Deconstructing the 'Rosenfeld Curve': The Problem with Energy Intensities[☆]

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Abstract

As policy makers the world over seek to mitigate the growth in our demand for energy, examples of populations that appear to have achieved this end are of widespread interest. One such example is California where, since the early 1970s, electricity consumption per capita has stayed nearly constant even as it has risen steadily for the US as a whole. We use empirical data to estimate the fraction of the dierence between California and the United States owing to policy independent characteristics such as climate, industry structure or demographics, and the residual fraction that may be due to state program measures aimed at saving energy. We analyze historical trends in the commercial, industrial and residential sectors using aggregate survey statistics from various sources. In 2005 we estimate that over two thirds of the overall difference in energy intensity between California and the United States may be explained by structural differences between the two populations with the remaining third possibly a consequence of state policies to improve energy efficiency. We conclude that while a signicant policy effect may exist, caution needs to be exercised in using the California example to inform expectations from similar measures in other regions.

Keywords: Rosenfeld effect, California electricity, Energy Efficiency

1. Introduction

California's energy use patterns have garnered much interest in recent years. Since the early 1970s, electricity consumption per capita in California has stayed nearly constant, while rising

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steadily for the US as a whole. Alongside this empirical fact, state energy policies have led the nation in encouraging energy efficiency programs and stringent appliance and building standards. In addition to regulatory policy, California has incentivized utilities to implement a diverse set of programs with the aim of reducing consumer demand for energy through the adoption of efficient technologies and conservation behavior. Eom and Sweeney (2009) provide an overview of some of these activities, most of which are primarily focused on the demand side. Gillingham et al. (2006) provide a more national level review of demand side programs.

In this context, it is unsurprising that a causal link is often drawn (especially in policy discourse outside academia) between a set of regulatory policies and utility programs and the differential between state and national electricity per-capita consumption levels. Indeed a graph comparing retail sales of electricity per capita for California and the United States is often casually referred to as the 'Rosenfeld Curve', after Arthur Rosenfeld, the influential member of California's Energy Commission (See Figures 1 and 2). The ubiquity of this term and the use of illustrations (see Rosenfeld 2005) such as Figure 1 has sometimes led to the assumption that if only the rest of the nation were to have followed California's lead, they might have achieved similar outcomes.

The California experiment with energy efficiency has become a well known case study today. So much so that in a recent issue of the Journal of Environmental Research Letters, an article entitled *'Defining a standard metric for electricity savings'* (Koomey et al. 2010) authored by many of the United State's leading energy and environment economists and engineers suggested creating a unit to measure energy efficiency savings called the 'Rosenfeld', "*...in honor of the person most responsible for the discovery and widespread adoption of the underlying scientific principle in question—Dr Arthur H Rosenfeld.*" A recent discussion of energy efficiency in the widely read Science journal (Charles, 2009) also focused on the Rosenfeld curve.

As other states in the US (and countries abroad), seek to put in place similar regulations and programs it is important to determine ways of evaluating such programs. If California policy is to be emulated elsewhere in the world, it is necessary to understand exactly how much of the Rosenfeld effect could owe to policy. This helps us understand whether other populations could indeed duplicate the California experience and provides a basis for understanding the degree to which energy efficiency can aid in the global effort to reduce energy intensities. While looking at the Rosenfeld curve what we should look to ask is how much the state would have consumed absent policy, or equivalently, what the the United States as a whole might have looked like if the

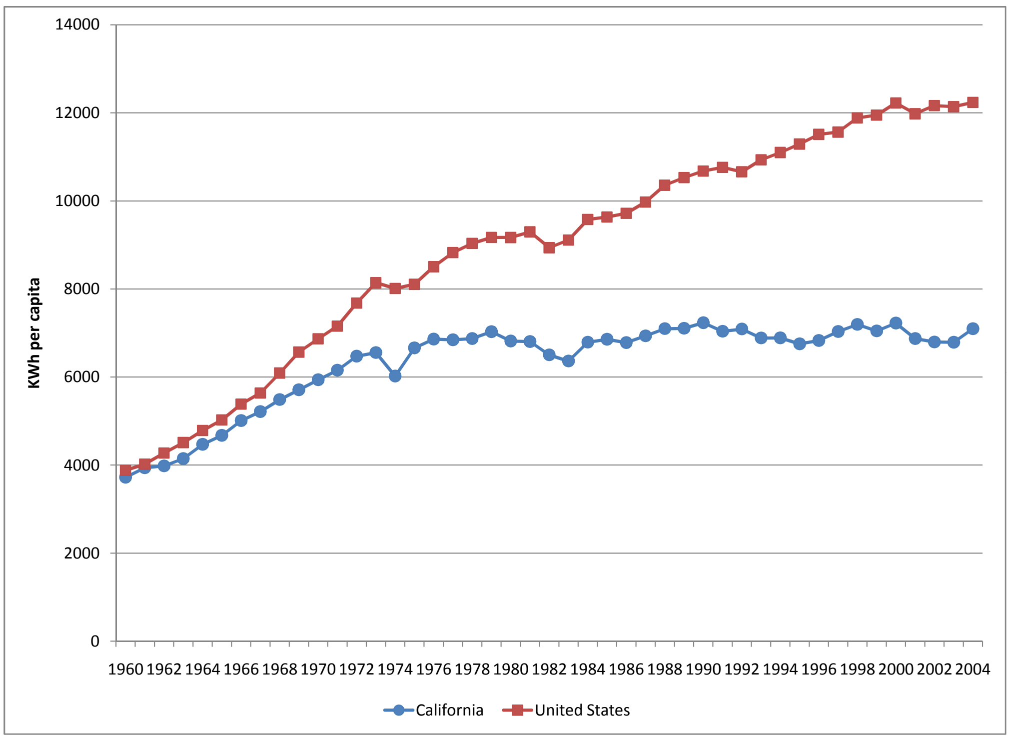

Figure 1: The Rosenfeld Curve showing the evolution of per capita electricity consumption in California and the United States

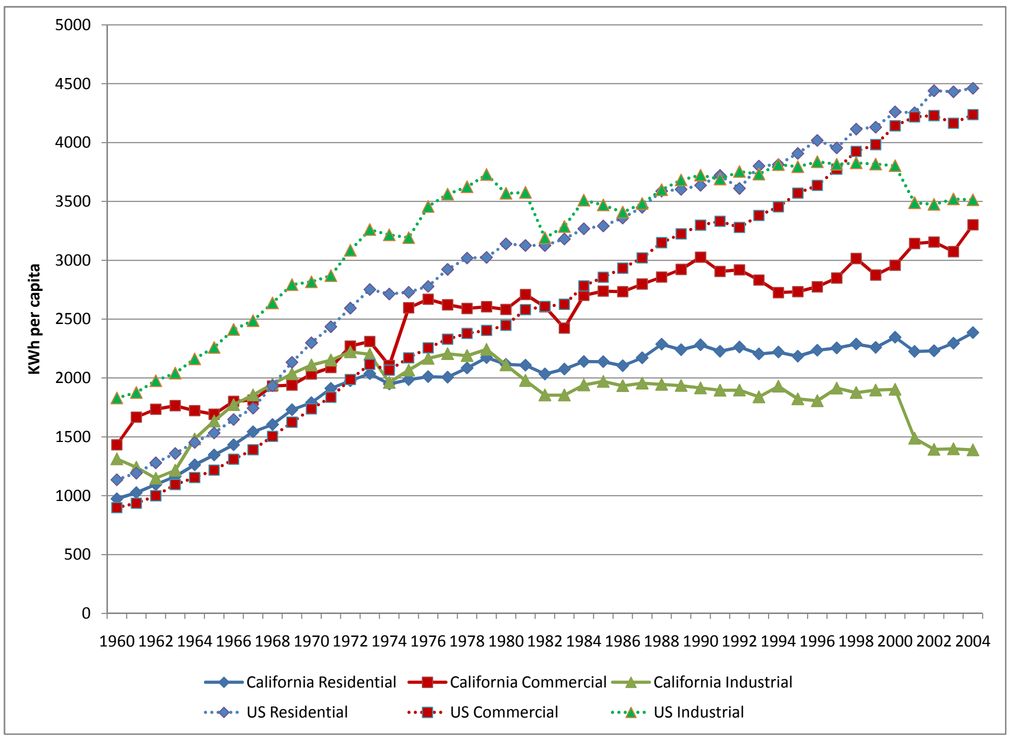

Figure 2: Sector-wise comparison of California and US electricity consumption (Source: EIA electricity sales figures).

country had the same structural characteristics (climate, demographics, industry structure etc) as California.

This paper demonstrates why answering that question is complicated and presents a simple analysis to show that state programs are not the primary determinant of California's low energy intensities. Additionally it serves to remind us of the limited utility of aggregate statistics such as energy intensity (expressed per capita or otherwise) in comparing populations. These statistics and others derived from energy indices (including those obtained from index decomposition methods) have grown increasingly popular in the literature on applied energy policy literature. While useful for many purposes, caution should be exercised in drawing causal inferences from such statistics (see also Horowitz, 2008) and this paper provides further evidence to that end.

While this paper does not claim to rigorously determine the precise impact of California efficiency programs or substitute for econometric evaluation techniques (see for example Sudarshan 2010), we do show that examining energy intensities can be misleading and demonstrate how a variety of structural factors are important to account for when evaluating energy demand characteristics. This argument holds not merely for California, but more generally for intensity centered population comparisons in general.

2. Background

The causes underlying the differences in electricity intensity between California and the United States have been speculated about in recent years, but for the most part the energy economics literature has not directly analysed this problem. Bernstein et al. (2000) studied the public benefits of energy use changes and improved efficiencies in California without looking at the causes in detail. The California Energy Commission publishes savings estimates (see California Energy Commission 2003) that are obtained 'bottom up' using a combination of scenarios generated by an energy systems model, self reported utility estimates and expert inputs. Some early work focusing specifically on California and relying on empirical data is that of Schipper and McMahon (1995)[1]. More recently, Kahn and Costa (2010) examine a dataset of homes from a few districts within California and conclude that building standards and political ideology play a large part in explaining why some households consume less energy.

On a related question though, a few studies have sought to estimate the average cost effectiveness of utility efficiency programs at a national level. This body of work has sometimes come to mixed conclusions (see for example Loughran and Kulick 2004 and Auffhammer et al. 2008), but as a whole, these studies do suggest that utility programs implemented nationwide have produced cost effective savings, albeit with these savings making up only a small fraction of overall energy use. In perhaps the most thorough recent analysis, Arimura et al. (2009) concluded that demand side management (DSM) expenditures over the last 18 years have resulted in a central estimate of 1.1 percent electricity savings at a weighted average cost to utilities (or other program funders) of about 6 cents per kWh saved. Unfortunately this conclusion does not tell us very much about why one state, California, differs so much from the rest of the nation.

In terms of exploring state nation differences, (Horowitz 2004, 2007) is work that is perhaps closest in spirit to our objective. The author uses simple reduced form equations relating historic energy consumption to state level efficiency program spending levels and employs a difference in differences estimator and a counter-factual comparison to obtain 'policy effects' for states with high levels of efficiency spending.

3. Outline

Our first task is to investigate the importance of a variety of structural factors in driving differences in electricity consumption between California and the country as a whole. In order to do so, aggregate statistics derived from empirical survey data are used to carry out a simple decomposition analysis[2]. This is described in Sections 4,5,6 which deal with the industrial, commercial and residential sectors respectively. Historical trends are also considered, and Section 8 discusses how an analysis of data from years past sheds light on the divergence over time between the state and nation.

The conclusions from this exercise are summarized in Section 10. While state-nation differences in the commercial and industrial sector can largely be explained by a single factor (floorspace distribution and industry mix respectively), the residential sector is much more complicated. Examination of the empirical data reveals that important structural differences exist between California and US households. Overall we find that the structural variables examined here are crucial in determining how much electricity the state has consumed. There have been significant shifts in this structure over time, in a manner consistent with the overall trend. This analysis suggests that observable heterogeneity between populations has large effects on electricity consumption and consequently it is not straightforward to determine whether or not California provides an example of successful policy (in spite of the dramatic effects suggested by Figure 1).

4. Industrial Sector Electricity Consumption

We begin this analysis by considering the industrial sector. In 2005, about 20 percent of California's electricity sales were reported as being to the industrial sector. This was a lower percentage than the corresponding figure for the United States in the same year, where industrial sales made up about 29 percent of the total. In absolute terms also, per capita industrial electricity consumption in California was significantly lower than for the nation as a whole. State per capita electricity sales to industry were 1391 KWh in 2005, 60 percent lower than the national average of 3438 KWh (all figures computed using EIA retail sales figures and 2005 American Community Survey population estimates).

This is a large difference and before determining how much efficiency policies may have contributed, it is important to adjust for a few first order structural factors. Part of the difference between the state of California and the US could be due to smaller, lighter industry, relative to the national industry profile. There are two important aspects of the industrial sector that influence energy use. The first is obviously the type of industry - refineries and chemical industry units for example, are far more energy intensive than firms manufacturing microprocessors. Apart from the type of industry, the size of units makes a substantial difference to energy intensities - partly due to economies of scale, and partly because the product mix of smaller and larger manufacturing units may differ. Finally, it is necessary to account for the different forms of energy that may be used by the industry. In the present context we are interested in electricity consumption.

The first stage in our analysis of this sector is therefore to account for differences due to the nature of industry. We disaggregate the sector both by industry type (based on NAICS codes) and by size, as measured by the number of employees. The latter metric of size better captures potential differences in the manufacturing process being used by the industry. Corresponding to this choice one can write the following general expression for per capita industrial electricity consumption

$$E^{ind} = \frac{\sum_i \sum_j \alpha_{ij} \eta_i p_{ij}}{P} \tag{1}$$

where

E^{ind} is the industrial electricity consumption per capita,

α_{ij} is the average energy use per employee in industry type i, belonging to employee size group j,

η_i is electricity as a fraction of total energy consumption in industry type i,
p_{ij} is the number of employees working in units of type i and size group j,
P is the total population.

Consider evaluating expression 1 with national averages for α_{ij} and η_i but with the actual California distribution of p_{ij} and P. This provides a hypothetical number representing what California industrial energy per capita would have been when adjusted for the actual industry structure but *without* any role for additional state specific energy efficiency. This figure will be higher than the actual California statistic to the extent that energy use efficiencies exist, over and above differences induced purely by industry structure. It will be lower than the US statistic to the extent the average California industry structure differs significantly from the national average.

We use the United States Economic Census and the 2005 Statistics of US Business survey to obtain information on the distribution (by number of employees) of different industries in both California and the United States. The 2006 Manufacturing Energy Consumption Survey (Energy Information Administration 2006) provides energy intensities (energy use per employee) for different unit sizes and NAICS codes. The industrial sector was categorized into manufacturing industries, construction, mining and agriculture, forestry and fishing subsectors. The manufacturing subsector was further broken down into different industry types covering over 96 percent of the total number of employees in manufacturing. Because electricity intensities in the manufacturing sector differ not just based on the type of industry but also the size of units within each type, it is not straightforward to summarize this analysis in a single table. Some insight may be gained from Table 1 while keeping in mind that the electricity intensity listed is for the average unit size which may be different from the unit sizes actually present in the two populations. In many instances this 'within group' variation further enhances the divergence between state and nation.

We find that a significant fraction of the observed difference in industrial electricity consumption between the nation and the state may be explained simply by which industries make up the largest share of the industrial sector, and the unit sizes most prevalent. Based on these factors alone, California's per capita industrial electricity sales are predicted to be only about 81.30 percent of the nationwide figure or about 2796 KWh. Thus a 18.70 percent reduction is accounted for simply by differences in industry structure (see Table 2).

NAICS	Industry Name	CA Employment Percentage	US Employment Percentage	CA-US % Difference
334	Computer and Electronic Product Mfg	9.73%	5.02%	4.71%
23	Construction	36.69%	32.12%	4.58%
315	Apparel Mfg	3.61%	1.15%	2.46%
	Other	2.19%	0.67%	1.51%
339	Miscellaneous Mfg	4.27%	3.26%	1.01%
312	Beverage and Tobacco	1.41%	0.73%	0.67%
324	Petroleum	0.50%	0.00%	0.50%
11	Agriculture, forestry, fishing, & hunting	1.01%	0.80%	0.21%
337	Furniture and related products	2.53%	2.59%	-0.06%
327	Nonmetallic Mineral Product Mfg	1.96%	2.22%	-0.26%
311	Food Mfg	6.64%	6.96%	-0.32%
323	Printing and support activities	2.71%	3.12%	-0.40%
325	Chemical Mfg	3.27%	3.84%	-0.56%
335	Electrical equipment, appliance, component mfg	1.42%	2.02%	-0.60%
314	Textile Product Mills	0.00%	0.78%	-0.78%
332	Fabricated Metal Product Mfg	6.32%	7.20%	-0.88%
326	Plastics and rubber products	3.35%	4.27%	-0.92%
313	Textile Mills	0.00%	0.99%	-0.99%
322	Paper mfg	1.15%	2.15%	-1.00%
321	Wood Product mfg	1.56%	2.63%	-1.08%
21	Mining	0.83%	2.36%	-1.52%
336	Transportation Equipment Mfg	5.72%	7.75%	-2.02%
333	Machinery Mfg	3.13%	5.24%	-2.12%
331	Primary Metal mfg	0.00%	2.14%	-2.14%

Table 1: Electricity intensity and industry structure for California and the United States at the two digit NAICS level (Source: 2005 SUSBS and 2006 MECS)

4.1. Industry Self Generation

Aside from the structural makeup of the industrial sector, an additional factor influencing retail electricity sales is the percentage of electricity generated on-site, since electricity generated on-site is not included in data on electricity sales (or adjusted for in Figure 1), even though it represents electricity use. There is a greater fraction of on-site generation in California than in the United States. While total on-site generation nationally stood at 144,739 KWh in 2005 (14.20 percent of total industrial sales), in California the corresponding figure was 16,615 KWh (33.61 percent of state industrial electricity sales). Were the share of self generation in California the same as the national average, an increase in state retail electricity sales mighted be expected. Expressed as a percentage of national average industrial sector energy consumption this implies an adjustment by about 6.6 percent of the national average (all figures based on EIA records)[3].

Adjusting for these two factors explains about half (48 percent) of the difference between state and national figures. The remainder must owe to other causes including higher efficiency in California's industrial sector. This does not rule out other forces contributing to the observed difference. Nor does it rule out the possibility that California industry are more efficient for reasons independent of any efforts made by the state or utilities. With those caveats however, one could start by regarding 52 percent of the observed US-CA difference in 2005 as being an approximate upper bound on the effects of policy. In per capita energy units this is about 1061 KWh per capita (see Table **2)**. The propogation of statistical sampling errors in our corrections is accounted for wherever original sampling errors are available to us. In the case of the industrial sector statistical error is associated with the estimates of manufacturing sector electricity consumption figures (from the EIA MECS 2002, 2006 surveys), but not with the counts of establishments of a particular size and type (those numbers are based on universal counts from the Census Bureau). Table 2 contains statistical errors corresponding to 90 percent confidence.

5. Commercial Sector Electricity Consumption

As a primarily services oriented economy, most of California's economic output comes from activities classified as belonging to the commercial sector. On a per capita basis nearly half of electricity sales are to commercial consumers. Unlike in the case of industry, most use of electricity in this sector is for lighting, space conditioning and the use of various appliances (such as office equipment). Because most energy demands in the sector are associated with building related loads, a natural variable to examine in understanding the commercial sector is building floor space. Thus just as NAICS codes and business size were used as the basis for studying the industrial sector, square feet of building space and the distribution of floor space end uses will be employed as the basis for studying units in the commercial sector.

The energy intensities of different parts of the commercial sector differ widely. For example, food sales and food service (restaurants, cafeterias, food stores, etc.) establishments use about 50 KWh of electricity per square foot, significantly more than the educational sector, where energy intensities are about 11 KWh per sq ft (national average figures, from the 2003 Commercial Buildings Energy Consumption Survey). Thus the distribution of end uses in the commercial sector can potentially have a significant impact on electricity consumed. Additionally, there are significant differences in the per capita density of commercial floorspace between California and the US. The US as a whole uses more commercial floorspace per capita, across all end uses, than does California (see Figure 5). Consequently independent of any efficiency differences (for instance high efficiency lighting, or better HVAC systems) the state electricity consumption would be lowered because of this fact.

Commercial electricity sales may be estimated as

$$E^{com} = \sum_i \frac{\alpha_i f_i}{P} \tag{2}$$

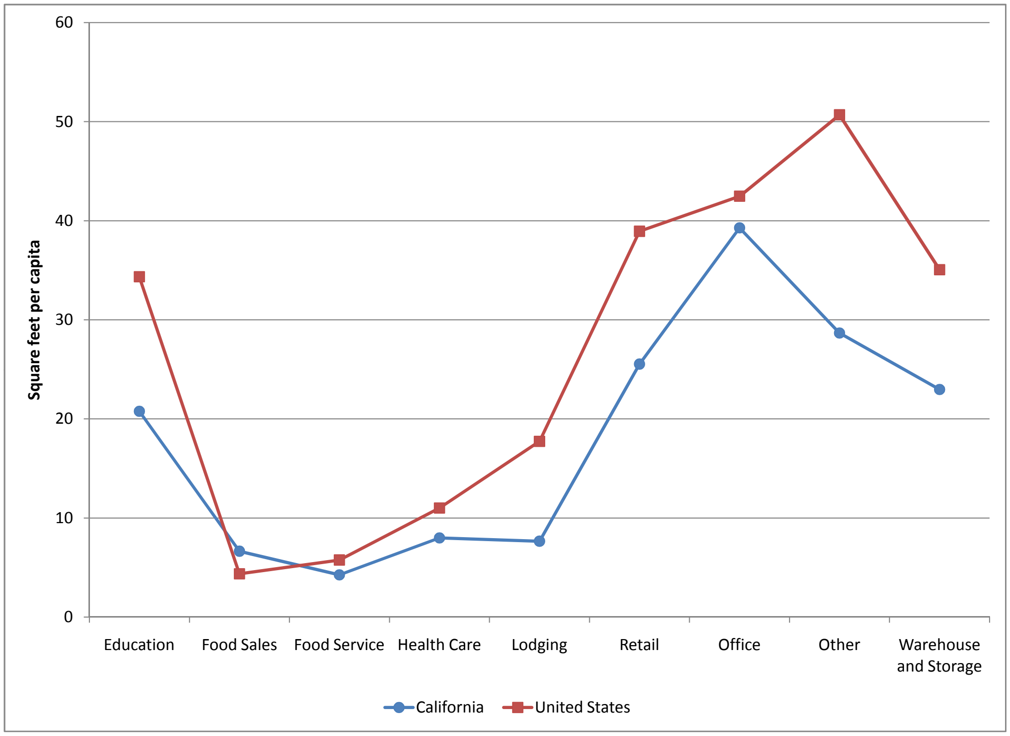

Figure 3: A comparison of California and US commercial floorspace. Source: California Energy Commission 2003, Energy Information Administration 2003

where

α_i is the electricity intensity for floorspace belonging to end use type i,

f_i is the floorspace occupied by buildings of end use type i,

P is the total state population.

Evaluating expression 2 with national energy intensity averages (α_i, the KWh per square foot across different end uses) but the actual distribution of floorspace in California (f_i) provides us with a counterfactual estimate of what state commercial sector consumption would be, corrected for floorspace differences but not accounting for any additional state specific energy efficiency improvements. Using 2003 figures (the latest year of the CBECS survey), and comparing this with the corresponding US figure, indicates that state-nation differences in per capita commercial floorspace density alone, account for California's per capita consumption being about 27 percent lower than the national figure. The actual difference in 2003, based on a comparison of CEC sales figures for the state and EIA statistics for the nation, was only somewhat greater (33 percent of the US figure). It therefore seems that most of the difference between state and national level commercial electricity sales can be explained by differences in floor space intensity (square feet per capita), and the sector usage shares. The residual can then be regarded as a combination of the effects of policy variables (efficiency measures, utility programs, prices, appliance and building standards) and other unaccounted structural factors. Table 2 presents the 2003 estimates extrapolated to 2005 (to provide all sectoral results for a common year). Figure 5 illustrates the results of a historical decomposition using available data from the CBECS surveys back to 1979.

6. Residential Sector Electricity Consumption

The largest and fastest growing electricity consuming sector in California is the residential sector. It is both complicated and interesting because a variety of factors affect use of electricity and because many of these factors can be influenced to change consumption. The basic consuming unit within this sector is the household; consequently our interest is in factors that influence the electricity consumption of households. In keeping with the goal of this paper, we quantify factors such as demographics or climate that are independent from energy efficiency policies, and distinguish these from other forces, such as prices and technology characteristics, that are directly influenced by energy efficiency policies. Whether any given factor is a structural or policy independent variable is to an extent a matter of assumption, but by attempting to explicitly calculating the contribution of different factors to the Rosenfeld effect we hope to highlight just how much of a difference observable heterogeneity makes. Some variables one might regard as structural are listed below.

1. Household income distribution
2. Household size distribution
3. Householder age profile
4. Climate characteristics
5. Urbanization
6. Housing unit floor space
7. Housing unit age
8. Fuel choices (for space conditioning and water heating)

In attempting to quantify the role of each of these variables on residential sector electricity consumption, the following general methodology is employed. Beginning with aggregate data from surveys of consumption and household data[4], we define test statistics that are measures of the expected household electricity consumption in California and the US, corrected for state-nation differences in one factor alone. This is similar to the adjustments made in analysing the commercial and industrial sectors, except repeated for more factors. In general terms we have

$$\begin{aligned} \hat{E}_{us} &= f(\alpha_{us}, X_{us}) \\ \hat{E}^{ca}_{adj} &= f(\alpha_{us}, X_{ca}) \end{aligned}$$

Here $\hat{E}_{us}$ is an expression for per capita residential electricity consumption written as a function of a vector of structural parameters X_{us} (such as the number of households of a particular size) and a vector of 'efficiency' parameters α_{us} (such as the national average electricity use for a household in a given size group). By using national average values for α_{us} and X an estimate of the national average electricity consumption is obtained. When we substitute values of the state structural parameters X_{ca} in place of the national structure, while leaving the efficiency parameters α_{us} at the national average, we obtain $\hat{E}^{ca}_{adj}$. $\hat{E}^{ca}_{adj}$ is an estimate of what the national figure $\hat{E}_{us}$ would have been, had the US structure looked like California but efficiency remained unchanged. To obtain the empirical estimates required to carry this out, we rely on the EIA Residential Energy Consumption Surveys (RECS) as well as the American Community Survey and Census data (primarily as a source of accurate population counts). Because a significant sampling error is associated with inputs X, α(since our best estimates of these are sample surveys such as the EIA RECS survey), We derive a standard error for all test statistics as well. I then look for statistically significant differences between the US and CA values. That is we test the hypothesis $\hat{E}_{us} \neq \hat{E}^{ca}_{adj}$ against the null hypothesis $\hat{E}_{us} = \hat{E}^{ca}_{adj}$. A significant difference between the two values is then attributed to state-nation differences in the particular characteristic in question.

In spirit this type of analysis is similar to index decomposition techniques such as the Laspeyres or Divisia index methods that are often used to analyze time series of macro data (see for example Schipper and McMahon 1995, Metcalf 2008). One concern which is common in these studies is that while the data for decomposition are often obtained from empirical surveys, typically no assessment is made of the extent to which sampling standard errors influence the derived indices. In this paper, wherever possible, we explicitly account for the sampling error in our data. This ensures that structural factors are incorporated in the decomposition only if they are likely to be significant[5]. The aggregation over various structural factors is multiplicative. Before proceeding we should acknowledge a problem that the alert reader will no doubt have already noticed. By aggregating the effect of different structural variables we assume that these are independent forces. To the extent that this is not true, we may end up double counting certain structural effects. Sudarshan (2010) takes a different approach to this problem and estimates a complete econometric model of household demand that addresses this concern for the residential sector.

6.1. Household Income Distribution

Household income is a key driver of energy consumption patterns, through its link to increased living standards and consequently lifestyle changes. In general, lower household incomes are associated with lower energy consumption. As income rises, so does the demand for energy, primarily owing to increasing appliance stocks. At high income levels some flattening or even reductions in consumption may be observed. This is both due to saturation in energy demand, as well as an increasing ability to afford energy efficient technologies.

In testing for the effect of household income we define two quantities

$$\hat{E}_{ca}^{adj} = \sum_i \frac{H_{ca}^i \alpha_{us}^i}{P_{ca}} \text{ and } \hat{E}_{us} = \sum_i \frac{H_{us}^i \alpha_{us}^i}{P_{us}}$$

where

H_{ca}^i and H_{us}^i are the numbers of CA and US households in income group i, respectively,

P_{ca} and P_{us} are the total number of households in California and the US, respectively,

α_{us}^i is the national average household electricity consumption (annually) for a household in income group i.

$\hat{E}_{us}$ is the average household electricity consumption in the United States. $\hat{E}_{ca}^{adj}$ estimates what the average household electricity consumption in California would be, if the state differed from the nation only in the distribution of households by income. Differences between $\bar{E}_{us}$ and E_{ca}^{in} can then be interpreted as differences in average per capita consumption that result purely from differences in the distributions of households by income group. Formally we test the hypothesis $H_0 : \hat{E}_{ca}^{adj} = \hat{E}_{us}$ versus the alternative $H_1 : \hat{E}_{ca}^{adj} \neq \hat{E}_{us}$ and thus account for standard errors in empirical data.

We find that state-nation differences in household income distribution alone, would cause California's household electricity consumption to *exceed* the national figure by about 5.90 percent

(±2.48 percent) of the US average. This difference is significant at a 90 percent confidence level and thus H_0 is rejected[6].

6.2. Household Size Distribution

A demographic characteristic that could affect observed per capita electricity consumption is the average size of households in a state. Larger families are able to attain economies of scale (see O'Neill and Chen 2002) and therefore systematic differences in the size of households in California as compared to the national average could reduce per capita residential energy consumption figures. Census data indicates that such a difference does exist, with the average household size in 2005 in California being 2.92 members as compared to 2.60 for the United States.

The test statistic in this case is conceptually the same as that for household income. We define the two quantities:

$$\hat{E}_{ca}^{adj} = \sum_i \frac{H_{ca}^i \alpha_{us}^i}{P_{ca}} \text{ and } \hat{E}_{us} = \sum_i \frac{H_{us}^i \alpha_{us}^i}{P_{us}}$$

where,

H_{ca}^i and H_{ca}^i are the number of CA and US households in size group i, respectively,

P_{ca} and P_{us} are the total number of households in California and the US, respectively,

α_{us}^i is the national average household electricity consumption (annually) for a household in size group i.

$\hat{E}_{us}$ is the actual average electricity consumption per household for the US. $\hat{E}_{ca}^{adj}$ now estimates what the average household electricity consumption in California would be, if the only difference between California and the US were the distribution of households by size group.

We test the hypothesis $H_0 : \hat{E}_{ca}^{adj} = \hat{E}_{us}$ versus the alternative. We find no statistically significant difference between $\hat{E}_{ca}^{adj}$ and $\hat{E}_{us}$. This finding is consistent with the observation that economies of scale are obtained in larger households, allowing household size increases without significant increases in energy consumption. Since this is the case, we may compute a *per capita* figure for electricity consumption by dividing the *per household* electricity consumption by the average household size. This was done for the United States and California, and the difference was found to be statistically significant. California's greater household size was found to explain an approximately 9 percent reduction (± 3.74 percent) from the national average figures.

6.3. Climate Characteristics

In order to estimate the effect of climate on household electricity use, two distinct end uses were considered - space heating and air conditioning. For space heating, two factors need to be taken into account. The first is the difference in population weighted heating degree days between California and the United States. The second is the choice of heating fuel - the popularity of natural gas over electricity for heating in California households reduces observed electricity consumption. The heating energy load in California, adjusted for differences in climate and fuel type but not accounting for any additional efficiency improvements (ensured by using the national average level of energy intensity α_{us} in the formula) is given by $\hat{E}_{ca}^{adj}$ as follows.

$$\hat{E}_{ca}^{adj} = \eta_{ca} \frac{\alpha_{us}}{HDD_{us}} HDD_{ca}$$

Here HDD refers to population weighted heating degree days (climate effect) and η_{ca} is the fraction of households using electricity as the heating source (fuel substitution effect). α_{us} is the national average electricity consumption for space heating in households that use electricity as the primary heating energy source. $\hat{E}_{ca}^{adj}$ thus linearly adjusts the national average household heating electricity demand for the differences in climate (HDD) and appliance ownership/fuel choices (η) in California. α_{us} can be obtained from the RECS surveys.

For cooling, we distinguish between central and room air-conditioning. Electricity demand for air conditioning purposes is estimated as follows:

$$E_{ca}^{cool} = \eta_{ca}^{cac} \frac{\alpha_{us}^{cac}}{CDD_{us}} CDD_{ca} + \eta_{ca}^{rac} \frac{\alpha_{us}^{rac}}{CDD_{us}} CDD_{ca}$$

Here CDD refers to population weighted cooling degree days (climate effect) and η_{ca}^{cac} and η_{ca}^{rac} are the fraction of households using central AC equipment (cac) or room AC equipment (rac) respectively. α_{us}^{cac} and α_{us}^{rac} is the national average electricity consumption on air-conditioning for households using equipment type cac or rac respectively.

There are significant differences in HDD and CDD values between the nation as a whole and California. The milder climate in the state of California, lower appliance ownership and fuel substitution possibilities in space heating, are reflected in a statistically significant difference in the expected electricity consumption for space heating and cooling, independent of any other efficiency effects. For 2005, we find that point estimates suggest about a 7.92 percent (± 1.35 percent) reduction in electricity consumption for California due to reduced cooling needs, and a 4.31 percent (±

0.88 percent) reduction due to differences in space heating demand (both as a percentage of total US household electricity consumption).

6.4. Household Floor Space and Urbanization

The location of a household in a city, a suburb, or a rural area has a marked effect on residential energy use patterns. Rural and suburban locations also tend to be correlated with larger housing units all else equal. Indeed the availability of more living space is a major reason for population sprawl outside the metropolis. Yet for a given household size (number of persons), larger housing units (in terms of floorspace) will tend to use more energy, with higher heating and cooling loads as well as a greater lighting load. The effect of California's greater urbanization should therefore be reflected in a comparison on the basis of housing unit floor space distributions for the state and the nation. Comparing the distribution of housing unit floorspace between California and the United States reveals that within the state, dwellings tend to be smaller than the national average.[7]

In order to estimate the effect of smaller housing units on electricity consumption we define the quantity

$$\hat{E}_{ca}^{adj} = \eta_{us} \sum_i \frac{H_{ca}^i \alpha_{us}^i}{P_{ca}} \text{ and } \hat{E}_{us} = \eta_{us} \sum_i \frac{H_{us}^i \alpha_{us}^i}{P_{us}}$$

where

H_{ca}^i and H_{us}^i are California and US housing units in floorspace size-group i,
η_{us} is the national average electricity consumption as a fraction of household energy consumption,
α_{us}^i is the national average household energy consumption for a unit in floorspace group i,
P_{ca} and P_{us} are the total number of housing units in California and the US respectively.

Testing for differences between $\hat{E}_{ca}^{adj}$ and the national average figure ($\hat{E}_{us}$) suggests that floorspace differences account for a statistically significant reduction in California household electricity consumption of about 8.36 percent of the national average. The standard error on this estimate is relatively large (see Table 2) owing to the high sampling error of the RECS empirical data used to carry out this adjustment. Even so, the difference is significant at a 90 percent confidence level.[8]

6.5. Fuel Choices for Water Heating

It is no surprise that household fuel-mix differences translate to variations in electricity demand. The RECS 2005 reveals that on a national level electricity makes up 41.23 percent of the total energy consumed, while in California the same figure is 35.80 percent. We have already accounted for electricity demand differences due to the greater use of natural gas for space heating in California. A similar analysis of electricity consumption for water heating applications, reveals that California's greater reliance on fuels other than electricity for water heating, would account for some reduction in overall electricity demand in this sector. Nationwide, over 39 percent of households use electricity as the primary fuel for water heating, while in California this fraction is under 11 percent (based on the 2005 RECS). It is unsurprising therefore that water heating fuel choices accounts for a statistically significant reduction in California's electricity demand of about 7.81 percent (±0.5 percent) of the national average household electricity consumption[9].

6.6. Other Factors

The distribution of householder ages[10] and housing unit age were not found to be statistically significant contributers to the state nation difference in the aggregate decomposition analysis. Householder age profiles are very similar in the state and nation. While California does have slightly newer housing units, on combining housing unit age with electricity consumption as a function of unit age, insufficient evidence was found (based on the RECS 2005 survey and standard errors in those figures) to conclude that the effect is a significant dampener of electricity consumption.

Apart from these factors, it is also interesting to examine the role of lifestyles in influencing electricity use. The analysis here does not directly attempt to quantify such differences and it would be necessary to obtain more data to do so accurately. These are also variables that might be expected to change under the influence of state policy and utility programs, in particular educational and information campaigns. The 2005 RECS dataset does reveal some evidence of differences in the way Californians treat energy when compared with the rest of the nation.

Regarding heating for example, more Californian houses have programmable thermostats (54 percent) than the national average (34.55 percent). This is an increase since 2001 when the figures were 35.60 percent and 23.40 percent respectively, but the gap has not narrowed much. This is probably testament to the utility incentive programs that have been in place in the state for many years. However technology aside, more Californians lower the temperature in the day when the house is empty and while sleeping. As many as 45 percent of Californian residents reported that they switched off heating when the house was empty as opposed to about 8 percent for the nation as a whole. Thus there are differences in both technology (which regulators and utilities programs have tried hard to encourage and incentivize), and behavior. Explicitly switching off heating both at night and when the house is unoccupied does reduce energy use - whether motivated by cost or other considerations such as environmental concern. Similar differences obtain when looking at other appliances. For example not only do fewer California household's possess in home washing machines, of those that do about 33 percent have Energy Star washers. Nationwide the figure stands at about 24 percent.

7. The Role of Prices

In the discussion up to this point, there has not been a separate estimate of any reduction in demand due to the higher average electricity prices that prevail in California. The state's electricity tariffs are somewhat higher on average than the rest of the nation. But electricity bills are often lower than the national average (in part thanks to lower consumption aided by greater efficiency of use). Electricity prices are strongly influenced by state policy, including regulations on utilities and the supply sources they are allowed to use. Consequently the fraction of the difference between California and the United States that we fail to explain after adjusting for various structural factors needs to be understood as *including* the effects of higher prices.

From the point of view of our analysis, this makes sense because electricity prices in California (and indeed the United States as a whole) are very much influenced by policy. In addition it is not easy to figure out what role prices play in modulating electricity use, as distinct from other regulatory influences. This is partly because tariff increases by utilities (sometimes mandated or indirectly caused by regulators) often go hand in hand with the adoption of efficiency enhancing technologies. Since such adoption is partly as a result of mandated standards and partly a rational optimization process by consumers to a modified monetary incentive, separating the two is difficult. Sudarshan (2010) outlines a more detailed discussion of price effects in the context of an economic model of residential electricity demand, applied to understanding the California-US difference in consumption. The analysis there provides for a detailed treatment of price and estimates a separate price effect.

8. Historical Trends in Electricity Consumption

The discussion to this point has focused on examining different factors contributing to low electricity consumption in California, for a snapshot of time in the recent past (2005 to be precise). This is the latest year for which the date needed is available. That said, given that the difference between California's electricity consumption levels and the national average has gradually increased over the last four decades, it is important to examine years before 2005 in order to test whether the observed time trend of increasing divergence between the state and nation in Figure 2 can be explained by this type of analysis.

We therefore decompose historical data, using the same methods described earlier in this paper. For the residential sector RECS surveys for years before 2005 are used in conjunction with US census data for population counts. In some cases older data for California (specifically information on appliance saturation used to quantify heating and cooling loads) has been sourced from CEC energy model outputs[11] (California Energy Commission 2003). Similarly for the commercial sector we draw upon historical floorspace data from the California Energy Commission demand forecasts.

Data constraints are most severe for the industrial sector as a result of the switch from the SIC to NAICS classification in 1997. This reclassification has made it difficult to obtain comparable employee data for years before 1997. Fortunately, the difference in electricity consumption levels between the state and nation in the industrial sector has changed very slowly over the past twenty years. Both the United States and California display relatively flat levels of industrial electricity consumption (per capita) in recent years. At first glance, this trend is not surprising since energy costs are an important part of total costs in some industries. Economically beneficial energy savings are likely to spread faster nationwide in the industrial sector than in the residential sector. Thus it is possible that the relatively stable difference is largely a consequence of consistent differences in industrial sector composition and on-site generation differences[12]. Even so, the portion of the California-US differential attributed to the residual (interpreted as policy) term does increase with time. This is because the consumption gap owing to structural differences shrinks somewhat over time. Figure 6 illustrates the time trend we obtain.

The three sectors seem to exhibit distinctly different trends. Perhaps the most surprising is the commercial sector where the average floorspace distribution has tracked changes in electricity consumption very closely. The majority of the difference between the state and and national numbers is captured by this single variable and this is true even as we look at data from years before 2003. The kink in Figure 5 is also difficult to explain since to the best of my knowledge, no structural shock consistent with such a sharp deviation occured around that time. The 1992 estimate is therefore likely to be unreliable, possibly due to errors in our figures on floorspace distribution in that year (most probably due to inaccurate estimates for California). This analysis does not delve into the question of why California has smaller commercial establishments than the

US average. Two explanations we regard as plausible are first, the higher costs of land ownership including the costs of property taxes, and second cultural differences and good weather in California which makes it possible for more activities to take place outside. While this is only speculation, it is possible that this results in schools, restaurants and office buildings choosing to set aside more open air space for occupants in California than elsewhere.

As far as industry structure is concerned, there is evidence of a fairly consistent trend in California of shifts in industry towards less energy intensive activities. This explains a large fraction of the overall difference although even after correcting for industry structure, there remains a signficant residual that has steadily increased from near zero about 10 years ago to a projected value of over 1000 KWh per capita in 2005.

Most intriguing is the residential sector where Figure 4 only skims the surface of the types of changes that explain the Rosenfeld effect over time. For instance, household sizes in California have steadily grown over time while in the rest of the United States precisely the opposite trend has occured. In 1970 the average household sizes in the country was about 3.1 members per household while the California statistic was about 2.5. Fast forwarding to 2005, California households have grown to an average size of 2.92 while the rest of the nation has fragmented to the extent that the average size today nationally is only 2.60 persons. This shift underlies the trend in Figure 4 where the 'household size' effect is seen to be increasing over time. Similarly the difference between the floorspace of California homes (smaller on average) and the national average has also increased over time which is even more significant when one considers that the number of persons in a household has gone up. On the other hand there has been some decline in the importance of climate as the state has seen increasing population growth in relatively more extreme climate zones (particularly in colder regions of the state), alongside an increase in air conditioning appliance saturation numbers. All told however, the residual between national statistics and California numbers has risen slowly. This is consistent with the hypothesis that aggressive program measures coupled with higher average prices and tiered rate structures have increased the efficiency savings the state has managed to achieve.

9. Results

In the case of the industrial and residential sectors the most recent data analyzed here is from 2005[13]. For the commercial sector we do not go beyond 2003 since that is the most recent year

Residential 2005				
US per capita average			4415	
US per household average			11480	
Structural Adjustment Factor	Value (KWh)	Adjustment Percentage	90 % SE	Adjusted (KWh)
Heating load (Climate and Fuel Choices)	495	4.31%	0.88%	10985
Cooling load (Climate)	909	7.92%	1.35%	10077
Water Heating load	897	7.81%	0.50%	9180
Income	-542	-5.90%	2.48%	9721
Floorspace	813	8.36%	8.33%	8909
Per capita adjusted				3426
After Household Size Adjustment	311	9.07%	3.74%	3116
California Household Average	2395			
Residual Per Capita	**721**	**35.68%**	**(share of residual in difference)**	
Industrial 2005				
US per capita average			3438	
Structural Adjustment Factor	Value (KWh)	Adjustment %	90 % SE	Adjusted (KWh)
Industry structure	642	18.67%	4.30%	2796
Self generation	227	6.60%	-	2367
California per capita average	1391			
Residual Per Capita	**1178**	**57.56%**	**(share of residual in difference)**	
Commercial 2005				
US per capita average			4586	
Structural Adjustment Factor	Value (KWh)	Adjustment %	90 % SE	Adjusted (KWh)
Floorspace Distribution	1244	27.13%	-	3342
California per capita average	3253			
Residual Per Capita	**89**	**6.65%**	**(share of residual in difference)**	

Table 2: Structural and residual (policy) contributions to California-US differences in electricity consumption by sector. Standard errors are provided where they could be estimated (where data sources carried information on sampling errors).

of data from the EIA Commercial Building and Energy Consumption survey (the primary data source for this study). Table 2 presents results for 2005, with the commercial sector estimates extrapolated from the analysis for 2003. The value column provides the portion of difference explained by structural differences. The Adjustment Percentage column represents the value as a percentage of the national figure. The adjusted value is simply the national average after correcting for successive structural drivers. The residual per capita row provides the unexplained portion hypothesized as owing to policy and prices along with its contribution to the overall difference. Figures 4,5,6 graphically represent the deconstruction over time for the three sectors separately.

The difference in per capita electricity consumption between California and the United States is represented here as a combination of an structural difference and a residual difference. The first term

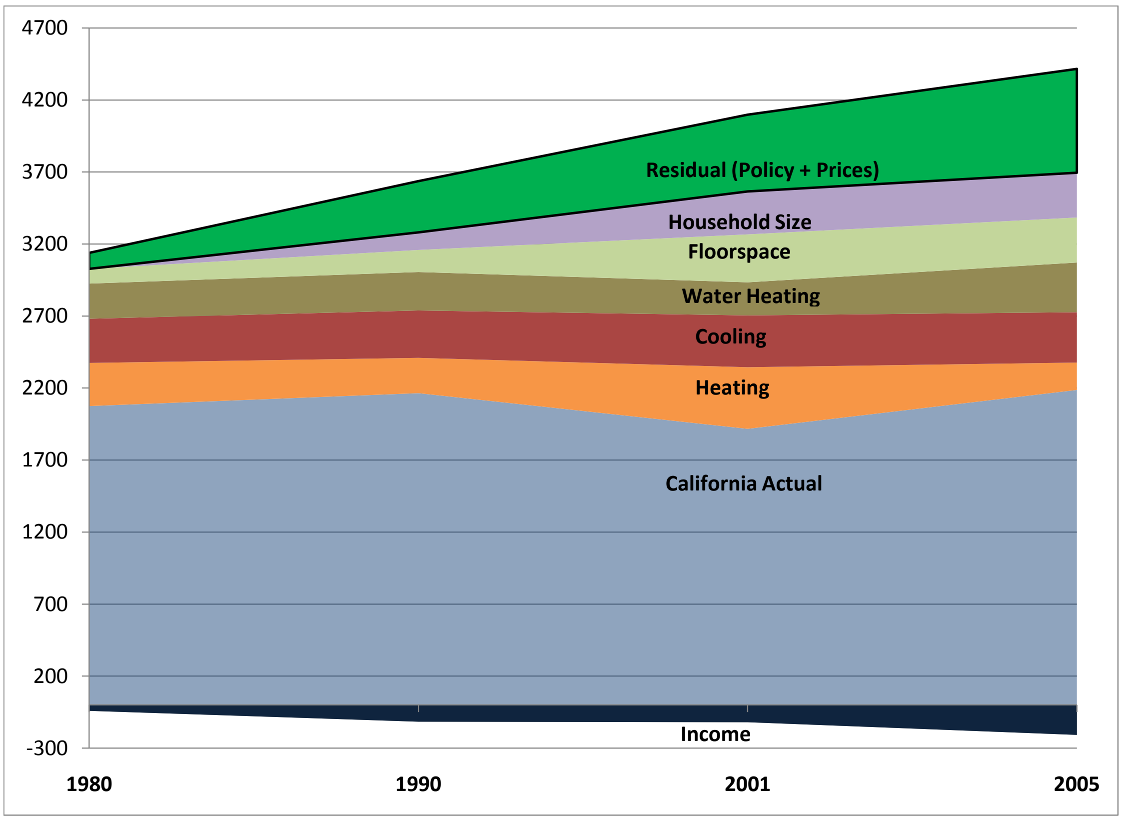

Figure 4: Decomposition of the residential sector (1980-2005). Note the increasing share of the residual but also time variations in structural differences

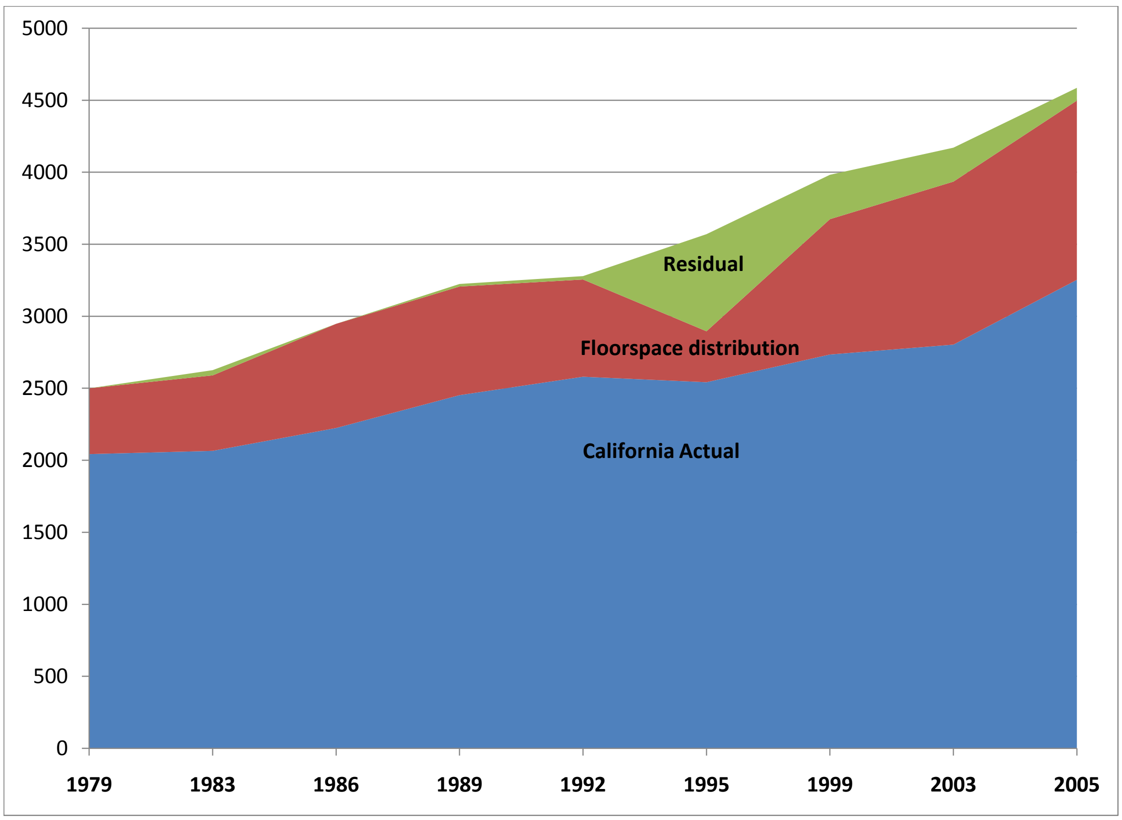

Figure 5: Decomposition of the commercial sector (1979-2005). Note the decreasing share of the residual.We are not aware of the existence of a structural shock explaining the kink in 1995 and this may be indicative of problems with the floorspace data (CBECS 1995) for that year.

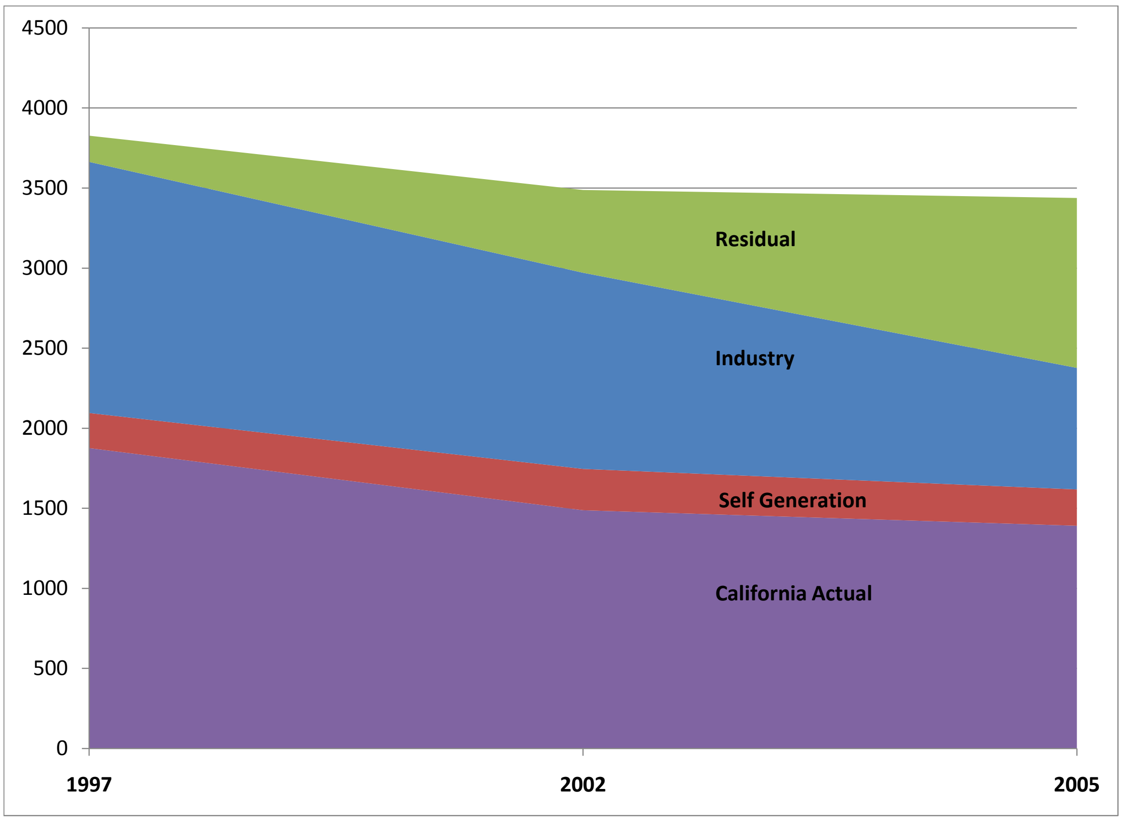

Figure 6: Decomposition of the industrial sector (1997-2005). Note the increasing share of the residual as the difference in industry structure shrinks.

is the portion of the observed difference that can be explained by the structural adjustments applied cumulatively to the US average. The residual is the portion unexplained by observed structural differences. This fraction can therefore be regarded as owing to policy, price effects as well as other forces that might be missing from our decomposition. To the extent that this analysis is successful in accounting for most of the policy independent factors that might significantly influence electricity demand, the residual will be close to the effects of policy and price differences. At the very least this provides a starting point for thinking about how much of the Rosenfeld effect is easily duplicated elsewhere, even with the adoption of similar policies. Using 2005 statistics, we find that nearly 35 percent of the difference lies in the residual, a very significant fraction. This is made up of a residual of about 721 KWh per capita for the residential sector, 1061 KWh per capita for the industrial sector and 89 KWh per capita for the commercial sector. This suggests that California policy has been extremely influential in making the Rosenfeld curve a reality. At the same time about two-thirds of this difference does not seem to require an appeal to greater efficiency or conservation behavior to explain. This underscores the fact that California's more aggressive policies are only a part of the story behind the Rosenfeld curve. Many other factors are more important.

As Figures 4, 5 and 6 indicate, the decomposition results are consistent with the trend of increasing divergence between the two populations. The residual share (attributed at least partly to policy and prices) has indeed grown with time. Interestingly however, structural factors influencing electricity use have also changed significantly with time. For instance over the period from 1970 to the present the average size of California households has grown steadily, while the average size of US households has dropped. Further, while climate variations may have remained roughly constant (not entirely so because population weights have shifted), their importance to the difference between state and nation has changed. This is because the ownership of air-conditioning has grown at different rates in California (where cooling is not always needed) versus the national average. Other drivers seem to have grown less important over time. For instance, floorspace differences between the state and nation have declined in recent years. Table 3 presents the residual portions (interpreted as a policy effect) of the Rosenfeld effect for 2001 and 2005.

9.1. California Energy Commission Forecasts

Over the years California has gradually instituted many programs and policy measures aimed at demand side management, energy savings and energy efficiency. These include programs run by investor owned utilities, rebates to emerging technology, retrofitting aid and surveys, education and training programs, appliance recycling and advocacy efforts. In addition, building and appliance standards of increasing stringency have been enforced by the California Energy Commission (CEC), acting under the Warren-Alquist Act. Recent efforts include instituting widespread demand response management schemes allowing utilities to exercise some control over peaking loads and aggressive incentives for the investor-owned utilities to encourage their customers to invest in energy efficiency. Thus policy efforts have grown more aggressive over time, utility spending has increased and many of the technological improvements put in place deliver cumulative reductions into the future. For these reasons we might reasonably expect an increasing share of the state-nation difference to be independent of structural differences.

An attempted comparison with California Energy Commission (CEC) estimates of the effects of utility programs and regulatory standards is instructive. It is a difficult task to accurately quantify savings gained from these efforts, in large part because of the variety and number of individual utility programs. Since the first version of this analysis, presented in 2008, the CEC does produced updated savings figures, compiled from the aggregation of various quantification methodologies applied to individual programs, the outputs from a detailed energy system model, and self reported utility estimates of savings[14]. The figures reported in Table 3 are the total savings estimates for 2001 and 2005 from the California Energy Demand 2010 - 2020 Commission-Adopted Forecast, which contains revised estimates of efficiency savings. For the residential sector, it is interesting that these are relatively close to the results we obtain given that they rely on a more detailed bottom up approach.

For the commercial sector the 2001 estimates from the CEC and our analysis are quite close but a divergence occurs in 2005. Adjusting purely for floorspace explains much of the difference between state and national intensity estimates. One possibly explanation for this might lie in the fact that commercial properties outside the state may have grown more efficient, with efficient technologies diffusing more widely outside California. The difference between our estimate and the CEC estimate might then be viewed as a consequence of the difference between a comparison with the national average (our measure) versus a comparison against an exogenous baseline model of technology adoption (the CEC measure).

The California Energy Commission does not generate similar estimates emerging from a structural energy model for the industrial sector. Demand forecasts for industry are provided using econometric and statistical forecasting methods and declines in energy intensity far exceed the sav-

Year	Residential	CEC (Residential)	Industrial	CEC (Industrial)	Commercial	CEC (Commercial)
2001	533	427	517	-	290	258
2005	721	524	1178	-	89	307

Table 3: Total unexplained difference compared to revised 2010 CEC estimates of California programs from the 2010-2020 Demand Forecast. Energy commission estimates exclude market and price effects. Figures in KWh per capita.

ings claimed by utilities for their industry programs. This gap in the official reports, combined with the fact that our analysis suggests a very large unexplained residual in the industrial sector, points to the need for future work in order to examine the reasons why this part of the economy seems to have grown so much more efficient over time.

10. Conclusions

The motivation of this paper is twofold. First and foremost, we have sought to make the point that even a simple analysis of empirical data makes it clear that a variety of socio-economic factors need to be accounted for before comparing population energy intensities. Secondly we carried out an empirical analysis to estimate what fraction of the difference between California and the United States is the result of policy independent characteristics such as climate or demographics, and what fraction may be due to proactive policy measures aimed at saving energy. In order to accomplish this, we have estimated the effect of various policy independent factors and successively subtract their contribution from the overall difference. The results are instructive and suggest that we could do a lot better than using illustrations such as Figure 1 in arguing the effectiveness of energy efficiency.

The methods used here do have shortcomings. First, the results do not estimate spillover affects into other states due to California's policies. Accounting for such spillover benefits is a difficult task, but to the extent they exist, they make state policy even more significant than this type of comparison reveals. Of course this is not an issue if all we seek to do is explain the Rosenfeld effect itself, since that is a comparison net of spillovers.

Two other concerns remain. The first of these involves the possibility of indirect influences of policy on some of the other explanatory factors we have studied. For instance, if efficiency programs were to change average household sizes in California, then presumably the effect of the latter might owe to the former. The second, potentially more serious issue involves possible correlations among the structural factors that are considered here. In particular, for the residential sector, multiple variables are being corrected for and by cumulatively multiplying their influence we are assuming that they act independently. While this is an intuitively plausible assumption in some cases, it need not always hold. Rigorously accounting for correlations requires the specification and estimation of a full fledged economic model of household demand estimated using micro-data (see Sudarshan (2010) for an econometric analysis of the residential sector which produces similar results to those presented here).

That said, comparing energy intensities (normally defined as energy per unit GDP or per capita) is an activity ubiquitious in policy debates. The Rosenfeld curve is also a plot of energy intensity (with the denominator being population instead of GDP). As a statistic, energy intensity is an outcome variable, the net result of a variety of forces. In most cases we are interested not only in what the energy intensity of a population looks like but also, why it appears that way. Energy intensity therefore carries useful but limited meaning from the point of view of policy evaluation or as a tool for setting expectations from efficiency policy spending. Unfortunately this has not always been the way it is interpreted, both within the energy literature and in popular discourse and as the analysis here demonstrates, the stunning performance of California may be difficult to duplicate through state policy alone.

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Notes

[1]The authors concentrate on overall energy use and use decomposition methods to estimate activity, structure and efficiency effects. The efficiency index is shown to 'explain' about a third of the state nation difference.

[2]The term 'decomposition' here does not refer to the same techniques as are used in the large literature on index decomposition techniques applied to energy analysis. Unlike those methods the approach in this paper is akin more to a sequence of statistical tests of empirical data and our object is not to generate indices representing aggregate forces such as 'efficiency' or 'activitiy'. The residual in this analysis has a specific meaning and provides a bound on the policy effect. Thus we are interested precisely in the size of this residual (unlike index decomposition techniques for which a residual is a methodological concern and in some sense represents a degree of error).

[3]The national average consumption was over two and a half times state consumption in 2005. This percentage is approximately 19 percent expressed as a fraction of state per capita figures.

[4]Data are primarily from the decennial US Census reports, the American Community Surveys and from sample surveys such as the EIA Residential Electricity Consumption Survey (Energy Information Administration 2005).

[5]Unfortunately a statistical significance test is not always possible because of shortcomings in data sources in some cases, especially in analysing data before 2005. Table 2 provides estimates with error bounds wherever possible.

[6]We assume a Gaussian distribution for the t-statistic in this test because of the fact that sample sizes involved are large, and treating the denominator (which is a complete population count from the census) as constant. The latter assumption allows the use of a standard Gaussian test as opposed to the much more complicated test for a normal ratio distribution.

[7]It is interesting that while the average family size in California is larger than the national average, the average size of the housing unit appears to be smaller. Urbanization might be one reason for this. Both RECS data and estimates from the American Community Survey suggest that the fraction of housing units located outside of towns and cities nationwide, exceeds the corresponding fraction in California.

[8]The difference between state and nation floorspace distribution and consequent effects on electricity consumption is even more marked for years prior to 2005.

[9]It could be argued that state policy has had an indirect influence on fuel-mix decisions. For example, Title-24 building standards may have made it harder to construct all electric homes in California. However, simple switches in the form of energy used do not necessarily imply direct reductions in energy use and carbon emissions. For this reason it makes sense to separately quantify reductions in electricity consumption due to fuel mix differences.

[10]A demographic characteristic that is a partial determinant of household energy consumption is the age of the householder. In part, this is because household income is correlated with age, with income rising with age. However, apart from the income effect, there is evidence to suggest that householder age differences may independently affect energy use patterns (see O'Neill and Chen (2002)).

[11]In these cases standard errors cannot be estimated because the numbers used are not from sample surveys.

[12]This does not mean that California industry has not grown more efficient, only that these efficiencies are likely to have spread nationwide, with the spillover effects thus dampening the Rosenfeld effect - a measure of the difference between state and nation, not absolute efficiency.

[13]To be precise in the case of the industrial sector decomposition we rely on the 2006 MECS for electricity intensity values, in conjunction with industry structure data from 2005

[14]Details on the methodology used in making forecasts and savings estimates are available in the Energy Demand Forecast Methods Report (California Energy Commission 2005).