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Deconstructing the Rosenfeld curve: Making sense of California's low electricity intensity☆

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ABSTRACT

Regulatory regimes that have increased household energy efficiency are of widespread interest to policymakers today. A prominent example is the state of California where electricity intensities in the residential sector have stayed near constant since the 1970s in sharp contrast to nationwide trends in the United States. A structural model of residential energy consumption is used to show that the use of energy intensities alone to evaluate the success of California efficiency programs is misleading and glosses over important policy independent factors. We quantify important effects of price, climate conditions and demographic characteristics on energy consumption in California. We also provide evidence of split incentive considerations in residential energy consumption patterns. We conclude that while state policy may have had some effect on efficiency, caution needs to be exercised in using the California example to inform expectations from similar measures in other regions.

1. Introduction

Increasing energy efficiency has become an important objective for energy policy makers. In the United States, over the last three decades, many policies targeted at enhancing energy efficiency have been implemented involving both significant costs and claims of large benefits. Gillingham et al. (2006) review energy savings estimates from building and appliance standards and Auffhammer et al. (2008) and Arimura et al. (2009) provide a useful discussion of the impact of utility efficiency programs.

A particularly well known and much discussed case study for the benefits of energy efficiency is the state of California. Since the early 1970s, residential electricity consumption per capita in California has stayed nearly constant, while rising steadily for the US as a whole (see Fig. 1). At the same time, 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.

California's importance as a poster-child for energy efficiency is exemplified by a graph comparing retail sales of electricity per capita for California and the United States that is often casually referred to as the ‘Rosenfeld Curve’, after Arthur Rosenfeld, the influential member of California's Energy Commission. In the Journal of Environmental Research Letters for instance, an article entitled ‘*Defining a standard metric for electricity savings*’ (Koomey et al., 2010) authored by many of the United States' 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 discussion of energy efficiency in the widely read journal Science (Charles, 2009) also focuses on the Rosenfeld curve. The Rosenfeld curve has been cited as evidence of the transformative potential of energy efficiency programs in policy reports and presentations made all over the world (see for example Rosenfeld, 2007; Schwartz, 2003).

It is worthwhile to note that California has been different from the rest of the United States both in terms of early adoption of a variety of programs aimed at enhancing energy efficiency and through the implementation of stricter standards. For instance, while a building energy codes has existed both nationally and in California over the last three decades, California's Title 24 standards have been generally stricter than federal standards. Similarly appliance standards were introduced much earlier in California than the rest of the nation (see Table 1) and have stayed relatively more stringent as well. The American Council for an Energy Efficient Economy publishes scoreboards ranking states

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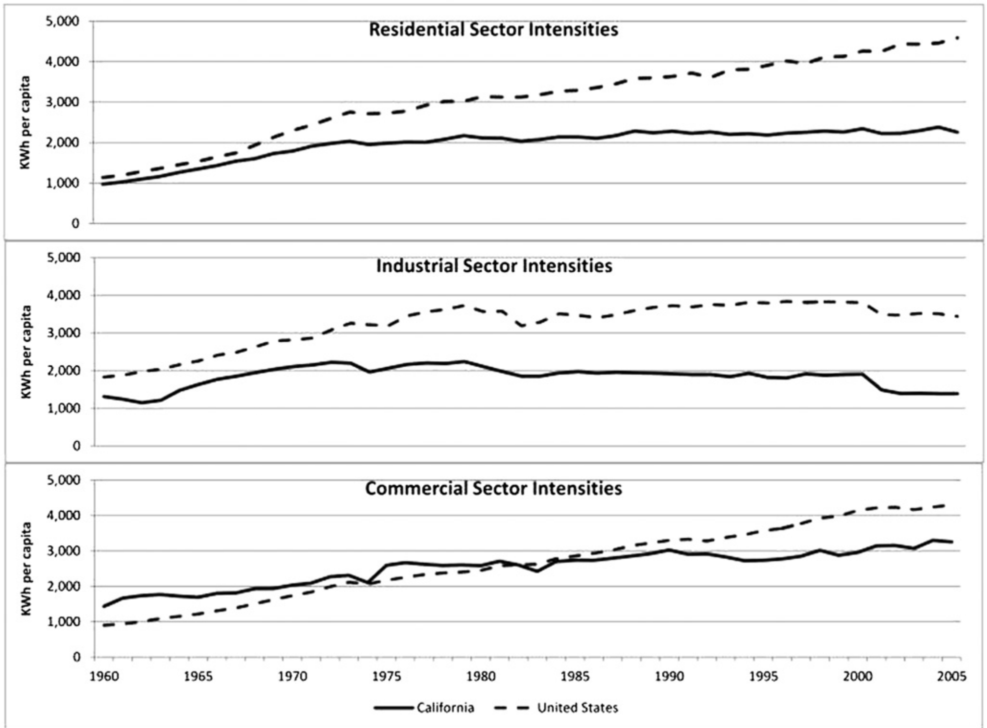

Fig. 1. Sector-wise comparison of California and US electricity consumption.
Source: EIA electricity sales figures.

on their efforts to encourage energy efficiency. California has consistently ranked in the top few states in terms of program expenditures and other measures (see ACEEE, 2007, 2008, 2009).

Unfortunately, expenditures on efficiency programs have not been accompanied by equally rigorous evaluation of their effects. Aggregate statistics such as energy intensity (expressed per capita or otherwise) as well as other energy indices (including those obtained from index decomposition methods) are 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). While it is well understood that energy intensity is not the same as energy efficiency, this has not stopped energy intensity indices from being used as a metric of success or failure (with the Rosenfeld Curve being a good example).

This paper seeks to use available household microdata to show that – for the residential sector at least – California's low energy intensities are a misleading measure to use to evaluate the success of failure of state run efficiency programs. Over 80% of the difference between California and United States per capita residential electricity consumption can be explained without recourse to any program interventions — in particular as a consequence of differences in climate, demographic differences, prices, appliance distributions, urbanization, fuel choices. We also suggest that specific efficiency policy measures such as building standards may have been most effective in modulating energy demand and find evidence of split incentive considerations influencing household energy consumption.

Table 1
Date of setting of first appliance standards (Martin, 1997; via Gillingham et al., 2006).

	California	National
Refrigerators	1976	1990, 1992
Air conditioning	1976	1990
Heat pump	1977	1990
Clothes washers	1977	1988
Water heaters	1976	1990
Lamp ballasts	1983	1990

In what follows, Sections 2 and 3 set up the econometric model that we use to understand the nature of residential energy demand in California. Section 4 contains a description of the empirical data we use to estimate the parameters of the demand model and Section 5 describes the estimation methodology used. Section 6 introduces and discusses some of the results in detail. Section 7 synthesizes the effects of different factors and places them in the context of the Rosenfeld curve.

2. Economic model of energy demand

This paper explores overall energy use in the household, addressing both electricity demand and demand for heating fuels. We derive a household demand function for both electricity and the secondary heating fuels. Households are assumed to maximize an indirect utility function $v(p,I)$ of the following form[1]

$$v = \begin{cases} y + \psi[\exp(-\theta_e P_e) + \exp(-\theta_h P_h)] & \text{when secondary fuel consumption occurs} \\ y + \psi[\exp(-\theta_e P_e)] & \text{when no secondary fuel is consumed} \end{cases}$$

where y is income, v is total utility and P_e and P_h are the average prices of electricity and the secondary heating fuels consumed. When heating is provided by natural gas or fuel oil, consumption decisions must optimize over both electricity and the heating fuel. This formulation thus separates the decision to use a secondary fuel, from the decision on how much to consume. The first is assumed to be implicitly made when a home is chosen while the second is an ongoing process of utility maximization conditional on the first decision.

[1] This functional form for utility has been used in the literature studying demand for telephone minutes (e.g. Narayanan et al., 2007). It is attractive for our purposes primarily because it lends itself to an easily estimable and flexible demand function, is suited to applications where income elasticity is insignificant, does not impose constant price elasticities, and is consistent with risk averse agents.