California Energy Efficiency:
Lessons for the Rest of the World, or Not?

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Abstract

Starting in the 1970s California's residential electricity consumption per capita stopped increasing, while other states' electricity use continued to grow steadily. Similar patterns can be seen in non-electric energy, industry, and transportation. Had other states' energy use followed California's trajectory, the U.S. would have already achieved the Obama Administration's goal of reducing U.S. greenhouse gas emissions to 17 percent below 2005 levels by 2020. What accounts for California's residential electricity savings? Some credit regulations, especially the strict energy efficiency standards for buildings and appliances enacted by California in the mid-1970s. They argue that other states and countries could replicate California's gains, and that California should build on its own success by tightening those standards further. Skeptics point to three long-run trends that differentiate California's electricity demand from other states: (1) shifting of the U.S. population towards 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. Together, these trends account for virtually all of California's apparent residential electricity savings, thus providing no lessons for other states or countries considering adopting or tightening their energy efficiency standards.

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California's Energy Efficiency: Lessons for the Rest of the World, or Not?

Since the early 1970s, California's energy consumption per capita has departed from the trajectory followed by the rest of the United States. In 1973, California's energy consumption began declining at almost one percent annually while other states' consumption plateaued. By 2009, had California energy use kept pace, the state would have been consuming 25 percent more energy, or 2.0 quadrillion BTUs. Had the rest of the country mimicked California, national energy consumption by 2009 would have been 20 percent lower, or 18.7 quadrillion BTUs. Such a reduction would by itself be sufficient to achieve the Obama Administration's goal of reducing U.S. greenhouse gas emissions to 17 percent below 2005 levels by 2020.[1]

Figure 1 makes this point more clearly than possible with prose. Drawn for one particular component of energy use, residential electricity, versions of Figure 1 often appear as part of campaigns to support policies promoting or mandating energy efficiency. The middle line depicts residential energy per capita in California; the top line plots other states. By 2009, residential electricity in California had grown 36 percent less than in other states. Yet the figure by itself does not reveal the reason for California's slower electricity consumption growth or whether it could be replicated by other states or countries.

Proponents of regulations give credit 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 this view, other states and countries could achieve California-sized energy savings by adopting California-style regulations like those in Table 1.

California's own 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 by almost 50 percent."[2] U.S. Energy Secretary Steven Chu concurs that California's "history of very progressive energy policies" deserve credit for the state's savings.[3] The Natural Resources Defense Council says that California's policies "offer lessons to states and utilities outside California that want to expand clean energy and provide even greater environmental and economic benefits to their residents" (Ettenson, 2011). And the World Bank devoted an entire page of its 2010 *World Development Report* to California and a reproduction of Figure 1 as a lesson for the rest of the planet.

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[1] 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.

[2] California Public Utilities Commission and California Energy Commission, "Energy Efficiency: California's Highest-Priority Resource" June 2006.

[3] Steven Chu interviewed by Larry Klein and published in NOVA Online January 20, 2009. (www.pbs.org/wgbh/nova/tech/energy-secretary-chu.html)

There are, however, reasons to be skeptical about crediting regulatory changes with California's apparent savings in Figure 1. 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. Third, California's relative energy savings, depicted by the bottom line in Figure 1, appear as a smooth trend that begins before 1970, long before the state's regulations took effect. And fourth, the energy savings have occurred in all sectors, even those not targeted by the regulations. That leaves open the question of what does explain the savings, and the sections that follow test the critics' main hypotheses one-by-one.

In the skeptics' 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. With regard to residential energy consumption, skeptics have three hypotheses: population migration, climate, and demographics.[4] First: migration. Over the past several decades, the United States population has shifted from the North and East to the South and Southwest. The Southwest has larger homes and higher demand for air conditioning, leading to higher energy consumption. 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, California has saved energy relative to other states.

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 the bottom-up engineering approach typical of regulatory impact analyses conducted by government agencies proposing energy efficiency regulations. Bottom-up engineering analyses typically disregard consumers' and industries' behavioral response to changes in energy efficiency. One potentially important response would be to use more energy – the Jevons paradox or "rebound effect." CEC standards make appliances and buildings more energy efficient, lowering the cost of energy services, which may in turn increase energy consumption and offset some of the mandated efficiency gains. If bottom-up analyses simply 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, discuss 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

[4] See, for example, Tanton (2008), Clemente (2011), and Mitchell *et al.* (2009).

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 increasing share of immigrants in the population has changed California's household size and income distribution, with different effects on energy consumption.

Instead of a bottom up or top down model, I take more of a piece-by-piece accounting approach, similar to that taken by Sudarshan (2010). I focus on residential electricity because that has attracted the most attention. Later, I briefly discuss manufacturing and transportation, sectors in which California energy consumption per capita also declined relative to other states. In each case, I ask how much of the perceived energy savings can be explained by factors unrelated to the regulations. For example, how much less energy would the rest of the country be using had the population not shifted to states with warmer climates and greater demand for air conditioning? Or, how much of the 2 quads California appears to have saved can be explained by changes in California's demographics – age, household size, income, etc. – relative to other states? Or, how much energy would California be using today if changes to its industrial composition or driving patterns had paralleled national changes since 1963?

The question posed here, how much of California's energy savings can be explained by coincidental trends rather than the state's 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.

The results of this exercise suggest that California's regulations have not been the main cause of its energy savings relative to the rest of the U.S. The trend began before 1973, seems unaffected by regulatory changes, and appears in sectors not targeted by those changes. Residential electricity shows the most dramatic apparent savings, but those gains appear almost entirely driven by the shifting of the U.S. population to the Southwest, California's relatively mild climate, and other demographic differences between California and other states. The sector with the greatest energy demands is transportation, and California's apparent savings in that sector come entirely from residents of other states driving more, not from Californians driving more fuel efficient vehicles. The most promising sector is industrial energy use. California's

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

industries appear to be steadily using less energy per capita and per dollar of value added than other states' industries, despite the fact that the changing scale and composition of California's industries would have increased its relative energy consumption.

Energy Savings in Other Sectors

Although residential electricity has been the focus of claims about the success of regulatory policy, figures similar to Figure 1 drawn for other energy sources and uses show similar patterns. Table 2 makes this point. The top row of Table 2 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. (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.) The difference, 52 or 66 MBTU in columns (5) and (6) of Table 2, means that total energy consumption in California fell 19 or 23 percent relative to those other states. Some subcategories fell even more. Residential electricity consumption per capita in California dropped 36 or 48 percent relative to other states, depending on whether you use other states' percentage or absolute energy growth. Commercial electricity consumption in California dropped 52 or 39 percent. These more eye-catching drops are the ones typically used to highlight the success of California's energy efficiency policies (Rosenfeld and Poskanzer, 2009), even though they account for a relatively small portion of California's overall apparent per-capita energy savings.

Figure 2 graphs these calculations, using the data from columns (1) and (5) of Table 2. 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 2 and Figure 2 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 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 the states' energy budgets. In the end, how much each sector *really* contributes to energy efficiency savings depends on how much of those savings come from energy efficiency and how much come from other factors driving energy consumption, including geography and climate, household demographics, industrial composition, and transportation patterns.

Each of the alternative explanations for California's energy savings requires a somewhat different approach, with different data and empirical strategies. Hence, the sections of the paper are largely independent. At the end I return to ask how much of California's overall energy savings are explained by the sum of these non-regulatory trends that presumably do not hold lessons for other states or countries. But first I start with the highest profile sector, and the one featured in Figure 1 and numerous campaigns to promote mandated efficiency standards: residential electricity.

I. Residential Energy: Population Shifts, Climate, and the Income Elasticity of Heating and Cooling

Figure 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 demand for air conditioning and electricity in states other than California. Second, even if the population hadn't 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 each explanation in turn. In the next section I discuss a third explanation; California incomes shrank and household sizes grew relative to other states, and with those changes came declines in energy consumption per capita.

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 Figure 1 that holds the populations of the other states fixed. Figure 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. This measure, plotted as the top line in Figure 1, changes over time because of changes in various states' energy intensities *and* state populations.

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*:

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

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. Figure 3 plots this line for residential electricity. By 2009 the line $\hat{\theta}$ had grown by 234 percent, a bit less than the line plotting other states' actual consumption, and this adjustment accounts for 15 percent of the gap between other states' and California's consumption.

Table 3 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 3, 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 2 and Figure 2, migration and geography mask some of those savings.

The final column of Table 3 helps explain what is going on. 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 to 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 to 15 percent of California's savings in this category.

The bottom panel of Table 3 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 (7). 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.

Population Shifts and Climate

This climate-related explanation for California's efficiency gains can be examined separately. Line (1) of Figure 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*.[6] 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 Figure 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

[6] 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°.

similar graph for California would show heating degree days flat at 2600 per year, and cooling degree days flat at 900 per year.

Has this population shift in the rest of the country been enough to noticeably increase energy consumption relative to California, and if so, how much does it explain of the 4.7 MBTUs per capita of electricity California appears to have saved? To find out, I first predict state energy consumption per capita based on average annual state heating and cooling degree days:

$$\theta_{s,t} = \alpha + \beta_1 \overline{HDD}_s + \beta_2 \overline{CDD}_s + \beta_3 trend_t + \epsilon_{s,t} \quad (1)$$

Table 4 shows estimates of equation (1) for various categories of energy consumption. Column (1) shows that one extra average heating degree day in a state is associated with a decrease in per capita residential electricity consumption of 220 BTUs per capita, but an extra cooling degree is associated with an increase of 1222 BTUs. Columns (2) through (4) of Table 4 report results for other categories of energy. In general, states with more heating degree days use less electricity and more other energy, and states with more cooling degree days use more of both types of energy.

Figure 5 uses the regressions in Table 4 to plot predicted residential electricity consumption per capita. Line (1) plots the predictions for California, based solely on heating and cooling degree days.[7]

$$\hat{E}(1)_t = \hat{\alpha} + \hat{\beta}_1 HDD_{ts} + \hat{\beta}_2 CDD_{ts}$$

Line (2) uses the average heating and cooling degree days, which is why the line is completely flat.

$$\hat{E}(2)_t = \hat{\alpha} + \hat{\beta}_1 \overline{HDD}_s + \hat{\beta}_2 \overline{CDD}_s$$

More interestingly, lines (3) and (4) plot the predicted electricity use per capita in the other states. These lines trend up because of the population shift towards states with fewer heating degree days and more cooling degree days, as shown in Figure 4. On balance, the extra energy used for cooling more than offsets savings from less heating, and predicted residential electricity use per capita in states other than California has grown by 365 thousand BTU or 3.1 percent.

Table 5 summarizes these calculations. Column (1) predicts the difference in other states' energy consumption per capita, based solely on temperatures. The average annual number of heating degree days experienced by the average person outside California declined by 457; the average number of cooling degree days rose by 206. Applying these changes to the coefficients in Table 4, we would expect non-California residential electricity to rise by 351 thousand BTU per capita per year and other residential energy to fall by 1185 thousand BTU per year. Column

[7] The year trend in equation (1) is defined such that the average is zero, so it is excluded from the predictions.

(2) compares these climate-based predicted changes to the migration-based predictions in Table 3. This climate-based explanation, from a simple regression of energy use on HDD and CDD, captures a substantial portion of the migration-based explanation, ranging from 37 percent for non-electric commercial energy to 93 percent for nonelectric residential energy. What explains the rest? Surely some comes from the minimalism of the regression in Table 4. State fixed effects, state-specific year trends, and polynomial terms in HDD and CDD capture more of the variation in energy use. But those regressions also risk overfitting the data and attributing some of that energy use to HDD and CDD that is actually coming from other state characteristics – home sizes, household sizes, landscaping, etc. I study those demographic effects in section II.

To sum up the analysis at this point, geographic shifts in the U.S. population have increased residential and commercial electricity demand, largely due to the increased cooling degree days experienced by the average American outside of California. And the shifts have decreased residential and commercial demand for non-electric energy, largely due to the decreased number of heating degree days.

There may be, however, a second climate-related explanation for California's 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.

Climate and Income

To test whether California energy demand is less income elastic than 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.

$$BTU_i = \alpha + \beta_1\overline{HDD}_i + \beta_2\overline{CDD}_i + \beta_3(income_i) + \beta_4\overline{HDD}_i \times (income_i) + \beta_5\overline{CDD}_i \times (income_i) + \beta_6 h'holdsize_i + \beta_7 trend_i + \sum_d \delta_d D_i + \epsilon_i \quad (2)$$

Equation (2) 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 for California. 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 equation (2) $\overline{HDD}$ 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 6 contains two estimates of equation (2): for electricity and for non-electric energy. Marginal effects calculated from interaction coefficients at the means of right-hand-side variables are at the bottom of the table. 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 1390 BTUs of electricity use for a household with the mean income, or about 4 percent.[8] Other energy use (column (3)) also increases with income and in colder climates (HDD), but does not increase faster with income in colder areas.

Table 7 demonstrates the magnitude of these effects. Using the point estimates in Table 6, an extra $1000 of income increases electricity consumption for the average household by 68,000 BTUs in California and 173,000 BTUs in other states. [9] Income growth adds less to California's residential electricity demand than to other states because of California's mild climate. Columns (4) shows this same calculation for non-electric residential energy, where income growth does not increase energy use by more in California.

How large is this effect? From 1963 to 2009, real mean household income in the United States grew by more than 50 percent, from $44 thousand to $69 thousand. Applying the predictions from Table 6 and Table 7, this would mean an increase in electricity use per household of 1.7 million BTUs in California and 4.3 million BTUs in other states, or a difference of 2.6 million BTUs. Each household used on average 34 million BTUs of electricity (see Table 6), so this difference amounts to about 8 percent of electricity consumption. Recall from Table 2 that California appears to have saved 36 percent 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 row of Table 7.

The first of the skeptical explanations is that California's apparent electricity savings come from the unique geography of the United States, combined with regional patterns of population shifts and California's mild climate. I have examined this explanation from three angles. First, migration patterns alone explain some of the apparent savings from residential and commercial electricity consumption, but for non-electric energy the effect works in the opposite direction. Most of this pattern is explained by climate, and the fact that electric energy is used for air conditioning while other sources of energy are used for heating. Finally, a significant share of California's apparent electricity savings seems to come from its mild climate, where increasing

[8] 1390=100×(6.06+0.153×51.2).
[9] 138=1×(61 + 0.00448 × (2601 HDDs) + 0.0726 × (901 CDDs)).

household incomes have not lead to increased cooling-related energy consumption as they have in other parts of the country.

Figure 1 suggests that since 1963 California has saved 4.7 MBTU of residential electricity per capita relative to other states, or 36 percent. The calculations in this section indicate that part of those savings is illusory: 15 percent of the savings 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. But that leaves another 65 percent of the residential electricity savings in Figure 1 unexplained, and it does not account for the apparent savings in non-electric energy use, where migration patterns work in the opposite direction and mask some potential energy efficiency gains in California. For those reasons, in the next section I explore the other proffered explanation for Figure 1: differences between the demographic changes in California and in other U.S. states.

II. Residential Energy: Population and Housing Characteristics

A second hypothesis for California's apparent energy savings involves the changing composition of California's demographics relative to other U.S. states. Table 8 documents a set of simple descriptive statistics and their changes.[10] Some of the differences between California and other states are stark. Household incomes grew nationwide, but by 26% 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 touted as an objective by proponents of energy efficiency regulations.

[10] 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".

Begin by singling out one important characteristic, household size, in the seventh row of Table 8. 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 household sizes fell everywhere, they fell more slowly in California. California went from having smaller household sizes than other states in 1960 to having larger household sizes in 2009, gaining 0.6 members per household.

California's growing relative household size matters because energy use per capita shrinks with household sizes. Examine Figure 7. 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 1.8 fewer MBTUs of annual electricity use per household member.[11] Recall from Table 2 that California's apparent savings, depicted in Figure 1, amount to 4.7 MBTUs per person. Household size alone, without accounting for any other demographic differences between California and other states, explains 38 percent of California's apparent savings. For non-electric energy, the household-size explanation is even larger. An additional 0.6 household members reduces non-electric energy use by 6.5 MBTUs per capita, or 75 percent of California's apparent savings of 8.6 MBTUs per capita.

Household size is only one of the demographic changes depicted in Table 8. To predict how all of the demographic changes combined affected residential energy use, I use the pooled 1987 through 2005 RECS to estimate a version of equation (2) in which the dependent variable is BTU per household member, and which includes the following additional demographic characteristics chosen to match those in Table 8: number of children, number of rooms, number of bedrooms, an indicator for owner occupation, and indicators for homes built pre-1950 and post-1980.

Table 9 presents results of this regression. Although the RECS contains information about many other household and demographic characteristics, I have limited the regressions to variables available separately for California in the 1960 Census of Population and Housing, so that I can use the results from Table 9 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 Table 9 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 9 conform to intuition. Household income increases electricity use at the mean levels of heating and cooling degree days. Large households use less

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[11] Based on a regression of energy per household member on household size and fixed effects by year and census division.

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 and more non-electric energy.

In Table 9 owner-occupancy is associated with more energy use, 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 (size, a rural dummy, structure type, and dummies for the presence of dishwashers, clothes washers and swimming pools) the coefficient on owner occupancy is negative and statistically significant. This makes more intuitive sense, given that rental properties' tenants typically either don't pay their utility bills or don't choose their homes' appliances (Levinson and Neimann, 2004).

Table 10 combines the results in Table 9 with the relative changes in key household characteristics from Table 8. 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 153 thousand BTUs per household member – a small amount relative to the average electricity consumption of 15 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.[12] 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 9, this would result in a decline of 2294 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 and nearly 90 percent of the 8.6 million BTUs of non-electric energy savings.[13]

Together, the predicted effects of the long-term changes in household and home characteristics account for 2.8 million BTUs of residential electricity per household member, and 5.4 million BTUs of non-electric energy. More importantly, the energy use predicted from California's demographic changes account for 59 percent of California's apparent residential electricity savings, and 63 percent of the non-electric energy 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 9 imply that the long-run changes

[12] 153 thousand BTUs is calculated from the coefficients on income and the interaction terms with HDD and CDD in Table 9: $153=-\$11.11\times(-11.51+0.00019\times4380 \text{ HDDs} + 0.018\times1338 \text{ CDDs})$

[13] If we consider these predicted savings from demographic changes as a share of California's apparent energy savings based on the *absolute* growth in energy consumption (7.7 MBTU and 11.0 MBTU), the predictions explain 36% and 49% of California's apparent savings.

in household and home characteristics explain the majority of the apparent energy savings documented in Table 2 and Figure 2 and promoted by pictures like Figure 1.

Putting the three parts of this together, Figure 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. Another 21 percent can be attributed to the fact that nationwide income growth did less to increase energy demand in California's temperate climate. And a remaining 59 percent comes from a collection of demographic changes, such as California's rising relative household sizes and smaller homes. Together, 95 percent of the electricity savings appear coincidental, unrelated to regulations passed by California, and irrelevant to other states or countries considering passing or tightening energy efficiency standards.

None of this means that California's regulations have not been effective or beneficial. It simply means that figures like Figure 1 are uninformative as to those benefits.

III. 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 Figure 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 2 summarizes what those other figures would look like. Although residential electricity depicted in Figure 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 22 percent, respectively, and so even though California's energy efficiency gains were smaller for those sectors in percentage terms, those two sectors contributed more to California's overall energy efficiency gains. This section examines industry and transportation in turn.

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. Figure 8 depicts how net electricity use has changed over that time for each 3-digit North American Industrial Classification (NAICS) code.[14,15] 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 electricity use. 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.

To begin to assess those claims, Figure 9 plots the share of total manufacturing value added, in 1963 and 2009, for both California and other states. The pattern is similar. 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 scale of the change differs, 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 combine the information in Figure 8 and Figure 9 to 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.

$$\hat{E}_t^M = \sum_i \left(E_{i,1991}^M / v_{i,1991}\right) \times v_{it} \tag{3}$$

where $E_{i,1991}^M / v_{i,1991}$ 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*, 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.

Figure 10 plots equation (3) 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.

[14] 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.
[15] I use "net" electricity use because some industries cogenerate electricity as part of their production.

Table 11 shows the details of the calculations in equation (3), 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 11 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 savings shown in Figure 2 and Table 2.

Intra-industry Composition

Some of the observed energy efficiency gains may have come from true increases in energy efficiency, and some may come from intra-industry composition changes. Primary metals, for example, includes factories that produce aluminum from raw materials and pipes from purchased steel. The aluminum uses far more energy, and to the extent that production in the broad primary metals category has shifted away from aluminum and towards 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 Table 11 and Figure 9 and Figure 10. Recent years 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 avoid disclosing confidential business information. Consequently, at the bottom of Table 11 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 stayed flat or even shrank 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 towards 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.

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 travelled 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.

Figure 11 plots California and other U.S. states' motor fuel consumption per capita, indexed so that 1966 equals 100 (the first year of the DOT data). The pattern looks similar to that in Figure 1, the same figure drawn for residential electricity. At the bottom of Figure 11 I have plotted the difference between the two lines, and transportation fuel use shows the same pattern, a steadily increasing gap between California and the rest of the country. What explains this gap. The dashed line plots the growth rate using California's vehicle miles traveled per capita, divided by the national average fuel economy (miles per gallon). In other words, the dashed line plots what the growth of California motor fuel use would have been had California vehicles had the national fuel economy rather than California fuel economy. None of the gains are explained by fuel economy; Californians simply increased their driving miles by less than residents of other states.

IV. Conclusions: Adding Up the Contributions to Apparent Savings

The poster-child for energy efficiency regulations is residential electricity. Although it only accounts for 4 percent of California's 2009 energy use, it exhibits the most dramatic difference between California's growth rate since 1963 and that in other states. It turns out, however, that most of those apparent savings can be explained by long run trends unrelated to energy efficiency. Fifteen percent comes from the migration of the U.S. population from the North to the Southwest. Twenty-one percent comes from California's low income-elasticity of energy demand that is a consequence of its mild climate. And nearly 60 percent of the apparent savings can be explained by differences in the way the demographics of California and other states have changed: household incomes, household sizes, home sizes, etc. Although some of these changes may arguably be related to, or even a consequence of, energy efficiency regulations, they are decidedly not the objective of those regulations. California's laws were not designed to lower California incomes or home sizes, or to increase California household sizes relative to other states.

The largest share of energy consumption occurs in the transport sector, and here the energy efficiency gains are 100 percent illusory. All of them can be explained by a relative decline in miles driven by Californians. While that may be a worthy outcome, and may be driven by public policies such as fuel taxes or public transportation subsidies, it is not the result of energy efficiency. If there is a case to be made for California's energy efficiency gains, the strongest evidence comes from the industrial sector. Energy consumption by California's manufacturers has grown less quickly than in other states, despite the fact that the scale and composition of California's industries would suggest its energy use would have grown faster.

In the end, the findings here undermine Figure 1 as evidence for the efficacy 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. All we can say is that pictures such as Figure 1 do not demonstrate those standards' efficacy. 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.

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Table 1: California Energy Policies

Warren Alquist Act	Established the California Energy Commission (CEC) with authority to regulate appliances and (later) buildings.	1974
Title 20	First appliance standards in the US.	1976
Title 24	First building standards in the US.	1978
Decoupling natural gas profits from sales.		1978
Decoupling electric utility profits from power sales.		1982
AB 1890	Restructuring of electricity industry, mandated investment in public benefit programs.	1996
AB 32	Global Warming Solutions Act	2006

Source: Roland-Holst (2008)

Table 2: 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.

Table 3: 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 2*		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)
*Applies the share in columns (5) and (6) to the savings in Table 2.

Table 4: State Energy Consumption per Capita Predicted by Heating and Cooling Degree Days

	Residential		Commercial	
Dependent variable:	Electricity	Other Energy	Electricity	Other Energy
1000 BTUs/capita	(1)	(2)	(3)	(4)
Heating degree days	-0.220*	2.863*	-0.161*	1.953*
	(0.090)	(0.183)	(0.056)	(0.169)
Cooling degree days	1.222*	0.601	0.378*	2.548*
	(0.245)	(0.463)	(0.135)	(0.389)
Year trend	249.8*	139.8*	268.2*	483.4*
	(4.5)	(11.5)	(3.2)	(11.6)
Constant	11,494*	42,945*	10,134*	26,301*
	(761)	(1,422)	(429)	(1,230)
R-squared	0.594	0.357	0.743	0.440
Observations (48 states, 50 years)	2,400	2,400	2,400	2,400

Robust standard errors in parentheses.
*Statistically significant at 5 percent.

Table 5: Climate, Population Shifts, and Energy Consumption

	Predicted change in other states' energy/capita from HDD and CDD	Share of migration savings[a]
	MBTU/capita (1)	(2)
Residential		
Electricity	0.351	0.50
Other energy	−1.185	0.93
Commercial		
Electricity	0.151	0.72
Other energy	−0.371	0.37

Source: Predictions from Table 4.
[a]The shares in column (2) are simply the MBTU/capita from column (1) divided by the apparent MBTU/capita savings from migration in column (3) of Table 3.

Table 6: Household Energy Consumption per Household Predicted by Climate and Income

Dependent variable: 1000 BTUs	Means	Regression Coefficients: Electricity	Regression Coefficients: Non-electric Energy
	(1)	(2)	(3)
HDD division avg.	4,390	-0.658	16.18*
	(1,530)	(0.813)	(2.89)
CDD division avg.	1,327	6.061*	13.35
	(597)	(2.302)	(6.82)
Household income	51.2	-130.0*	395.3*
($1000s 2010)	(36.9)	(29.3)	(115.3)
HDD × income	226,487	0.0231*	-0.0146
	(189,210)	(0.0029)	(0.0216)
CDD × income	66,348	0.153*	-0.0643
	(58,832)	(0.016)	(0.0379)
Household size	2.66	3,656*	5,355*
	(1.47)	(481)	(944)
Trend (1963=1)	31.9	420*	-887*
	(6.0)	(67)	(165)
Constant		-3,060	-2,140
		(4,862)	(23,254)
Mean and std. dev. of dependent variable		33,910	88,907
		(23,878)	(54,356)
R-squared		0.259	0.193
Observations	33,531	33,531	23,395
Marginal effects			
Income at mean HDD and CDD		174	246
HDD at mean income		0.53	15.4
CDD at mean income		13.90	10.1

Standard errors in parentheses clustered by census division.
*Statistically significant at 5 percent.
Source: Residential Energy Consumption Surveys: 1987, 1990, 1993, 1997, 2001, 2005.

Table 7: Predicted Increase in Residential Energy From a $1000 Increase in Household Income (2010 dollars)

	Average HDD	Average CDD	Predicted Energy Increase (1000s of BTUs per Household) Electricity	Non-electric energy
	(1)	(2)	(3)	(4)
California	2,601	901	67.9	229.4
Other states	4,830	1,248	172.5	244.5
absolute diff (1000 BTUs/capita)			104.7	-54.8
per household member			39.2	-20.6
Share of apparent savings from $25,000 increase in household income.			20.2%	-6.0%

Uses regression coefficients in Table 6.

Table 8: Housing, Climate, and Household Characteristics

	California			Other US States			CA change relative to other states
	1960-1963	2009	Change	1960-1963	2009	Change	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Residential electricity per capita[g] (MBTU)	3.76	8.29	+4.53	4.98	17.21	+12.22	-7.70
Residential other energy per capita[g] (MBTU)	35.56	33.03	-3.53	53.21	60.65	+7.44	-10.97
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%
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%)
Occupied housing units (1000s)[b]	4,982	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
Rooms per house[b]	4.49	5.20	+0.71	4.90	5.67	+0.77	-0.06
Bedrooms per house[b]	2.05	2.58	+0.53	2.26	2.70	+0.44	+0.08
Built pre-1950[e]	0.600	0.305	-0.295	0.738	0.312	-0.426	+0.131
Built post-1980[e]	-	0.369	-	-	0.417	-	-0.048
Owner occupied[b]	0.584	0.566	-0.018	0.622	0.670	+0.048	-0.066
Kids < 14[d]	0.956	0.624	-0.332	1.092	0.535	-0.557	+0.225
Cooling degree days (population wtd avg)	901	901	-	1145	1349	+17.8%	+17.8%
Heating degree days (population wtd avg)	2601	2601	-	5066	4609	-9.0%	-9.0%

[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.

Table 9: Residential Energy Use per Household Member

Dependent variable: 1000 BTUs per household member	Means	Regression Coefficients	
		Electricity	Non-electric energy
	(1)	(2)	(3)
HDD	4,380	0.832*	3.944*
	(2,207)	(0.087)	(0.263)
CDD	1,338	1.002*	0.922
	(971)	(0.187)	(0.637)
Household income	53.0	-11.51	-31.13
($1000s 2010)	(37.0)	(7.68)	(22.10)
HDD × income		0.00019	-0.0027
		(0.00108)	(0.0030)
CDD × income		0.0180*	-0.0007
		(0.0025)	(0.0083)
Household size	2.76	-3,823*	-12,613*
	(1.47)	(64)	(192)
Kids	0.53	394*	2,752*
	(0.94)	(93)	(281)
Rooms	5.65	994*	3,412*
	(1.88)	(61)	(183)
Bedrooms	2.70	780*	2,526*
	(1.01)	(113)	(338)
Owner Occupied	0.067	1,679*	3,796*
		(154)	(477)
Built pre 1950	0.269	-2,287*	7,928*
		(152)	(438)
Built post 1980	0.282	585*	-5,106*
		(149)	(500)
Trend (1963=1)	33.6	133*	-445*
	(5.3)	(12)	(36)
Constant		7,112*	40,459*
		(717)	(2,188)
Mean and std. dev. of dependent variable		15,254	39,616
		(11,831)	(32,319)
R-squared		0.259	0.369
Observations	25,363	25,363	17,521

Regressions include 9 census division fixed effects.
Standard errors in parentheses.
*Statistically significant at 5 percent.
Source: Residential Energy Consumption Surveys: 1987, 1990, 1993, 1997, 2001, 2005.

Table 10: California Residential Energy Savings -- 1960-2009

Household characteristic	Average	Electricity: Coeff. from Table 9	Electricity: Predicted change (1000 BTUs)[b]	Non-electric Energy: Coeff. from Table 9	Non-electric Energy: Predicted change (1000 BTUs)[b]
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
(1) EIA Data					
Electricity /capita (1000 BTU)	11,374		-4,705		
Non-electric energy /capita (1000 BTU)	56,448				-8,637
(2) RECS Data and Predictions					
Real median household income ($2010)	-$11,408	13.4[a]	-153	-43.9[a]	+501
Household size	+0.60	-3,823	-2,294	-12,590	-7,568
Rooms per house	-0.06	994	-60	3,422	-205
Bedrooms per house	+0.08	780	+62	2,502	202
Built pre-1950	+0.131	-2,287	-300	8,844	1,039
Built post-1980	-0.048	585	-28	-3,983	245
Owner occupied	-0.066	1,679	-111	3,736	-251
Kids < 14	+0.225	394	89	2,610	619
Total Explained by Table 9 Regressions			-2,794		-5,417
Percent of apparent savings explained by regressions [(1)/(2)]			**59%**		**63%**

[a] The coefficient on income includes the coefficient on interactions with HDD and CDD in Table 9, multiplied by the means of HDD and CDD.
[b] The predicted changes are taken from the difference in percentage growth in per capita consumption, documented in Table 2. The fractions of savings are smaller (36% and 49%) of the predicted growth based on *absolute* growth.

Table 11: Predicted Manufacturing Energy Growth: 1963-2009

	Predicted energy use		Per capita	
Electricity Use based on 1991 MECS	**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

Figure 1: Residential Electricity Use per Capita 1963-2009

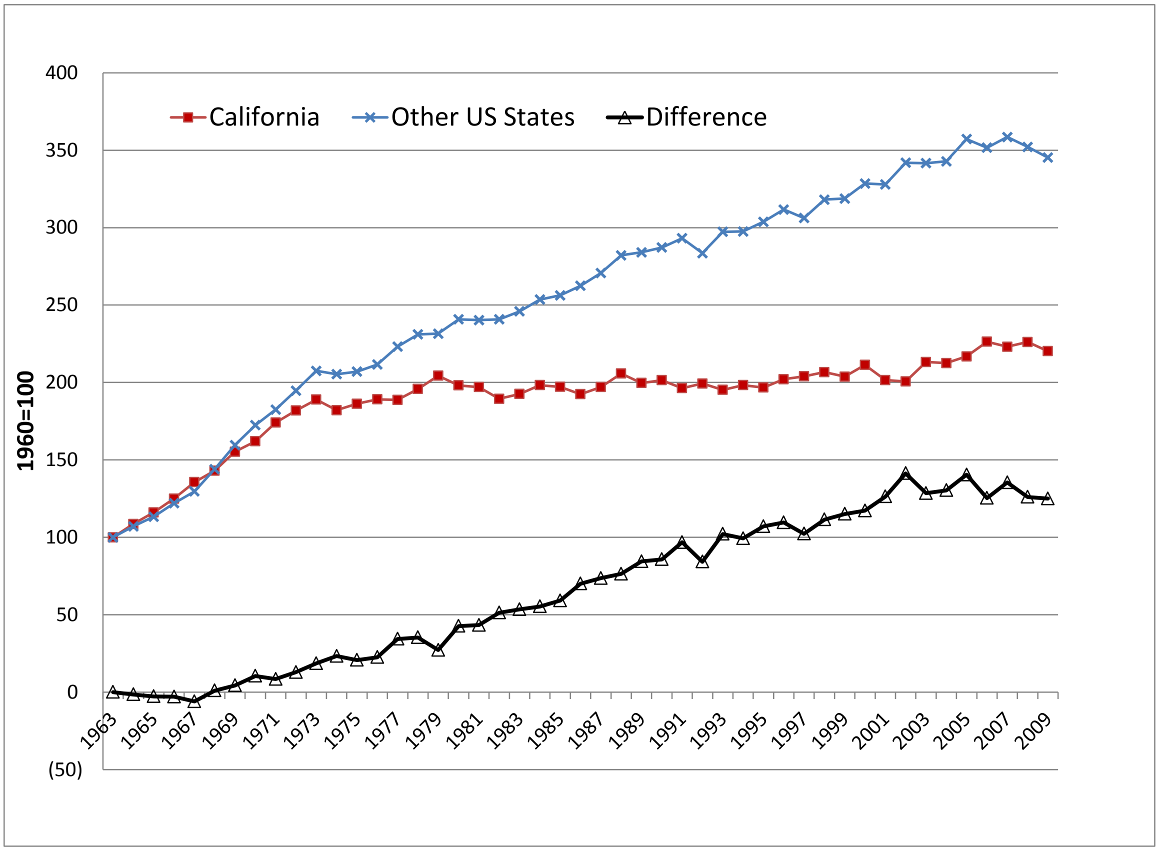

Figure 2: California Energy Savings 1963-2009

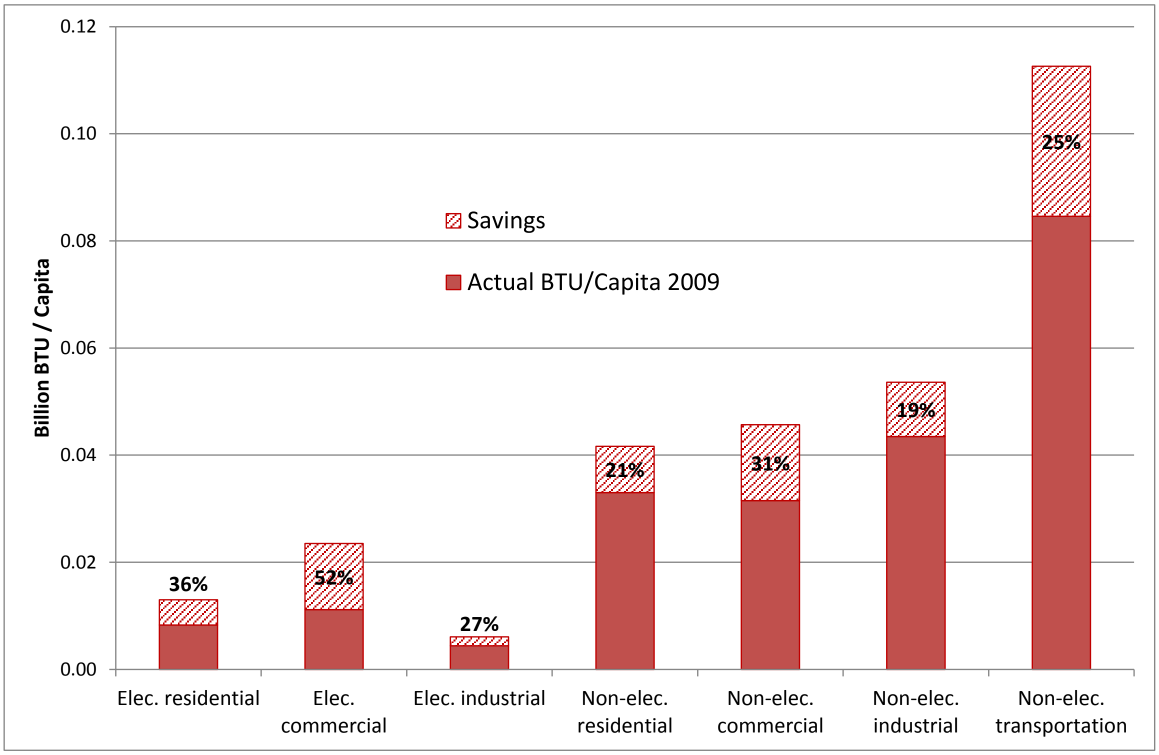

Figure 3: Population Shifts and Residential Electricity Use Per Capita

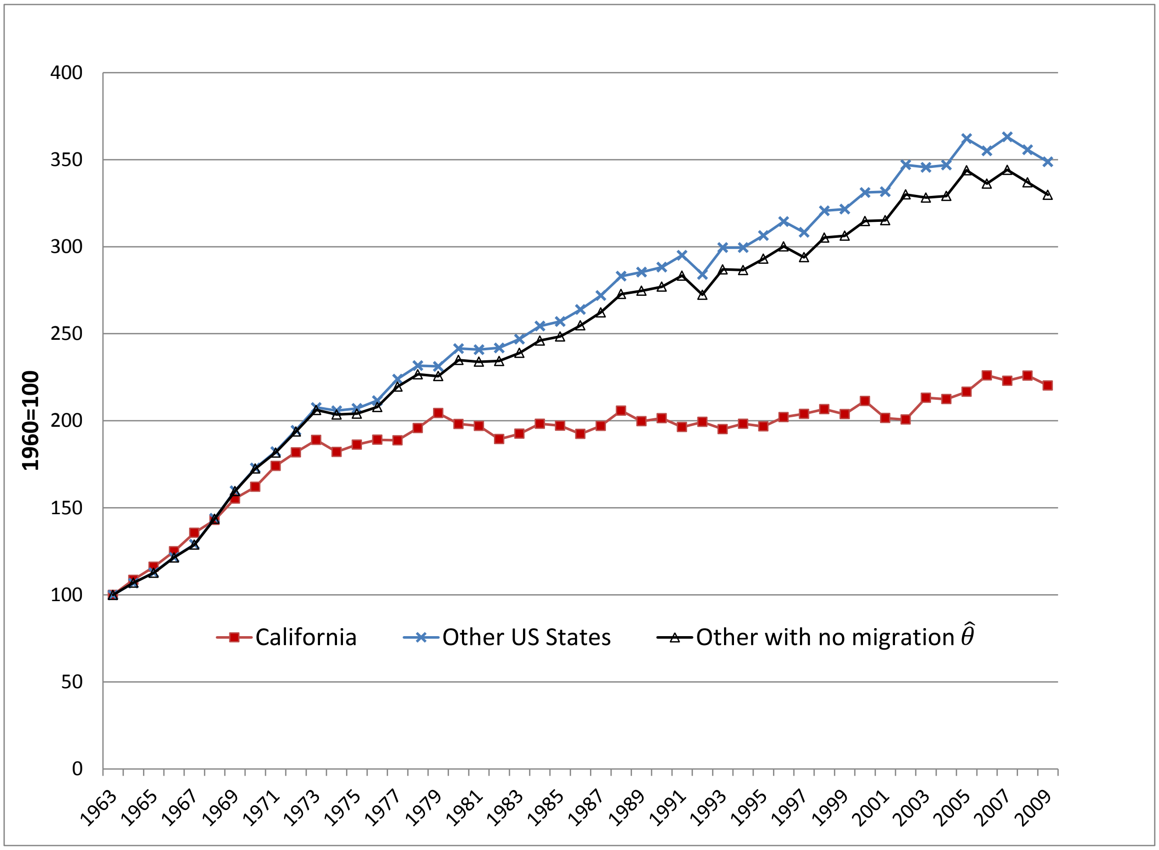

Figure 4: Population-weighted Heating and Cooling Degree Days 48 Contiguous States Aside from California

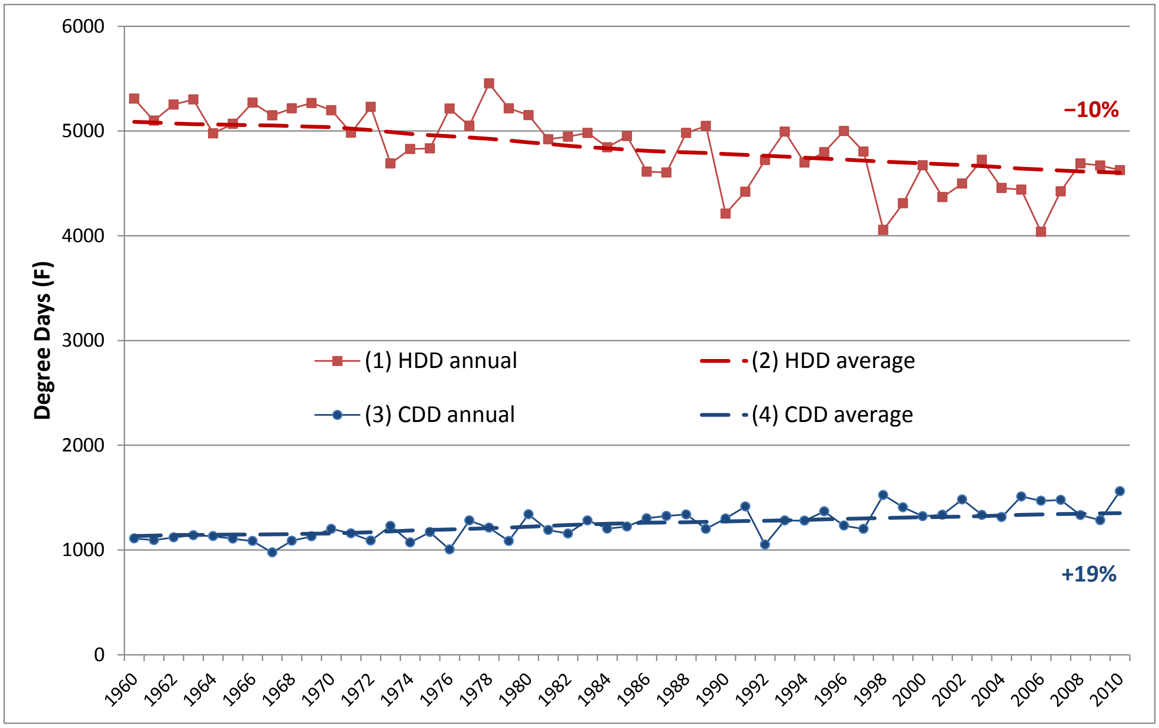

Figure 5: Predicted Residential Electricity Use per Capita
Based on State Heating and Cooling Degree Days

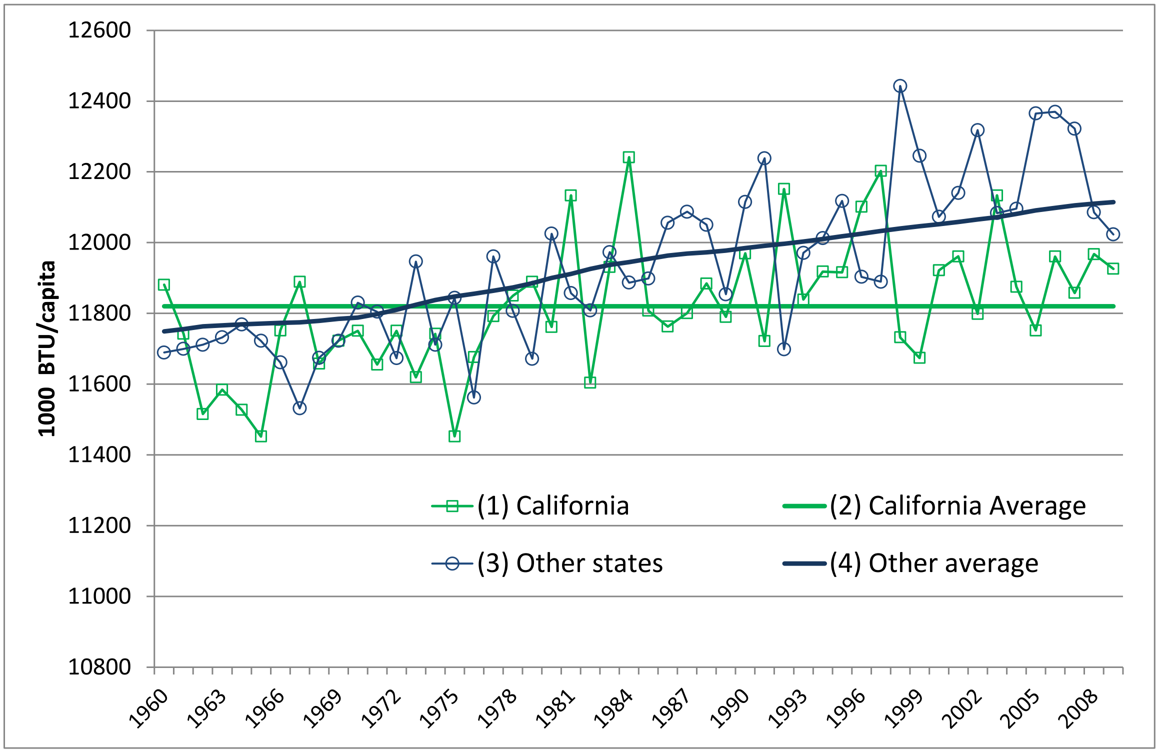

Figure 6: Overall Energy Use per Capita 1963-2009

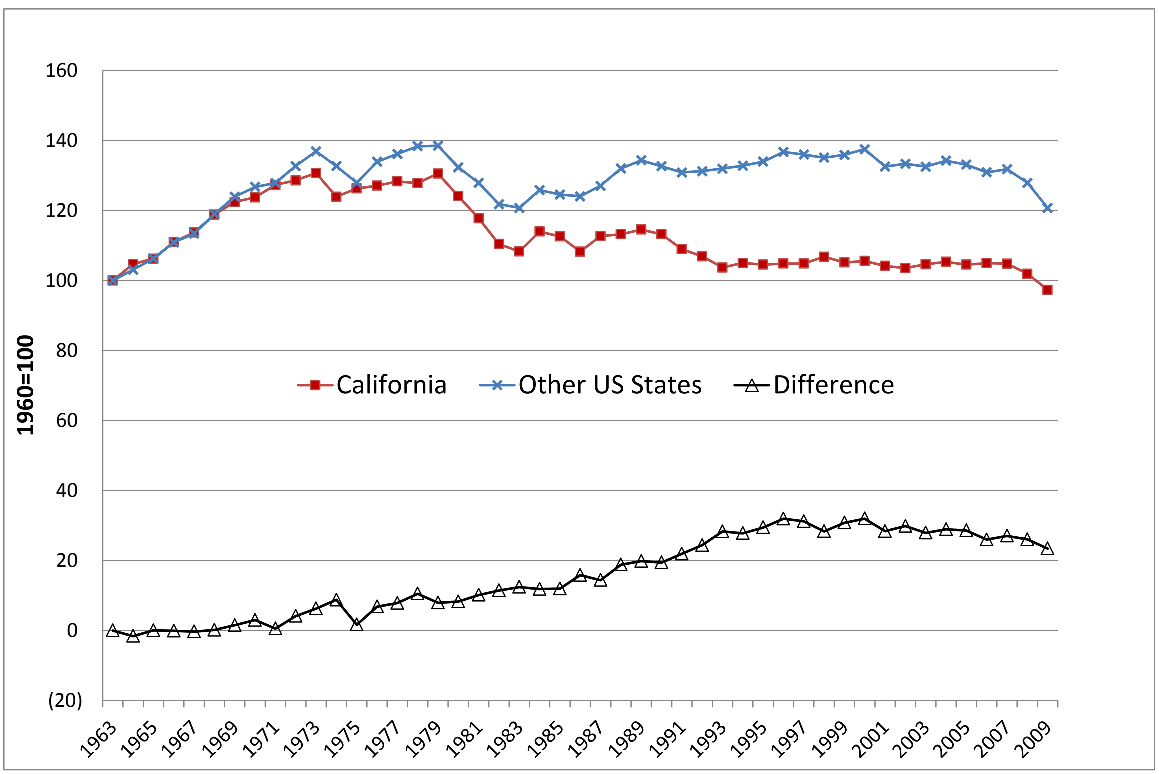

Figure 7: Residential Electricity Use by Household Size

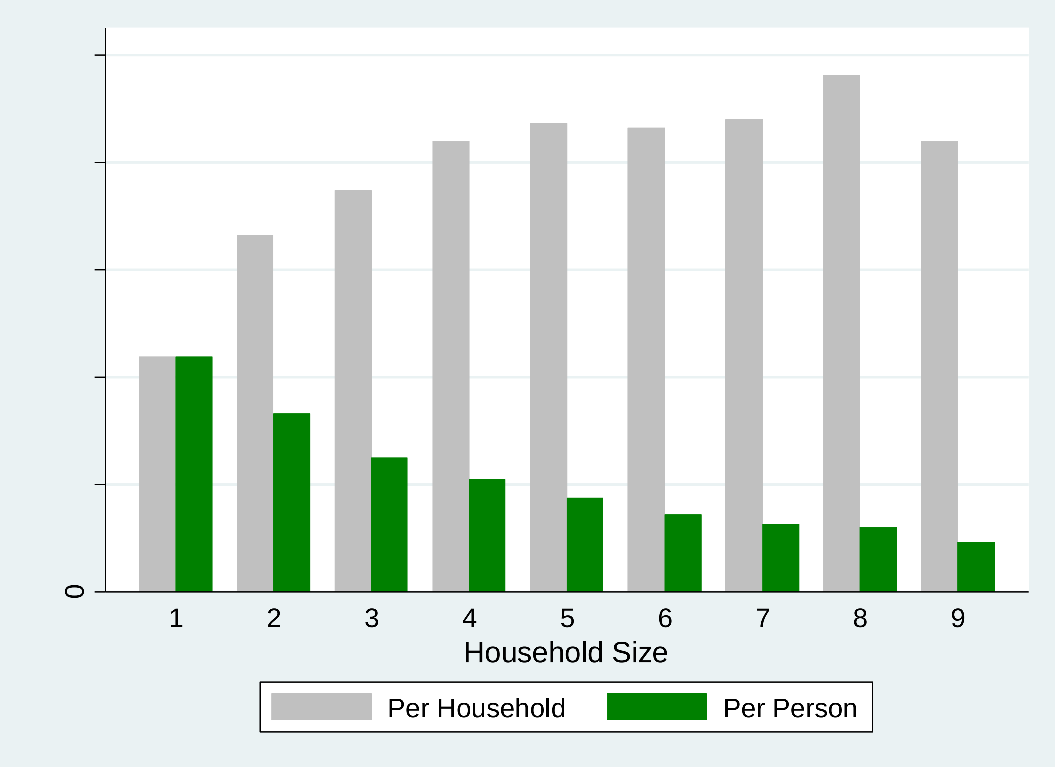

Figure 8: Changing U.S. Manufacturing Electricity Use

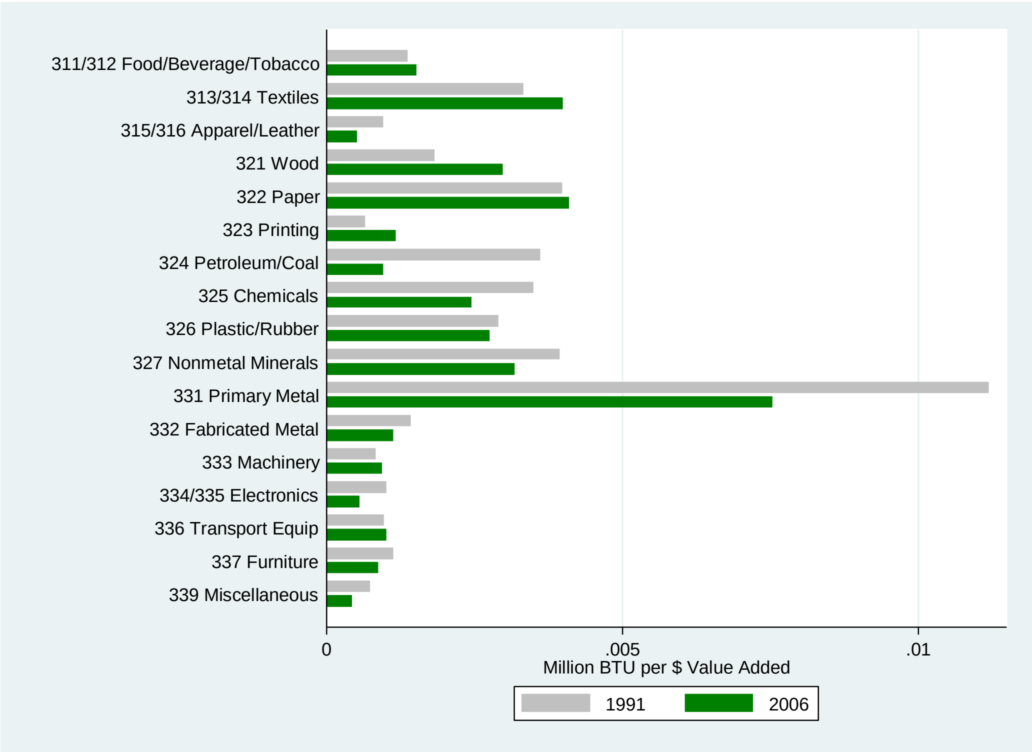

Figure 9: Changing Manufacturing Composition: 1963-2009

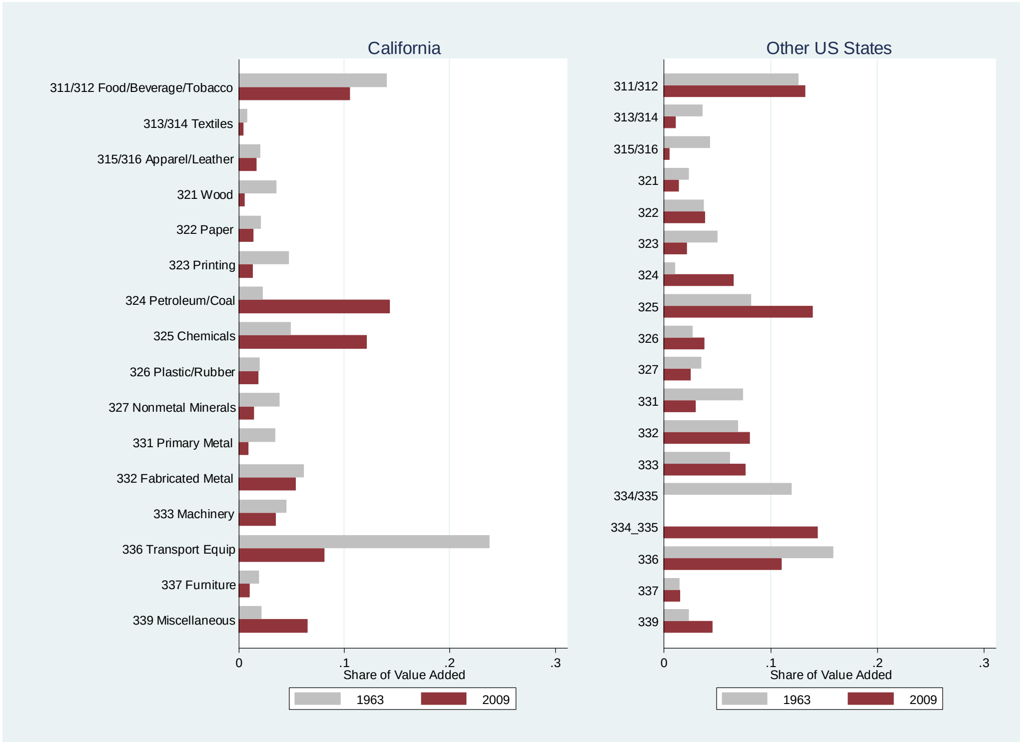

Figure 10: Predicted Manufacturing Electricity Use Per Capita: Based on 1991 MECS and Concurrent Industrial Composition

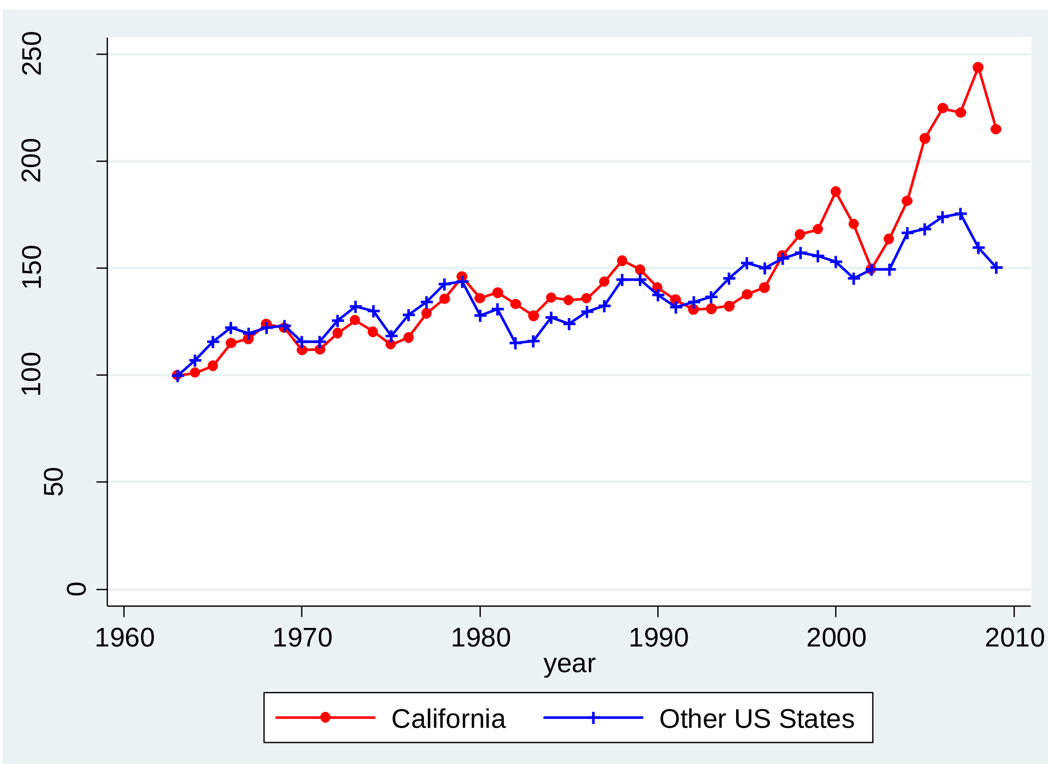

Figure 11: Motor Fuel Use per Capita