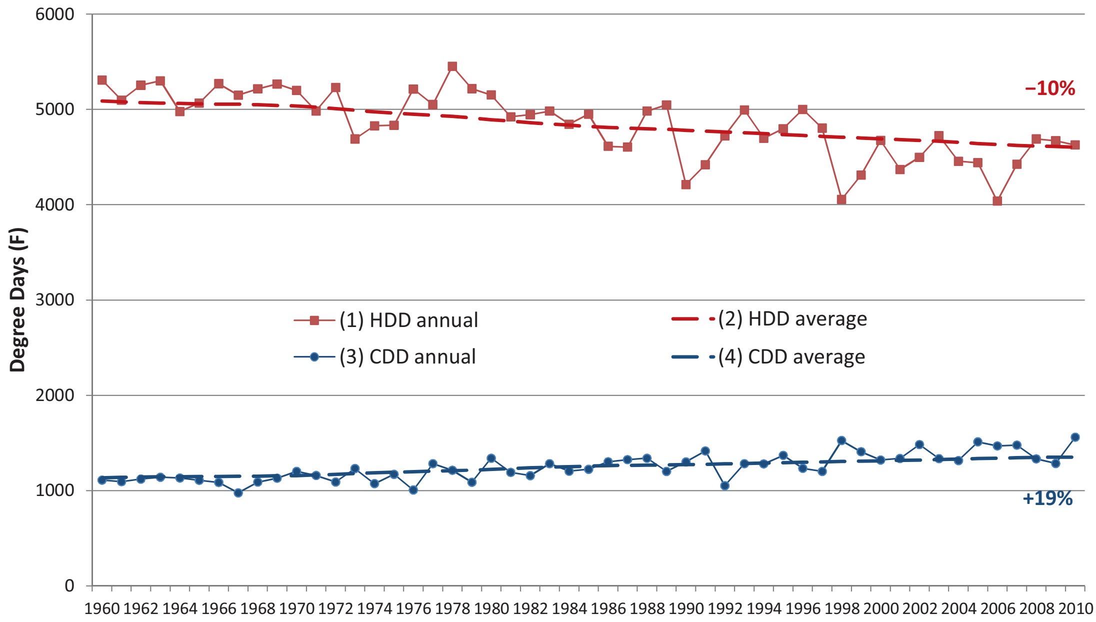

Fig. 4. Population-weighted heating and cooling degree days 48 contiguous states aside from California.

This measure changes over time only because energy consumption per capita changes. It describes what would have happened had the population of the U.S. not shifted toward the Southwest, but other states' energy consumption changed. Between 1963 and 2009 $\hat{\theta}$ grew by 234 percent, a bit less other states' actual consumption, and this adjustment accounts for 15 percent of the gap between other states' and California's consumption depicted in Fig. 1.

Table 2 summarizes this calculation for residential electricity and several other relevant categories of energy use. From 1963 to 2009 other states' residential electricity consumption grew 11.5 MBTU per capita, or 249 percent. Without migration, other states' consumption ($\hat{\theta}$) would have grown 0.7 MBTU less. That difference accounts for 15 percent of California's apparent 4.7 MBTU of savings as calculated from other states *percentage* growth over the period, or 9 percent of California's apparent 7.7 MBTU of savings calculated from other states' *absolute* growth.

For residential non-electric energy use, however, in the second row of Table 2, the pattern is reversed. Without migration, other states' consumption per capita would have grown 7.7 MBTU per capita rather than the actual 6.4 MBTU, or 1.28 MBTU more. The U.S. population shifted to states that use *less* non-electric residential energy. Rather than explaining California's apparent non-electric energy savings documented in Table 1 and Fig. 3, migration and geography mask some of those savings.

The final column of Table 2 helps explain this difference. It reports the correlation across all 50 states plus the District of Columbia between each jurisdiction's population growth and the various measures of energy intensity, averaged across the time period. That correlation is 0.093 for residential electricity because population grew more in states with higher average residential electricity consumption per capita. Hence migration helps explain 9–15 percent of California's apparent savings relative to the rest of the United States. The correlation is −0.42 for residential non-electric energy because the population grew more in states with lower average non-electric energy consumption per capita. So migration masks 12–15 percent of California's savings in this category.

The bottom panel of Table 2 presents the same calculation for commercial buildings such as offices, hospitals, hotels, and universities. Most of this sector's energy use comes from space heating, cooling, and lighting, and so it follows the same geographic pattern as residential energy. Two or three percent of California's commercial buildings' electricity savings are explained by population shifts in other states, and that is offset by a 6 or 7 percent swing in the other direction for non-electric energy. The reason the commercial sector's population-related swings are smaller than the residential sector's is also apparent from column (6). State commercial energy use per capita is less strongly correlated with state population growth.

A likely explanation for these patterns is climate. Residences and commercial buildings use electric energy for air conditioning in the Southwest and non-electric energy for space heating in the Northeast. The population shift from Northeast to Southwest has increased demand for residential and commercial electricity nationwide, and decreased demand for other categories of residential and commercial energy. As a result, California's residential and commercial electricity consumption per capita has grown more slowly than in the rest of the United States, and other energy consumption has grown more quickly.

2.1.1. Population shifts and climate

This climate-related explanation for California's efficiency gains can be examined separately. Line (1) of Fig. 4 plots the weighted average number of heating degree days in the 48 contiguous U.S. states other than California, where the weights are the states' populations in each year:

$$HDD(1)_t = \frac{1}{P'_t} \sum_{s \neq CA} HDD_{s,t} \times P_{s,t}$$

where $HDD_{s,t}$ is the heating degree days in state s in year t.[9] This calculation changes year-to-year because of both temperature changes and population changes. Line (2) uses the average number of heating degree days for the entire period for each state:

$$HDD(2)_t = \frac{1}{P'_t} \sum_{s \neq CA} \overline{HDD}_s \times P_{s,t}$$

where $\overline{HDD}_s$ is the average number of heating degree days for state s from 1960 to 2010. Its smooth decline results from population changes alone. The average number of heating degree days experienced by a typical non-California American has declined 10 percent, simply because the population has shifted out of the colder Northeast and Midwest.

The bottom two lines in Fig. 4 plot cooling degree days in an analogous way. The average number of cooling degree days experienced by a typical non-California American has *increased* by 19 percent, again simply because the population has shifted to warmer regions. A similar graph for California would show heating degree days flat at 2600 per year, and cooling degree days flat at 900 per year.

To sum up the analysis at this point, geographic shifts in the U.S. population have increased residential electricity demand, largely due to the increased cooling degree days experienced by the average American outside of California. This means that the average electricity consumption in other states serves as a poor comparison group for California, and that Fig. 1 overstates California's relative savings because residential electricity use per capita in other states increased for reasons unrelated to California's regulations.

2.1.2. One more aside: internal migration in California

Some readers of earlier versions of this paper noted that California has had its own internal migration over the past 50 years, and that if the state's population has shifted to warmer regions or regions that use more electricity per capita, that might offset my claim that 15 percent of California's apparent savings come from migration among other states. To address that concern, I conducted an analysis for counties within California similar to the one that Eq. (1) estimates for states within the U.S.

$$\hat{\theta}_t^{CA} = \frac{1}{P_t^{CA}} \sum_c \theta_{c,1990} P_{c,t} \tag{2}$$

Eq. (2) calculates the weighted average per capita residential electricity consumption in California ($\hat{\theta}_t^{CA}$), where the weights are the counties' populations in each decennial census from 1960 to 2010. Subscript t refers to those census years, and subscript c refers to counties. The earliest year for which I could find electricity per capita at the county level was 1990.[10]

Accounting for California's internal migration in this way, per capita residential electricity would be predicted to have *declined* by 58 percent. Even though more Californians live in warmer parts of the state where air conditioning is more desirable, those are poorer parts of the state where electricity consumption per capita is on average lower. Ignoring other demographic trends, migration to states that use more residential electricity has inflated the top line of Fig. 1, while migration to counties in California that use less electricity understates the bottom line of Fig. 1. Together they exaggerate California's apparent savings.

But as noted, this analysis is too simple, because other factors are changing at the same time. Migration and income and other demographic changes are correlated. In particular, there is a second climate-related explanation for California's residential energy savings. Even if the population had not moved disproportionately to states with different patterns of energy use, residential energy consumption might have increased nationwide simply because space heating and cooling are normal goods and household incomes have risen. That trend would matter less in California, where the relatively mild climate means that income elasticities of heating and cooling are smaller. California may have thus avoided some of the increased energy consumption associated with income growth in less temperate states.

[9] A degree day is the difference between the average of the daily maximum and minimum temperatures and 65 °F. A heating degree day occurs when that average temperature is less than 65°, and a cooling degree when it is greater than 65°.

[10] California county populations by decennial Census come from the U.S. Census Bureau. Residential electricity consumption data by California county back to 1990 were provided by staff at the California Energy Commission.

Table 3
Household electricity consumption per household member predicted by climate and income.

Dependent variable: 1000 BTUs per person	Means (1)	Coefficients (2)
HDD	4338	0.08
	(1647)	(0.12)
CDD	1363	4.73*
	(663)	(0.30)
Household income	53.1	−52.0*
($1000s 2010)	(37.2)	(13.1)
HDD × income		0.0112*
		(0.0018)
CDD × income		0.0386*
		(0.0045)
Household size	2.66	−3510*
	(1.49)	(44)
Trend		139*
		(10)
Constant		11,073*
		(1018)
Mean and std. dev. of dependent variable	16,530	
	(12,888)	
Observations = 34,292		$R^2 = 0.24$
Marginal effects		
Income at mean HDD and CDD		49.2
HDD at mean income		0.68
CDD at mean income		6.8

Source: Residential Energy Consumption Surveys: 1993, 1997, 2001, 2005, 2009.
Robust standard errors in parentheses.
* Statistically significant at 5 percent.

2.2. Climate and income

To test whether energy demand is less income elastic in California than in other states, and whether this is due to California's mild climate, I regress energy use on regional climate as measured by average heating and cooling degree days, household income, and the interaction between the two.

$$BTU_i = \alpha + \beta_1\overline{HDD}_i + \beta_2\overline{CDD}_i + \beta_3(income_i) + \beta_4\overline{HDD}_i \times (income_i) + \beta_5\overline{CDD}_i \times (income_i) + \beta_6 h'\,holdsize_i + \beta_7 trend_i + \sum_d \delta_d D_i + \epsilon_i \quad (3)$$

Eq. (3) cannot be estimated with the aggregate state data used in the previous sections, because aggregate state incomes only differ across years and it is not possible to separately identify income growth from the other trends that influence residential energy use. Instead, I need to use household data, so that I can compare energy use by households with different incomes, in the same year and place, and then to forecast how much energy use increases with income, and how that increase might differ in California's mild climate. For that I turn to the Residential Energy Consumption Survey (RECS). The RECS does not identify individual states, except a few large ones including California, but does identify nine census divisions, so in Eq. (3) $\overline{HDD}$ and $\overline{CDD}$ refer to the average annual HDD and CDD in household i's census division, and δ_d refers to fixed effects by census division. I include household size as the one extra demographic covariate.

Table 3 contains an estimate of Eq. (3). Marginal effects at the bottom of the table are calculated from interaction coefficients at the means of right-hand-side variables. Electricity use increases with household income at the mean levels of HDD and CDD, and electricity use increases faster with income in hotter areas (higher CDD). The coefficient on cooling days and its interaction with income, for example, suggests that an extra 100 cooling degree days (or 10 days of 10-degree hotter weather) is associated with an extra 680 BTUs of electricity use for a household with the mean income, or about 4 percent.[11]

Table 4 reports the magnitude of these effects. Using the point estimates in Table 3, an extra $1000 of income increases per capita electricity consumption for the average household by 11,900 BTUs in California and 50,200 BTUs in other states.[12] Income growth adds less to California's residential electricity demand than to other states because of California's mild climate. How large is this effect? From 1963 to 2009, real mean household income in the United States grew by more than 50

[11] $680 = 100 \times (4.73 + 0.0386 \times 53.1)$.
[12] For California: $11.9 = 1 \times (-52.02 + 0.0112 \times (2601\text{ HDDs}) + 0.0386 \times (901\text{ CDDs}))$.

Table 4
Predicted increase in residential electricity per capita from a $1000 increase in household income (2010 dollars).

	Average HDD	Average CDD	Predicted Electricity Increase (1000 BTUs/person)
	(1)	(2)	(3)
California	2601	901	11.9
Other states	4830	1248	50.2
Absolute diff (1000 BTUs/capita)			38.4
Difference for a $25,000 income increase			959.0
Share of apparent 4.7 MBTU savings			20.4%

Uses regression coefficients in Table 3.
The underlines signify the value below the line is the "difference" between the two lines above.

percent, from $44 thousand to $69 thousand. Applying the predictions from Tables 3 and 4, this would increase electricity use per capita by 959,000 BTUs in California relative to other states. Recall from Table 1 that California appears to have saved 4.7 MBTU per capita of residential electricity relative to other states. It seems that a significant fraction – around 20 percent – of those savings come from California's mild climate and low income elasticity of energy consumption. This calculation is reported in the bottom rows of Table 4.

The first of the skeptical explanations is that California's apparent residential electricity savings come from the particular geography of the United States combined with regional patterns of population shifts and California's mild climate. Fig. 1 suggests that since 1963 California has saved 4.7 MBTU of residential electricity per capita relative to other states. The calculations in this section indicate that part of those savings is illusory: 15 percent can be explained by the U.S. population shift to warmer climates that use more air conditioning and 20 percent by the fact that income growth in California's mild climate has not led to more air conditioning.[13] In the next section I explore a third explanation for Fig. 1: differences between the demographic changes in California and in other U.S. states.

3. Residential electricity: population and housing characteristics

California's and other states' demographics and housing characteristics have changed in different ways during the past 50 years. Some of those differences, documented in Table 5, are stark.[14] Household incomes grew nationwide, but by 26 percent less in California relative to other states. The number of occupants per home fell nationwide, but fell by 0.6 fewer in California.

In considering how these demographic changes might affect energy consumption and explain California's apparent savings, we need to be careful as to which characteristics are exogenous and not replicable elsewhere, compared with those that may be driven by policy, either intentionally or not. For example, the number of children living in the average household fell throughout the U.S., but fell less quickly in California. Over the past 50 years, the average California household *gained* 0.23 children relative to other states' households. This change in household size could have implications for energy consumption, but it seems unlikely that energy regulations caused those fertility changes and implausible that states would use fertility policies as a mechanism for energy savings. On the other hand, while house sizes have been growing throughout the U.S., the number of rooms in the typical California home *fell* over the past 50 years relative to the number of rooms in homes in other states. Perhaps regulations have been indirectly responsible for part of the slowing growth of California home sizes, and if they have that would in principle be a mechanism that other states or countries could replicate. Smaller homes do use less energy, but home size reduction has not been advertised as an objective of energy efficiency regulations.

Begin by singling out one important characteristic, household size, in the seventh row of Table 5. In 1960 the average California house had 3.19 people living in it; by 2009 that had fallen to 3.03. During the same time period in other states household sizes fell from 3.43 to 2.67. Although average household sizes fell everywhere, they fell more slowly in California. California went from having smaller average household sizes than other states in 1960 to having larger sizes in 2009, gaining 0.6 members relative to households in other states.

California's growing relative household size matters because energy use per capita shrinks with household sizes. Examine Fig. 5. While electricity use increases with the number of people in the home, it does so at a decreasing rate. As a consequence, electricity use per household member, or *per capita*, declines with household size. On average, an additional 0.6 household members in the RECS is associated with 1.9 fewer MBTUs of annual electricity use per household member.[15] Recall from Table 1 that California's apparent savings, depicted in Fig. 1, amount to 4.7 MBTUs per person. Household size alone, without accounting for any other demographic differences between California and other states, explains 40 percent of California's apparent savings. For non-electric energy, the household-size explanation is even larger. An additional 0.6

[13] Recall that the analyses so far cannot simply be summed, because each ignores the other and they are almost certainly correlated. Section 4 combines all of the observable non-regulatory factors driving electricity use in one analysis.
[14] Some statistics come from the decennial U.S. Census and are only available for 1960, which is why columns (1) and (4) are labeled "1960–1963".
[15] Based on a regression of energy per household member on a cubic in household size (plotted in Fig. 5).

Table 5
Housing, climate, and household characteristics.

	California			Other US states			CA change relative to other states	RECS averages 1993–2009
	1960–1963	2009	Change	1960–1963	2009	Change		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Residential electricity per capita[g] (MBTU)	3.76	8.29	+4.53	4.98	17.21	+12.22	−7.70	16.5
Residential other energy per capita[g] (MBTU)	35.56	33.03	−3.53	53.21	60.65	+7.44	−10.97	38.3
Population (1000s)[a]	17,668	36,962	+109%	171,632	270,521	+58%	+51%	
Real income per capita ($2010)[a]	$16,102	$38,834	+141%	$12,853	$35,091	+173%	−32%	$24,161
Real median household income ($2010)[f]	40,716	57,718	+$17,002 (41.8%)	37,723	63,133	+$28,410 (81.8%)	−$11,408 (−26%)	$43,197
Occupied housing units (1000s)[b]	4982	12,215	+145%	48,042	101,401	+111%	+34%	
Household size[b,c]	3.19	3.03	−0.16	3.43	2.67	−0.76	+0.60	2.66
Rooms per house[b]	4.49	5.20	+0.71	4.90	5.67	+0.77	−0.06	5.74
Bedrooms per house[b]	2.05	2.58	+0.53	2.26	2.70	+0.44	+0.08	2.72
Built pre-1950[e]	0.600	0.305	−0.295	0.738	0.312	−0.426	+0.131	0.230
Built post-1980[e]	–	0.369	–	–	0.417	–	−0.048	0.348
Owner occupied[b]	0.584	0.566	−0.018	0.622	0.670	+0.048	−0.066	0.671
Kids < 14[d]	0.956	0.624	−0.332	1.092	0.535	−0.557	+0.225	0.540
Cooling degree days (population wtd avg)	901	901	–	1145	1349	+17.8%	+17.8%	1363
Heating degree days (population wtd avg)	2601	2601	–	5066	4609	−9.0%	−9.0%	4337

[a] Bureau of Economic Analysis http://www.bea.gov/iTable/iTable.cfm?ReqID=70&step=1.
[b] 1960 Census of Housing, 2009 American Community Survey (ACS).
[c] Population/housing units in 1960 in Census and 2009 ACS.
[d] 1960 Census Table 45 (US) Table 16 (CA), ACS Demographic and Housing Estimates: 2009; Profile of General Population and Housing Characteristics (CA 2010 ACS).
[e] 1960 Census of Housing, Vol. 1 States and Small Areas, Part 1. United States, Table 5 (Ch. 4 p. 1-16); 2009 American Community Survey.
[f] 1960 Census: U.S. Ch. 5, p. 225, Table 95; CA p. 6-252, Table 66. 2010 American Community Survey. Median income for “other states” assumes distribution same in California and US.
1960 Census can be found at www.census.gov/prod/www/abs/decennial/1960.html.
[g] U.S. Energy Information Administration.

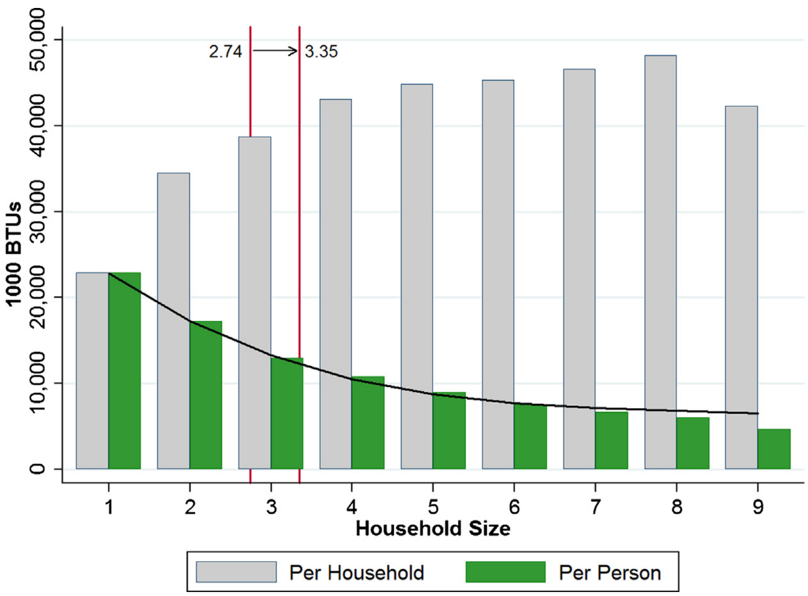

Fig. 5. Residential electricity use by household size.

Table 6
Residential energy use per household member.

Dependent variable: 1000 BTUs per capita	Means	Regression coefficients	
		Census variables	Other RECS variables
	(1)	(2)	(3)
HDD	4326	0.040	−0.17
	(2275)	(0.12)	(0.11)
CDD	1371	4.03*	2.95*
	(1037)	(0.28)	(0.27)
Household income ($1000s 2010)	54.4	−74.1*	−64.9*
	(37.4)	(12.6)	(12.0)
HDD × income		0.0077*	0.0045*
		(0.0017)	(0.0016)
CDD × income		0.0316*	0.0249*
		(0.0042)	(0.0041)
Household size	2.75	−4182*	−4259*
	(1.49)	(69)	(73)
Kids	0.54	451*	501*
	(0.96)	(68)	(70)
Rooms	5.80	1172*	647*
	(2.00)	(95)	(95)
Bedrooms	2.76	885*	333*
	(1.05)	(135)	(129)
Owner Occupied	0.67	1888*	−668*
		(149)	(167)
Built pre 1950	0.22	−2018*	−774*
		(153)	(151)
Built post 1980	0.36	928*	−502*
		(135)	(140)
Trend (1963 = 1)	39.3	91.7*	20.0*
	(6.4)	(9.2)	(9.1)
Rural, seniors, size, type, dishwasher, clothes washer, dryer, TVs, AC, pool		No	Yes
Constant		7750*	12,855*
		(964)	(965)
Mean and std. dev. of dependent variable	16,257		
	(12,592)		
Observations = 32,352		R^2 = 0.32	R^2 = 0.38

Source: Residential Energy Consumption Surveys: 1993, 1997, 2001, 2005, 2009.
Robust standard errors in parentheses.
* Statistically significant at 5 percent.

household members reduces non-electric energy use by 7.0 MBTUs per capita, or 81 percent of California's apparent savings of 8.6 MBTUs per capita.

Household size is only one of the demographic changes depicted in Table 5, and is certainly correlated with the others. To predict how all of the combined demographic changes affected residential energy use, I use the pooled 1993 through 2009 RECS to estimate a version of Eq. (3) in which the dependent variable is BTU per household member, and which includes additional demographic characteristics chosen to match those in Table 5: number of children, number of rooms and bedrooms, an indicator for owner occupation, and indicators for homes built pre-1950 and post-1980.

Table 6 presents results of this regression. Although the RECS contains information about many other household and demographic characteristics, in column (2) I limit the covariates to those available separately for California in the 1960 Census of Population and Housing, so that I can use the results to predict energy use changes over time due to the changing relative nature of California households. Key omitted variables include the size of the home in square feet and details about the home's energy-using appliances. To the extent those omitted variables are correlated with included measures such as the number of rooms in the home and the household income, the included measures will help predict those changes as well. In other words, in column (2) of Table 6 the "rooms" variable is correlated with higher energy use partly because houses with more rooms have more square feet of living space.

In general the coefficients in Table 6 conform to intuition. Household income increases electricity use at the mean levels of heating and cooling degree days. Large households use less energy per resident, and households with proportionally more kids use more energy per resident. Homes with more total rooms or proportionally more bedrooms use more energy. Older homes use less electricity.

In column (3) of Table 6 I add other home characteristics. The coefficients on the number of rooms and bedrooms shrink. Owner-occupancy is associated with more energy use in column (2), almost certainly because it is correlated with omitted home characteristics such as size in square feet, appliance use, and whether or not the home is an apartment. When other covariates are included in column (2) the coefficient on owner occupancy becomes negative. This makes more intuitive sense,

Table 7
California residential energy savings 1960–2009.

Household characteristic	Average	Electricity	
		Coeff. from Table 6	Predicted change (1000 BTUs)
	(1)	(2)	(3)
(1) EIA data			
Electricity/capita (1000 BTU)	11,374		−4705
(2) RECS data and predictions			
Real median household income ($2010)	−$11,408	2.7[a]	−31
Household size	+0.60	−4182	−2509
Rooms per house	−0.06	1172	−70
Bedrooms per house	+0.08	885	+71
Built pre-1950	+0.131	−2018	−264
Built post-1980	−0.048	928	−45
Owner occupied	−0.066	1888	−125
Kids < 14	+0.225	451	101
Total explained by Table 6 regressions			−2871
Percent of apparent savings explained by regressions [(1)/(2)]			61%

[a] The coefficient on income includes the coefficient on interactions with HDD and CDD in Table 6, multiplied by the means of HDD and CDD.

given that rental properties' tenants typically either do not pay their utility bills or do not choose their homes' appliances (Levinson and Niemann, 2004).

Table 7 combines the results in Table 6 with the relative changes in key household characteristics from Table 5. Real median household income in California *fell* by $11,408 relative to other states over the past 50 years. At the mean heating and cooling degree days, this would result in "savings" of 31 thousand BTUs per household member – a small amount relative to the average electricity consumption of 16.5 million BTUs in the RECS, or relative to California's apparent savings of 4.7 million BTUs of residential electricity per capita reported at the top of the table.[16] So California's apparent residential electricity savings are not an artifact of its relatively slower personal income growth. If income has anything to do with California's savings, it is because California's income growth has not translated into higher energy use the way it has in less temperate states, as documented in the previous section.

The number of people per household in California *grew* by 0.6 relative to other states. Using the coefficient in Table 6, this would result in a decline of 2509 thousand BTUs per household member – a significant fraction of average consumption and of California's apparent savings. In fact, this one demographic change alone explains nearly half of California's 4.7 million BTUs of apparent residential electricity savings per capita.[17]

Together, the predicted effects of the long-term changes in household and home characteristics account for 2.9 million BTUs of residential electricity per household member – 61 percent of California's apparent residential electricity savings. Without migration from the North to the Southwest, without accounting for California's temperate climate, and without any energy efficiency improvements, the predictions in Table 6 imply that the long-run changes in household and home characteristics explain the majority of the apparent energy savings promoted by pictures like Fig. 1.

Putting the three parts of this together, Fig. 1 looks like an artifact of changes having nothing to do with energy efficiency. Fifteen percent of the apparent electricity changes can be explained by the U.S. population shift to the Southwest, ignoring all of the other changing differences between Californians and residents of other states. Another 20 percent can be attributed to the fact that nationwide income growth did less to increase energy demand in California's temperate climate, again ignoring all of the other changing differences. And a remaining 61 percent comes from a collection of demographic changes, such as California's rising relative household sizes, ignoring changing relative climates and household incomes.

It may be tempting to add the three parts together and say that 95 percent of California's apparent electricity savings can be explained by coincidental trends, but that would be inaccurate because the three parts interact. The comparison group, US states other than California, simultaneously shifted from the Northeast to the Southwest, experienced income growth

[16] 31 thousand BTUs is calculated from the coefficients on income and the interaction terms with HDD and CDD in Table 6: $31 = -\$11.4 \times (-74.1 + 0.0077 \times 4830\ \text{HDDs} + 0.0316 \times 1248\ \text{CDDs})$.

[17] To be clear, this calculation works as follows. I assume the coefficients in Table 6 represent a static relationship between household characteristics and electricity consumption. I use those coefficients to ask how much each *relative* change in California's characteristic over time would affect a representative home's electricity use, all else equal. Finally, I compare that predicted change to the relative change implied by Figure 1, 4.7 MBTU. If instead I used the coefficients in Table 6 to predict the *level* of residential electricity consumption in 2009, and compared that to the differences between consumption in California and other states, I would get very different answers. For some characteristics, the relative change is larger than the absolute differences. California households gained 0.6 persons relative to other states since 1960, but were only 0.36 persons larger in 2009 because they started from a smaller base. For other house characteristics the reverse is true. California houses lost only 0.06 rooms relative to houses in other states but were 0.47 rooms smaller in 2009. Because Fig. 1 focuses on the change over time, I do the same here. In Section 4 I turn to a levels analysis due to data limitations.

resulting in more energy use, and underwent the demographic changes detailed in Table 5. The next section considers all of those differences simultaneously.

4. Adding it all up: a Oaxaca–Blinder decomposition of residential electricity use in 2009

We would like to estimate all of these effects simultaneously, to know how much each contributes to California's apparent energy savings holding constant the other concurrent changes. Unfortunately, no data on energy use and household characteristics have been collected consistently back to the 1960s. At best we can use current data to estimate how much of the current differences between California's and other states' energy consumption results from observed differences in household characteristics having nothing to do with energy efficiency. The remainder may or may not be attributable to California's energy regulations, but at least the size of that remainder provides an upper bound on the share of the apparent energy savings that could possibly be attributed to efficiency rules. The analytical tool for such an exercise – decomposing differences into those explained by observed characteristics and those possibly due to policy changes – was first described by Oaxaca (1973) and Blinder (1973).

The first step is to run two separate regressions of household electricity use per capita (E) on household characteristics ($\boldsymbol{X}$):

$$E_{CA} = \boldsymbol{X}'_{CA}\beta_{CA} + \varepsilon_{CA} \tag{4a}$$

$$E_O = \boldsymbol{X}'_O\beta_o + \varepsilon_O \tag{4b}$$

where subscript CA denotes data for households in California and subscript O denotes data for households in other states. The vector $\boldsymbol{X}$ includes the local climate, the age, income and size of the household, and characteristics of the home itself including number of rooms, total square feet, and the number of various appliances. They account for characteristics of households that affect electricity use but are not the target of California's energy policies.

The goal of the decomposition is to explain the difference between the mean electricity consumption per capita in California and elsewhere: call that difference $\Delta\bar{E} = \bar{E}_{CA} - \bar{E}_O$. Using Eqs. (4a) and (4b) we can decompose that difference as follows:

$$\Delta\bar{E} = \Delta X'\beta_O + X'_{CA}\Delta\beta \tag{5}$$

The first term on the right is the part of the difference in electricity use explained by the difference in the household characteristics (ΔX). This first term thus indicates the portion of the difference between California's and other states' energy use clearly *unrelated* to California's regulations. The second term is the part explained by the differences in the estimated parameters ($\Delta\beta$). This might be due to energy efficiency, the price of electricity, or some other unobserved characteristics of households that cause energy use to vary differently with observed characteristics in different regions.

Column (1) of Table 8 contains an estimate of Eq. (4a) – energy use for California households. Columns (2) and (3) of Table 8 contain estimates of Eq. (4b) – energy use for households in other states. The only difference between columns (2) and (3) is that the third column includes 26 regional fixed effects.[18] Two particular features of the table stand out. First, there are large differences between the coefficients (the βs) for California and for other states. And second, adding the regional fixed effects in column (3) does not have a dramatic effect on the βs for other states, with the obvious exception of the climate variables HDD and CDD which are inherently regional.[19]

Table 9 uses the coefficients in Table 8 to estimate versions of the Oaxaca–Blinder decomposition in Eq. (5). The difference in 2009 electricity consumption per capita in California and other states ($\Delta\bar{E}$) is 8126 thousand BTUs. Most of that difference is due to underlying differences in the household characteristics between the two samples (ΔX). Without including the regional fixed effects, using columns (1) and (2) of Table 8, those observable characteristics explain 61 percent of the difference. But that decomposition runs the risk of confounding the "explained" portion of the difference between California and other states with energy efficiency, which is supposed to be in the "unexplained" portion. Suppose for example that households in hot climates use more electricity, but states with hot climates have higher energy prices or stricter energy efficiency standards. Then the coefficient on heating degree days in column (2) understates the effect of hot weather because it captures the spurious correlation with other states' unobserved energy policies. The decomposition under-explains the role of hot weather and attributes too much to the residual unexplained portion. Tellingly, the climate variables in column (2) have signs consistent with this story.

When regional fixed effects are included, using columns (1) and (3) of Table 8, the observable characteristics other than the regional fixed effects explain 88 percent.[20] Only 12 percent is left to be explained by differences in the coefficients ($\Delta\beta$).

[18] The 2009 RECS identifies 27 geographic regions – 16 large states including California and 11 clusters of smaller states. Note, however, that those fixed effects do not explain the difference between California and other states; only the difference among the other states. There is no California fixed effect because the California regression is run separately in column (1).

[19] The correlation between the fixed effects in column (3) and states' or regions' 2009 residential electricity prices is −0.46. Places with higher-than-average electricity prices have lower-than-average-electricity consumption per capita.

[20] The Oaxaca-Blinder decomposition at the bottom of Table 9 is calculated using all of the β coefficients in Eq. (5) except for those associated with the 26 regional fixed effects.

Table 8
Predicted electricity per household member – 2009.

Dependent variable: 1000 BTUs per household member	Regression coefficients		
	CA	Other states	Other with 26 regional fixed effects[a]
	(1)	(2)	(3)
HDD	0.345	−0.585*	0.257
	(0.426)	(0.233)	(0.265)
CDD	0.678	−0.613	0.400
	(0.789)	(0.491)	(0.537)
Household income	−21.9	−35.3	−27.37
($1000s 2010)	(26.9)	(26.3)	(26.48)
HDD × income	−0.0074	0.0014	0.0011
	(0.0072)	(0.0035)	(0.0035)
CDD × income	0.0403*	0.0155*	0.0134
	(0.0186)	(0.0074)	(0.0074)
Household size	−2552*	−5215*	−5211*
	(181)	(137)	(137)
Rural	4543*	2705*	2424*
	(1333)	(292)	(298)
Kids	432*	860*	821*
	(214)	(137)	(136)
Seniors	720	−651*	−571*
	(382)	(180)	(179)
Total square feet	2.24*	0.797*	0.914*
	(0.68)	(0.128)	(0.129)
Rooms	178	767*	719*
	(204)	(190)	(190)
Bedrooms	−821	582*	597*
	(429)	(236)	(235)
Mobile home	105	1621*	1948*
	(1042)	(550)	(542)
Attached	92	−1590*	−1244*
	(590)	(355)	(373)
Apt bldg < 5 units	−515	−2640*	−1868*
	(572)	(449)	(461)
Apt bldg. >= 5 units	−853	−3739*	−3169*
	(606)	(449)	(465)
Owner occupied	−282	−555	−359
	(454)	(304)	(299)
Built 1950s	−456	−681	−797*
	(611)	(349)	(347)
Built 1960s	−450	−84	−371
	(612)	(385)	(386)
Built 1970s	−738	−177	−491
	(595)	(384)	(394)
Built 1980s	−1559*	−687	−940*
	(649)	(390)	(399)
Built 1990s	−1338	−826*	−1274*
	(696)	(414)	(428)
Built 2000s	−54	−2758*	−3190*
	(1206)	(429)	(445)
Dishwasher	891*	680*	826*
	(371)	(247)	(250)
Clothes washer	712	−1345*	−1278*
	(809)	(525)	(522)
Dryer	252	2457*	2181*
	(760)	(489)	(491)
TV sets	1093*	762*	797*
	(186)	(96)	(95)
Air conditioned	392	1182*	1460*
	(471)	(313)	(323)
Central air	−38	1406*	618*
	(566)	(267)	(289)
Swimming pool	3775*	5009*	5569*
	(783)	(509)	(505)
Stove/oven electric	816*	788.6*	877*
	(379)	(220)	(232)
Stove electric	860	−141.5	−331
	(1006)	(752)	(743)

Table 8 (*Continued*)

Dependent variable: 1000 BTUs per household member	Regression coefficients		
	CA	Other states	Other with 26 regional fixed effects[a]
Oven electric	−39	3349*	3271*
	(1060)	(619)	(609)
Heat electric	1590*	6430*	6203*
	(452)	(311)	(308)
Water electric	3656*	4132*	4081*
	(987)	(261)	(263)
26 region fixed effects[a]	No	No	Yes
Constant	8016*	18,712*	12,519*
	(1844)	(1959)	(2169)
Observations	1606	10,477	10,477
R-squared	0.50	0.48	0.49

Source: 2009 Residential Energy Consumption Survey.
Standard errors in parentheses.
* Statistically significant at 5 percent.
[a] The geographic regions here are the 15 large states and 11 clusters of smaller states identified in the 2009 RECS.

Table 9
Decomposition of electricity differences – 2009.

	Average electricity use per household member(1000 BTUs)	
California	10,396	
Other States	18,522	
Difference	8126	
Oaxaca–Blinder decomposition		
Without regional fixed effects		
Explained ($\Delta X'\beta$)	4925	61%
Unexplained ($X'\Delta\beta$)	3200	39%
With 26 regional fixed effects		
Explained ($\Delta X'\beta$)	7158	88%
Unexplained ($X'\Delta\beta$)	967	12%

Source: 2009 Residential Energy Consumption Survey and calculations from Table 8.
The underlines signify the value below the line is the “difference” between the two lines above.

This additional 12 percent includes other omitted household characteristics that are correlated with electricity use and differ between California and other states. One such variable might be energy efficiency; another might be energy prices. But at most those policy-related variables account for 12 percent of the 2009 difference between residential electricity consumption in California and other states.

In sum, the first part of this paper showed that California’s *relative decline* in residential energy consumption per capita from 1963 to 2009 can largely be explained by factors unrelated to energy efficiency: the migration of the US population to hotter states; the smaller income elasticity of demand for electricity in California’s mild climate; and relative changes in household characteristics, particularly household size. This part – the Oaxaca–Blinder decomposition – has shown that California’s *absolute difference* in residential energy consumption per capita in 2009 can also largely be explained by household and regional characteristics unrelated to energy efficiency. Fig. 1, held up by regulators, environmental advocacy groups, and the international development banks to demonstrate the efficacy of energy efficiency standards for buildings and appliances, demonstrates nothing of the kind. The vast majority of California’s apparent conservation relative to the rest of the country comes from coincidental features of geography and demographics. They have nothing to do with energy efficiency, are not replicable by other states or countries, and have no lessons for the rest of the world.

To be clear, this analysis does not mean that California’s regulations have not been effective or beneficial. It simply means that figures like Fig. 1 are uninformative as to those benefits. It might be, for example, that other US states and the US government quickly followed California’s regulatory example, in which case we should not expect to find relative differences in electricity consumption per capita except those driven by geography and demographics. It might be that California’s regulations, followed by other states, reduced electricity consumption everywhere lowering both the top and bottom lines in Fig. 1. Also, as Fig. 3 shows, residential electricity accounts for a relatively small part of California’s overall energy use. Other sectors also saw per capita declines in California relative to other states. Two in particular, manufacturing and transportation, account for the majority of California’s apparent savings. The next section briefly explores each of these.

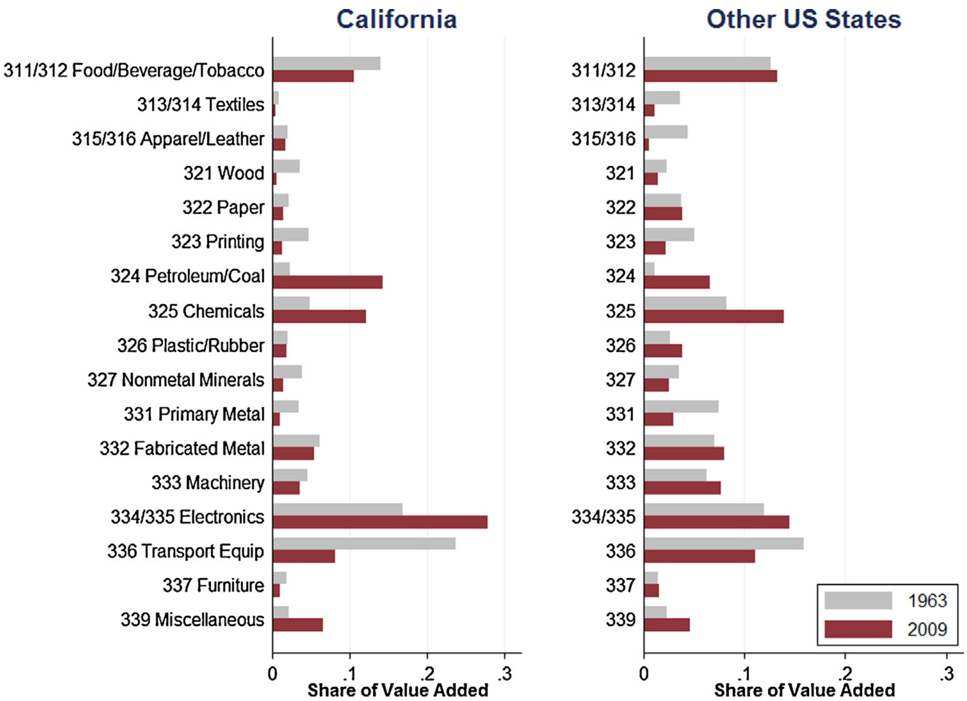

Fig. 6. Changing manufacturing composition: 1963–2009.

5. Other sectors: manufacturing and transportation

Although energy efficiency proponents point to residential electricity as the prime example of California's difference from other states, California's energy consumption per capita has been falling in every sector – residential, commercial, industrial, and transportation – and has been falling for both electricity and non-electric energy in each of those sectors. Figures similar to Fig. 1 can be drawn for each sector and energy type, and the line depicting California energy use per capita drops below the line for other states, though most sharply for residential electricity. Table 1 and Fig. 3 summarize what those other figures would look like. Although residential electricity depicted in Fig. 1 looks most impressive, the sector accounted for only 4 percent of California's energy consumption in 2009. Transportation and industrial energy use accounted for 39 and 20 percent, respectively, and so even though California's apparent energy efficiency gains were smaller for those two sectors in percentage terms, those sectors contributed more to California's overall apparent energy efficiency gains.

5.1. *Manufacturing: scale and economic composition*

Skeptics have hypothesized that California's four-decade-long improvement in *industrial* energy efficiency stems from the changing scale and composition of California's economy relative to that of other U.S. states. In other words, California may be simply losing manufacturing, and especially energy-intensive manufacturing, at a faster rate than other states. One might even be concerned that the costs of complying with California regulations could be the cause of that shift. If California's regulations succeeded in reducing the state's energy demand by driving energy-intensive industries to relocate out-of-state or overseas, that would not be replicable in turn by other jurisdictions, and California's regulations would not provide a model for national or global energy conservation.

To address this, I turn to the Manufacturing Energy Consumption Survey (MECS), which has been conducted every three to four years from 1991 to 2006 by the Energy Information Administration.[21] Not surprisingly, there is a wide variation across industries in electricity use per dollar of value added, and many industries show a large drop in net electricity use.[22] But these are national averages. The energy efficiency advocates would expect that energy use per dollar of value added will have fallen more in California than other states. The skeptics contend that California's manufacturing sector has simply shrunk in size or shifted away from the most energy-intensive industries, relative to other states.

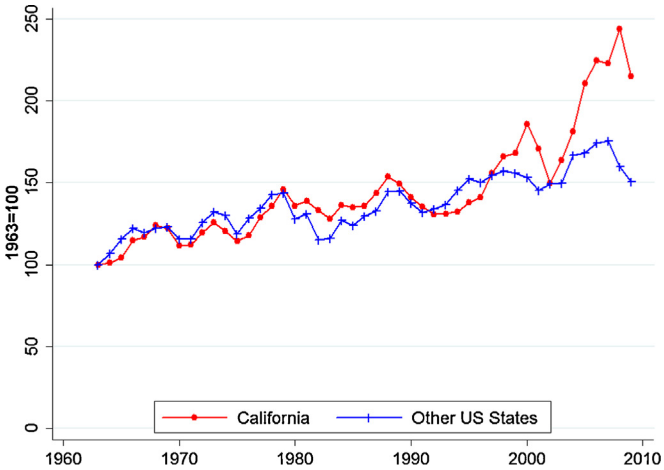

Fig. 7. Predicted manufacturing electricity use per capita: based on 1991 MECS and concurrent industrial composition.

To begin to assess those claims, Fig. 6 plots the share of total manufacturing value added, in 1963 and 2009, for California and other states. Both California and other states experienced large increases in petroleum and coal, chemicals, and electronics, and decreases in transport equipment, textiles and apparel. But the scales of the changes differ, leading to the possibility that industrial composition changes may have accounted for some of California's gains.

To separate the technological improvements from the composition changes, I predict net electricity use in each year ($\hat{E}_t^M$) based on each industry's value added in each year and the 1991 national electricity use per dollar of value added.

$$\hat{E}_t^M = \sum_i \left(\frac{E_{i,1991}^M}{v_{i,1991}} \right) \times v_{it} \tag{6}$$

where the term in brackets is the average electricity use per dollar of value added by industry i from the 1991 MECS, and v_{it} is the value added by industry i in year t, from the Annual Survey of Manufactures (ASM). Subscripts i refer to 3-digit NAICS codes. The calculation combines both the scale of the manufacturing sector and its composition.

Fig. 7 plots Eq. (6) separately for California and other states, indexed so that 1963 equals 100. The results are dramatic. Over the past 5 decades, California's industrial electricity demand, as predicted by its size and composition, has grown as much or more than the rest of the nation. If anything, declines in electricity use by California industry have come in spite of the fact that the state's mix of industries is working against it.

Table 10 shows the details of the calculations in Eq. (6), combining information about the contemporaneous size of each industry and the energy intensity of that industry in each year. Food and beverage production grew 221 percent from 1963 to 2009 in California and 176 percent in other states. With no change in electricity use per dollar of value added, the industry's energy use would have grown more in California than in other states. But because California's population grew faster, food and beverage energy use *per capita* would have grown more slowly in California. The middle panel of Table 10 presents the weighted average of energy growth of all 3-digit NAICS codes, weighted by 1991 energy consumption. If every industry used its 1991 electricity consumption per dollar of value added in every year, electricity use by California manufacturers would have grown 350 percent and only 138 percent in other states. But California's population also grew faster, doubling since 1960 while other states grew by 50 percent. Conducting exactly the same experiment with per-capita rather than total energy use by each manufacturing sector, electricity use per capita would still have grown faster in California: by 115 percent in California and 51 percent in other states.

The rest of that middle panel presents the same calculations using non-electric industrial energy and the 2006 MECS, with no change in the underlying result. California's manufacturing industry would have shown faster growth of total and per capita energy consumption than other U.S. states had it not been for a change in energy use within each 3-digit NAICS code. Rather than explaining apparent energy efficiency gains from California manufacturers, the changing mix of industries enlarges it. Something other than the size and mix of industries must explain the industrial energy savings shown in Fig. 3 and Table 1.

[21] The comparison is made slightly difficult by the fact that the 1991 survey used Standard Industrial Classifications (SIC) codes. I converted SIC codes to NAICS codes using a cross-walk provided by the Census Bureau.

[22] I use "net" electricity use because some industries cogenerate electricity as part of their production.

Table 10
Predicted manufacturing energy growth: 1963–2009.

Electricity use based on 1991 MECS	Predicted energy use		Per capita	
	California	Other states	California	Other states
311/312 food/beverage/tobacco	221%	176%	53%	75%
313/314 textiles	153%	−18%	21%	−48%
315/316 apparel/leather	249%	−65%	67%	−78%
321 wood	−26%	58%	−65%	0%
322 paper	188%	169%	38%	70%
323 printing	21%	13%	−42%	−28%
324 petroleum/coal	2558%	1480%	1170%	900%
325 chemicals	947%	346%	401%	182%
326 plastic/rubber	301%	269%	92%	134%
327 nonmetal minerals	63%	89%	−22%	20%
331 primary metal	19%	6%	−43%	−33%
332 fabricated metal	276%	202%	80%	91%
333 machinery	229%	223%	57%	104%
334/335 electronics	605%	216%	237%	100%
336 transport equip	47%	82%	−30%	15%
337 furniture	136%	176%	13%	75%
339 miscellaneous	1160%	406%	502%	221%
Weighted average of all manufacturing				
Electricity based on 1991 MECS	350%	138%	115%	51%
Non-electric Energy, 1991 MECS	1125%	427%	486%	234%
Electricity based on 2006 MECS	243%	122%	64%	40%
Non-electric Energy, 2006 MECS	669%	244%	267%	118%
Electricity use 1963–2007 based on 6-digit NAICS Codes in 2009 ASM				
Ignoring missing industry codes	645%	34%	264%	−13%
Dropping missing industry codes	788%	58%	333%	2%

Sources: Top two panels: 1991 and 2006 MECS, Annual Survey of Manufactures. Bottom panel: 1963 and 2007 Census of Manufactures, 2009 Annual Survey of Manufactures.

5.2. Intra-industry composition

Some of the observed energy efficiency gains may have come from true increases in energy efficiency, and some from intra-industry composition changes. Primary metals, for example, includes factories that produce aluminum from raw materials and pipes from purchased steel. Manufacturing aluminum uses far more energy, and to the extent that production in the broad primary metals category has shifted away from aluminum and toward pipes, energy consumption per dollar of value added will have declined, even without technological changes in energy efficiency.

To address this I need a measure of energy intensity more disaggregate than the 3-digit NAICS codes used in and Figs. 6 and 7. Recent versions of the ASM report net electricity use by six-digit NAICS code. These can be matched to the value added by each industry in California and other states using the four-digit SIC codes in the 1963 Census of Manufactures and the six-digit NAICS codes in the 2007 Census of Manufactures.

The task of examining industry composition at this finer level of disaggregation is complicated for two reasons. First, the match between four-digit SIC codes and six-digit NAICS codes is not one-to-one. And second, some codes are not reported for California so as to protect confidential business information. Consequently, at the bottom of Table 10 I report the percentage growth two ways, with and without the unmatched industry codes. I assigned each industry its current net electricity use, from the 2009 ASM. If each industry had used its 2009 electricity intensity, electricity demand by manufacturers would have grown by 34 percent in states other than California, and by an astonishing 645 percent in California. California's faster population growth accounts for some of this. Dividing by population, other states' industrial electricity use per capita would have stayed flat or even declined slightly, while California's grew by 264 or 333 percent, depending how I treat unmatched industry codes. Rather than revealing industrial composition changes favoring California that were hidden by the more aggregate analysis, this disaggregation shows that California's composition tilted even more toward electricity-using industries.

In sum, per capita energy used by California's manufacturing sector has declined relative to the energy used by other states' manufacturing. This has not been the result of California's manufacturing base shrinking relative to other states, nor has it been the result of California's industrial composition shifting to less energy-intensive products.

5.3. Transport

This sector is extremely simple, and this section can be correspondingly brief. Since 1966, motor fuel consumption per capita has grown by 12 percent in California and by 45 percent in other states. But California's relative savings are entirely explained by miles traveled rather than vehicle efficiency. California vehicles used 32 percent less fuel per mile driven in

2009 than in 1966, while other states' vehicles used 31 percent less. By contrast, California vehicles traveled 64 percent more miles per capita, while other states' vehicles traveled 111 percent more. California's apparent fuel savings come from other states' residents driving more, not California vehicles being more energy efficient.

In a way, the transport sector serves as a parable for the main point of this paper, that Fig. 1 is uninformative. Energy efficiency is measured as output per unit of energy input. For transport that efficiency measure is obvious, miles per gallon of gasoline, and it is easy to document that California cars have not gained energy efficiency relative to other states' cars. But for homes there is no simple measure of output to compare with residential energy consumption. Residential electricity is used for cooling, cooking, water heating, and entertainment, all measured in different units if they are measurable at all. The difficulty of measuring residential energy efficiency no doubt explains why policymakers turn to Fig. 1 instead – a plot of residential electricity consumption per capita rather than per unit of hard-to-measure output. For transport, we know that type of analysis would be misleading and that per capita gasoline consumption in California has declined relative to other states even though California cars have not gained energy efficiency. The bulk of this paper shows that Fig. 1 is equally misleading for residential electricity.

6. Concluding comments

The poster-child for energy efficiency regulations is residential electricity. Many groups have made the correlation-proves-causation argument supporting California's efficiency regulations by pointing to Fig. 1 and noting that California's energy slowdown seems to roughly coincide with the initiation of those regulations. It turns out, however, that most of the apparent energy savings in Fig. 1 can just as easily be explained by long run trends unrelated to energy efficiency. These include the shift of the U.S. population from the North to the Southwest, California's low income-elasticity of energy demand that is a consequence of its mild climate, and differences in the way the demographics of California and other states have changed. Together, nearly 90 percent of the difference between California's residential electricity consumption in 2009 and that in other states can be explained by household and geographic differences unrelated to energy efficiency.

It is worth returning briefly to the issue of energy prices, raised in the introduction but ignored intentionally since then. Inflation-adjusted electricity prices have increased in California during the past 50 years, while falling in other states. That price change could well explain some of California's apparent savings depicted in Fig. 1. And that would be a success story, applauded by economists and replicable by other jurisdictions. But however large it may be, that price effect cannot account for much of the gap depicted in Fig. 1, because the long-run trends this paper credits with most of that gap are unrelated to either energy efficiency *or* prices. California's building codes and energy prices caused no population shift from the Midwest to the Southwest. Building codes and energy prices are not responsible for California's mild climate and resulting small income elasticity of energy use. And if building codes or electricity prices have caused California household sizes to grow relative to the rest of the country, saving energy as a consequence, that has not been publicized as a selling point of the state's energy policies.

Efficiency standards appeal politically because they purport to conserve scarce resources while saving consumers money – a costless public policy. Even aside from skepticism about that claim, many economists find efficiency standards unappealing for two reasons. First, they are poorly targeted, requiring the same energy efficiency for appliances in constant use as for those used only rarely. Why should a homeowner buying a heater for a basement room used one weekend each winter be required to pay more for an energy efficient heater? The more expensive heater will save very little energy, and those costs could save more if spent differently. Second, efficiency mandates make polluting activities cheaper rather than more expensive. The economists' solution is to internalize the externality, to raise the marginal cost of using polluting resources. Efficiency standards do the opposite; they require people to pay a fixed cost in the form of more expensive appliances, homes, or vehicles in order to reduce the marginal cost of using them.

Despite these theoretical objections to efficiency standards, the U.S. has embraced them as policy and the relevant question is "have they worked?" That turns out to be difficult to answer because we cannot simply compare electricity consumption in energy-efficient and inefficient homes. People living in efficient homes may use more energy services because the cost is lower – the rebound effect. If air conditioning costs less because the walls are insulated, homeowners might leave their systems on while they go to work. And second, people who want to use more energy services may install energy efficiency features or buy more efficient homes – the selection effect. Together, the rebound and selection effects make the consequences of California's policies difficult to assess empirically and explain the appeal of Fig. 1, uninformative though it may be.

Finally, let me reiterate that just because Fig. 1 fails to prove that California's efficiency laws were effective does not mean they were not. Laws similar to those in California have been adopted by many states and the federal government, and if all those laws worked they have slowed electricity consumption everywhere, not just in California. The findings here do undermine Fig. 1 as evidence in support of California's standards, but they do not show that those standards have not been effective or that they should not be tightened further or promoted elsewhere. On that question, this paper is just as uninformative as Fig. 1. All this paper shows is Fig. 1 does not demonstrate the efficacy of efficiency standards, because even without California's regulations, its residential electricity consumption per capita would have been falling steadily relative to other U.S. states for the past 50 years.

Acknowledgments

Thanks to Jason Bordoff for asking the question that led to this project, Joe Aldy, Lucas Davis, Rema Hanna, Matt Harding, Matt Kotchen, James O'Brien, Kerry Smith, Rob Stavins, and Josh Graff Ziven for helpful feedback, Jenna Kirschner for exceptionally thorough and resourceful research assistance, Randy Becker at the Census Bureau for help with the crosswalk between SIC and NAICS industry codes, and officials at NOAA and the California Energy Commission for assistance with data.

References

American Council for an Energy-Efficient Economy (ACEEE), 2012. The 2012 State Energy Efficiency Scorecard. ACECE Report Number E12C.
Aroonruengsawat, A., Auffhammer, M., Sanstad, A.H., 2012. The impact of state level building codes on residential electricity consumption. Energy J. 33, 31–52.
Blinder, A.S., 1973. Wage discrimination: reduced form and structural estimates. J. Hum. Resour. 8, 436–455.
California Air Resources Board (CARB), 2008. Climate Change Scoping Plan, http://www.arb.ca.gov
California Public Utilities Commission and California Energy Commission, 2006. Energy Efficiency: California's Highest-Priority Resource. June 2006.
Chong, H., 2012. Building vintage and electricity use: old homes use less electricity in hot weather. Eur. Econ. Rev. 56, 906–930.
Clemente, J., 2011. Is California's electricity policy really a model for the United States? Innov. Energy Policies 1, 1–6.
Costa, D.L., Kahn, M.E., 2010. Why Has California's Residential Electricity Consumption Been So Flat since the 1980's: A Microeconometric Approach. NBER Working Paper 15978.
Department of Energy/Energy Information Administration (DOE/EIA), 2011. State Energy Price and Expenditure Estimates 1970 Through 2011. DOE/EIA-0376, June 13.
Ettenson, L., 2011. Energy efficiency: California's leading energy resource. Electric Light and Power. November 9.
Jacobsen, G.D., Kotchen, M.J., 2013. Are building codes effective at saving energy? Evidence from residential billing data in Florida. Rev. Econ. Stat. 95, 34–49.
Levinson, A., Niemann, S., 2004. Energy use by apartment tenants when landlords pay for utilities. Resour. Energy Econ. 26, 51–75.
Massachusetts Secretary of Energy and Environmental Affairs, 2010. Massachusetts Clean Energy and Climate Plan for 2020: A report to the Great and General Court pursuant to the Global Warming Solutions Act (www.mass.gov/eea/).
Mitchell, C., Deumling, R., Court, G., 2009. Stabilizing California's Demand: The Real Reasons Behind the State's Energy Savings. Public Util. Fortnightly 147, 50–62.
Oaxaca, R.L., 1973. Male–female wage differentials in urban labor markets. Int. Econ. Rev. 14, 693–709.
Palmer, K., Grausz, S., Beasley, B., Brennan, T., 2012. Putting a Floor on Energy Savings: Comparing State Energy Efficiency Resource Standards. Resources For the Future Discussion Paper 12-11. February 2012.
Rosenfeld, A.H., Poskanzer, D., 2009. A Graph Is Worth a Thousand Gigawatt-Hours: How California Came to Lead the United States in Energy Efficiency. Innovations Fall, 57–79.
Sudarshan, A., 2013. Deconstructing the Rosenfeld curve: making sense of California's low electricity intensity. Energy Econ. 39, 197–207.
Tanton, T., 2008. California's Energy Policy: A Cautionary Tale for the Nation. Competitive Enterprise Institute, Washington, DC.
U.S. Environmental Protection Agency (EPA), 2011. 2011 U.S. Greenhouse Gas Inventory Report. (April 2011) USEPA #430-R-11-005.