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Evidence of a Decline in Electricity Use by U.S. Households

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Evidence of a Decline in Electricity Use by U.S. Households

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Abstract

This paper shows that U.S. households use less electricity than they did five years ago. The decrease has been experienced broadly, in virtually all U.S. states and across all seasons of the year. This pattern stands in sharp contrast to steady increases throughout previous decades and has significant implications for household budgets, energy markets, and the environment. I discuss some of the implications of the decline and then take preliminary steps toward identifying potential explanations. While multiple factors have contributed, I argue that the rapid emergence of LEDs and other energy-efficient lighting has played a particularly important role.

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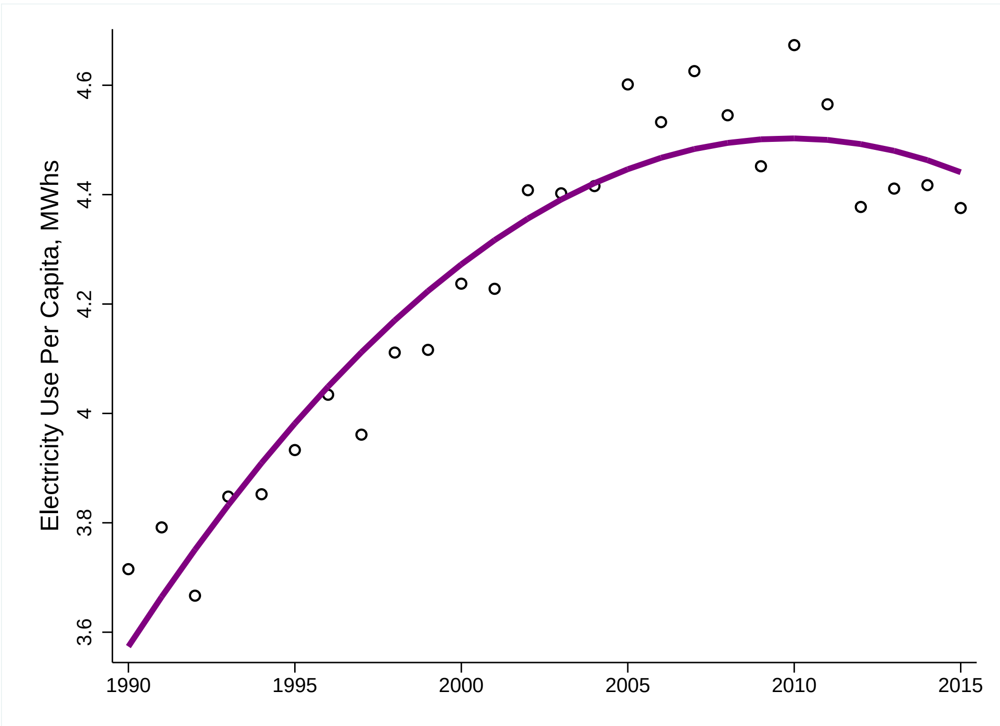
1 Introduction

Throughout history, humans have tended to consume more of everything. Driven by rising incomes and falling prices, we buy more food, live in larger homes, travel more, and spend more on health care. Energy is no exception. In the United States between 1950 and 2010, residential electricity consumption per capita increased 10-fold (U.S. Department of Energy, 2011; U.S. Census Bureau, 2017a), an annual average increase of 4% per year.

But that electricity trend has changed recently. Figure 1 plots U.S. residential electricity consumption per capita 1990-2015. Consumption dipped significantly in 2012 and has remained flat, even as the economy has improved considerably.

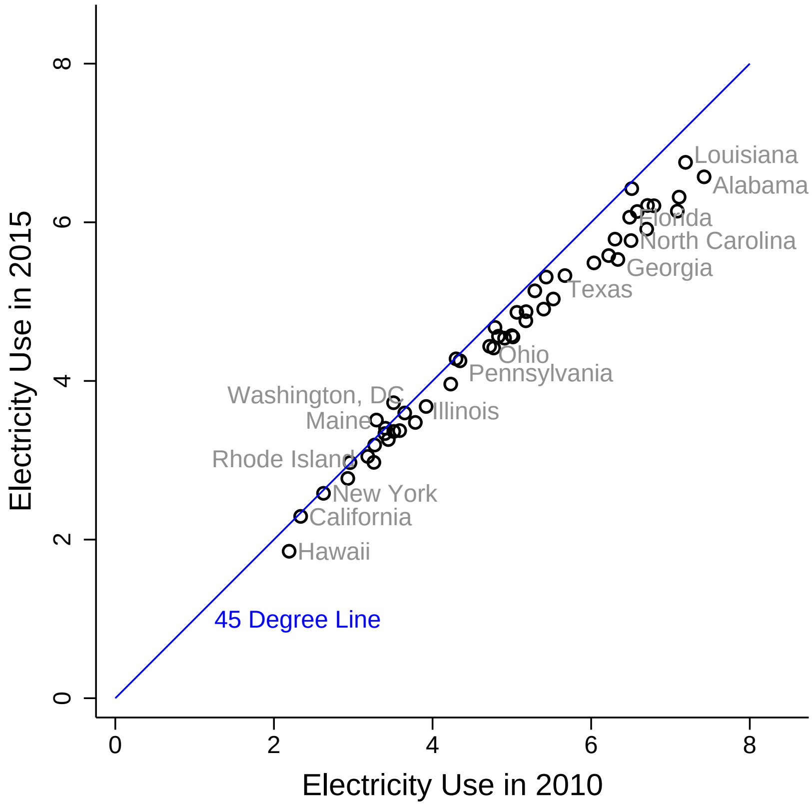
Figure 1: Has Electricity Consumption Peaked?



Note: This figure plots residential electricity consumption per capita in megawatt hours per year, along with a fitted cubic polynomial. Electricity sales data come from U.S. Department of Energy (2017b) and population estimates come from U.S. Census Bureau (2017b).

The decrease has been experienced broadly, in virtually all U.S. states. Figure 2 compares electricity use in 2015 versus 2010. Per capita residential electricity consumption decreased 6% over this period, with 48 out of 50 states experiencing decreases. Only Rhode Island, Maine, and the District of Columbia experienced increases.

Figure 2: Electricity Use Has Fallen in Most States Since 2010

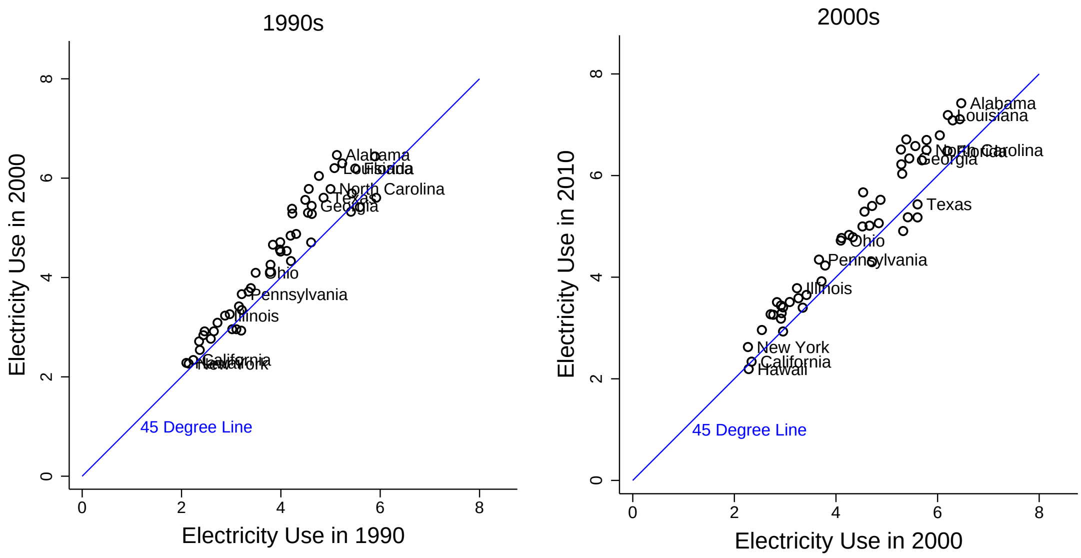


Note: This figure plots residential electricity consumption per capita in 2015 versus 2010 for all 50 U.S. states and the District of Columbia, measured in megawatt hours.

This recent pattern stands in sharp contrast to the steady increases observed in previous decades. Figure 3 plots energy use by state during the 1990s and 2000s. Electricity consumption per capita increased by 12% and 11% during the 1990s and 2000s, respectively, with the vast majority of states experiencing increases. Previous decades experienced much larger increases.

It is widely recognized that U.S. electricity sales have been slowing down, but this evidence of a decline is novel. Although the figures above rely on easily-available public data, I have not seen this evidence put together in this form. In the rest of the paper, I discuss some of the implications of this decline and then take preliminary steps toward identifying several potential explanations. While multiple factors contribute to the decline, I argue that the rapid emergence of LEDs and other energy-efficient lighting has played a particularly important role.

Figure 3: Electricity Use Increased Broadly During the 1990s and 2000s



Note: These figures plot residential electricity consumption per capita during the 1990s and 2000s for all 50 U.S. states and the District of Columbia, measured in megawatt hours.

2 Implications

The recent decline has significant implications for household budgets, the environment, and energy markets. Total U.S. residential electricity sales are $175 billion annually (U.S. Department of Energy, 2016a), so even this modest decrease represents billions annually in reduced electricity bills. U.S. wholesale electricity prices average $30 per megawatt hour (U.S. Department of Energy, 2017c), so a 6% decline in residential electricity consumption reduces generation costs by $2.6 billion per year.

The decrease also yields large environmental benefits. U.S. electricity generation is getting greener, but is still dominated by fossil fuels (U.S. Department of Energy, 2016a). Thus less electricity consumption means lower emissions of carbon dioxide, as well as decreased emissions of sulfur dioxide, nitrogen oxides, and other local pollutants associated with stroke, heart disease, lung cancer, respiratory disease and asthma. Economists have estimated that in the U.S. these environmental damages are worth $81 per megawatt hour (Holland et al., 2016), so a 6% decline generates environmental benefits worth $7.0 billion annually.

The decrease also has significant implications for energy markets. Lower demand pushes down wholesale electricity prices, reducing revenue for companies that own power plants. In the short-term these companies earn lower profits and, in the long-run, more of these plants will close. Lower demand also reduces the need for local distribution infrastructure and regional transmission investments. U.S. electric utilities spend $38 billion annually on transmission and distribution infrastructure (Edison Electric Insitute, 2015), so stemming energy demand increases could yield significant benefits in avoided infrastructure expenditures.

3 Energy-Efficient Lighting

Several factors contribute to the decrease, but the rapid emergence of LEDs and other energy-efficient lighting appears to have played a particularly important role. Over 450 million LEDs have been installed to date in the United States (U.S. Department of Energy, June 2016c), up from less than half a million in 2009. LEDs and other energy-efficient lighting now account for 80% of all U.S. lighting sales (Goldman Sachs, 2015) and according to a recent survey, 70% of Americans have purchased at least one LED bulb (Sylvania, 2016).

It is no surprise that LEDs have become so popular. LED prices have fallen 94% since 2008 (U.S. Department of Energy, 2016b), and a 60-watt equivalent LED lightbulb can now be purchased for about $2. LEDs use 85% less electricity than incandescents, so represent a significant savings in operating costs. LEDs are also much more durable than incandescents, are dimmable, and work in a wide-range of indoor and outdoor settings.

As a simple back-of-the-envelope test of plausibility, suppose that between LEDs and compact flourescent lightbulbs (CFLs) there are now one billion energy-efficient lightbulbs installed in U.S. homes. If operated 3 hours per day, this implies savings of 50 million megawatt hours per year, or 0.16 megawatt hours per capita, approximately the size of the decrease in Figure 1. This is a crude calculation that should be refined and improved as better data becomes available, but it demonstrates that the savings from energy-efficient lighting are indeed large enough to show up in the aggregate pattern.

Moreover, U.S. Department of Energy calculations support the hypothesis that energy-efficient lighting plays an important role in the recent decrease. According to the U.S. Department of Energy modeling, lighting represented 15% of U.S. residential electricity consumption in 2010, but then decreased 37% between 2010 and 2015, equivalent to a 5% decrease in total residential consumption (U.S. Department of Energy, 2010, 2017a). Thus the Department of Energy's "bottom-up" modeling appears to be highly consistent with the "top-down" evidence in aggregate data, both in terms of timing and magnitude.

No other household technology is as disruptive as lighting. Incandescent lightbulbs don't last very long, so when a new technology comes along it can quickly transform the installed stock. Other forms of energy-related equipment turn over much more slowly. Air conditioners, refrigerators, dishwashers, and other major appliances, for example are typically used for 10+ years. Thus, though these technologies have also become somewhat more energy-efficient during this period (Meyers et al., 2016), this is unlikely to explain the aggregate decrease.

4 Alternative Explanations

Other potential explanations appear less likely to explain the recent decrease. Average household incomes were increasing during this period, so if anything, income effects would have led electricity consumption to go up. This is true whether you look at U.S. GDP per capita which increased 7% between 2010 and 2015 or median household income which increased 5.5% during the same period (Federal Reserve Bank of St. Louis, 2017a,b).

Electricity price changes are also unlikely to explain the decrease. Between 2010 and 2015, the average price paid for electricity by U.S. residential customers increased from 11.54 cents per kilowatt hour in 2010 to 12.65 cents per kilowatt hour in 2015 (U.S. Department of Energy, 2016a). The consumer price index increased by 8.7% during this period, so in real terms, these two prices are almost identical. Moreover, while economists have indeed shown that residential customers respond to energy prices, the price elasticity of demand is small in magnitude (see, e.g., Ito, 2014).

Another potential explanation is weather. Electricity consumption increases during cold winters and hot summers, so year-to-year weather variation influences residential electricity consumption. Indeed the summer of 2010 was unusually hot, so this partly explains why electricity consumption was so high in that year. However, the broader pattern in Figure 1 is clear even if one ignores 2010 completely. Moreover, the supplemental materials confirm that there is a negative trend between 2005 and 2015 in all four seasons: Summer, Fall, Winter, and Spring.

During this period there has been increased utilization of peer comparison reports. The company OPower has partnered with dozens of U.S. electric utilities to send out home energy reports that provide information about how your household's energy consumption compares to your neighbors. These reports have been shown to trigger household conservation behavior, saving an average of about 2% per household (Allcott, 2011; Ayres et al., 2012; Allcott and Rogers, 2014; Allcott, 2015).

These energy savings contribute to the observed decrease, particularly in states like California with significant participation, but can't explain the widespread decrease across 48 of 50 states.

Lastly, during this time period there has also been a 10-fold increase in rooftop solar photovoltaics (see, e.g. Hughes and Podolefsky, 2015; Borenstein, forthcoming). Residential electricity consumption is measured net of any on-site generation, so the increase in rooftop solar could potentially help explain the decrease in consumption. Like peer comparison reports, however, solar installations are highly concentrated in California, Hawaii, and a small group of other states (Solar Energy Industries Association, 2017). Thus rooftop solar cannot explain the widespread decrease across virtually all U.S. states.

5 Discussion

5.1 Rebound Effect?

This is not the first time in history that lighting has experienced a significant increase in energy-efficiency. Nordhaus (1996) examines the history of light from open fires, to candles, to petroleum lamps, to electric lighting. Early incandescent lightbulbs circa 1900 were terribly inefficient compared to modern incandescents, but marked a 10-fold increase in lumens per watt compared to petroleum lamps. As lighting has become cheaper, humans have increased their consumption massively, consuming thousands of times more lumens than they did in the past (Fouquet and Pearson, 2006).

Economists refer to this as the "rebound effect" (see, e.g., Borenstein, 2015; Gillingham et al., 2015). An important unanswered question about LEDs and other recent improvements in energy-efficient lighting, is to what extent will these energy efficiency gains be offset by increased usage? Will households install more lighting now that the price per lumen has decreased? Will households leave their lights on more hours a day? Outdoor lighting, in particular, would seem particularly ripe for price-induced increases in consumption. These behavioral changes may take many years to manifest, as homeowners retrofit their outdoor areas to include additional lighting.

5.2 Concluding Comments

Economists have long recognized that demand for energy is derived from demand for services (Hausman, 1979; Dubin and McFadden, 1984). Households derive utility from heating, cooling, refrigeration, lighting, and other services that they produce in the home using electricity. To understand long-term trends in energy demand, it then becomes necessary to understand demand for these underlying services.

With some of these services it is tempting to think that U.S. households are approaching satiation. There is only a finite amount of heating and cooling that can be consumed before households reach their ideal level of thermal comfort at all hours of the day. Moreover, for even the most fastidious person there are only so many clothes that can be washed (Davis, 2008).

Still, history is replete with examples of households finding ingenious ways to consume ever greater amounts of services. Owen (2010) relates that his family growing up had only a single small refrigerator with a tiny freezer compartment, whereas today they have several refrigerators as well as a standalone freezer.

Electric vehicles are one important category where rapid growth could occur. Currently only a small fraction of vehicles are EVs, but widespread adoption would significantly increase residential electricity demand. It is worth highlighting, though, that this would be substitution away from another energy source (petroleum), with ambiguous impacts on total energy consumption and the environment (Holland et al., 2016), so the implications are different from most other categories of services.

Over a longer time horizon there will also be entirely new electricity-using services that come available, including services that are not yet even imagined. The 10-fold increase in electricity consumption since 1950 reflects, to a large degree, that U.S. households now use electricity for many more things than they did in the past. The recent decrease in U.S. household electricity consumption is historic and significant, but over the long-run it would be a mistake to bet against our ability to consume more energy.

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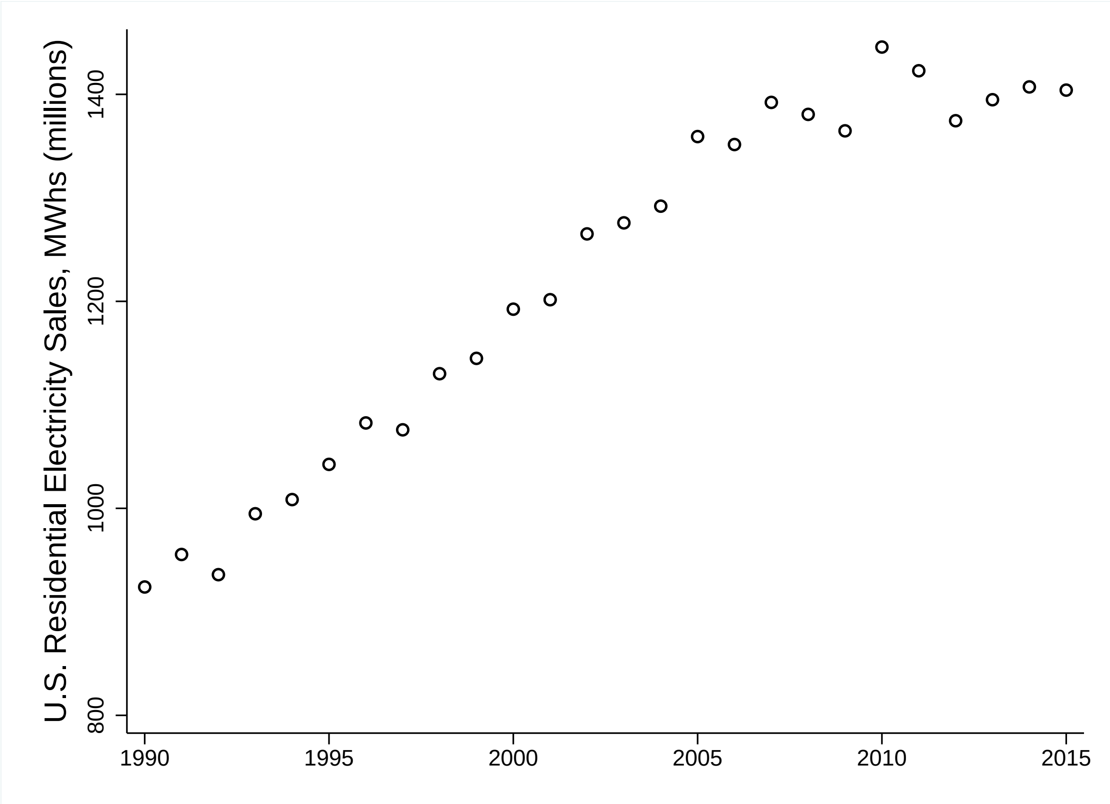
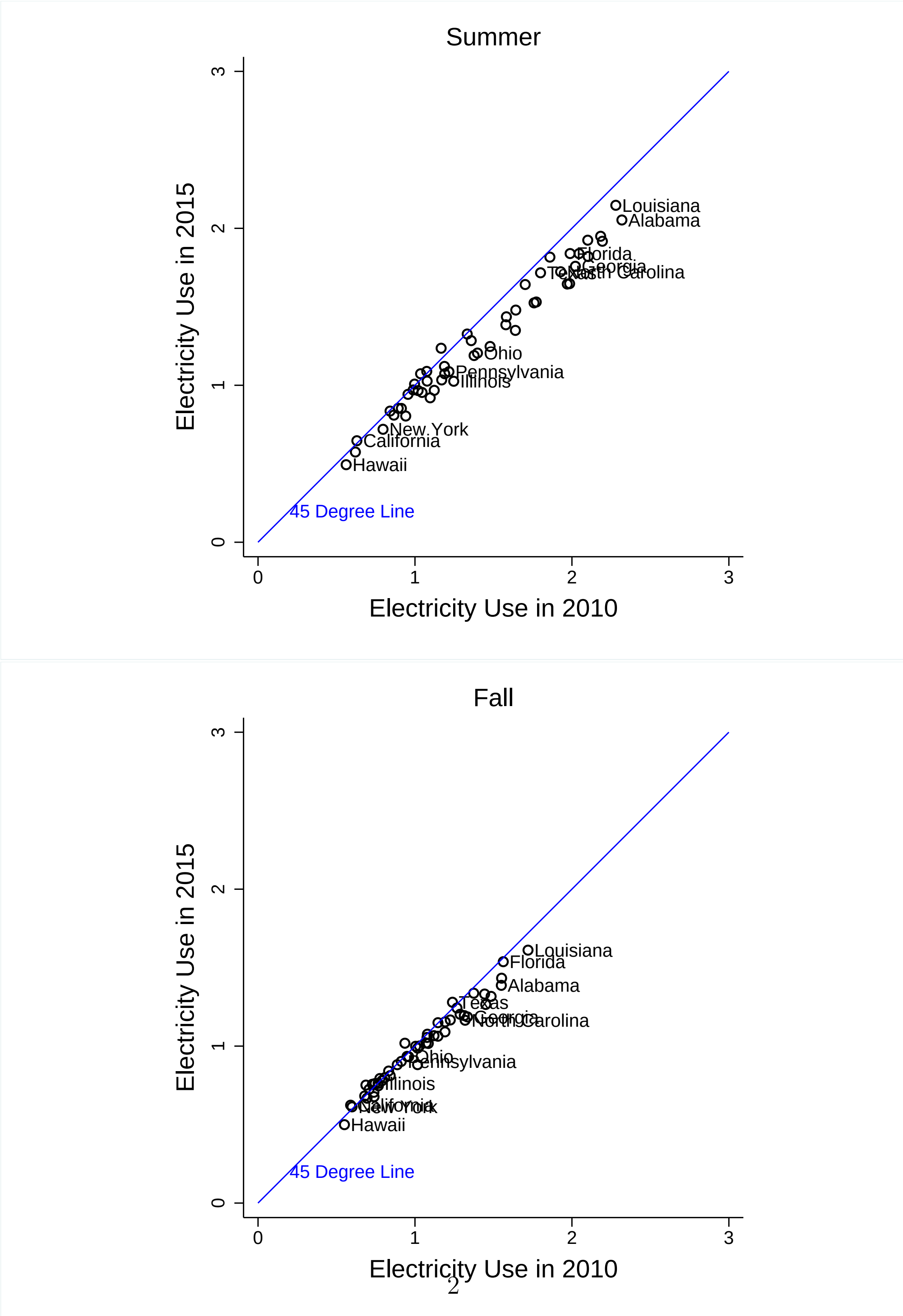
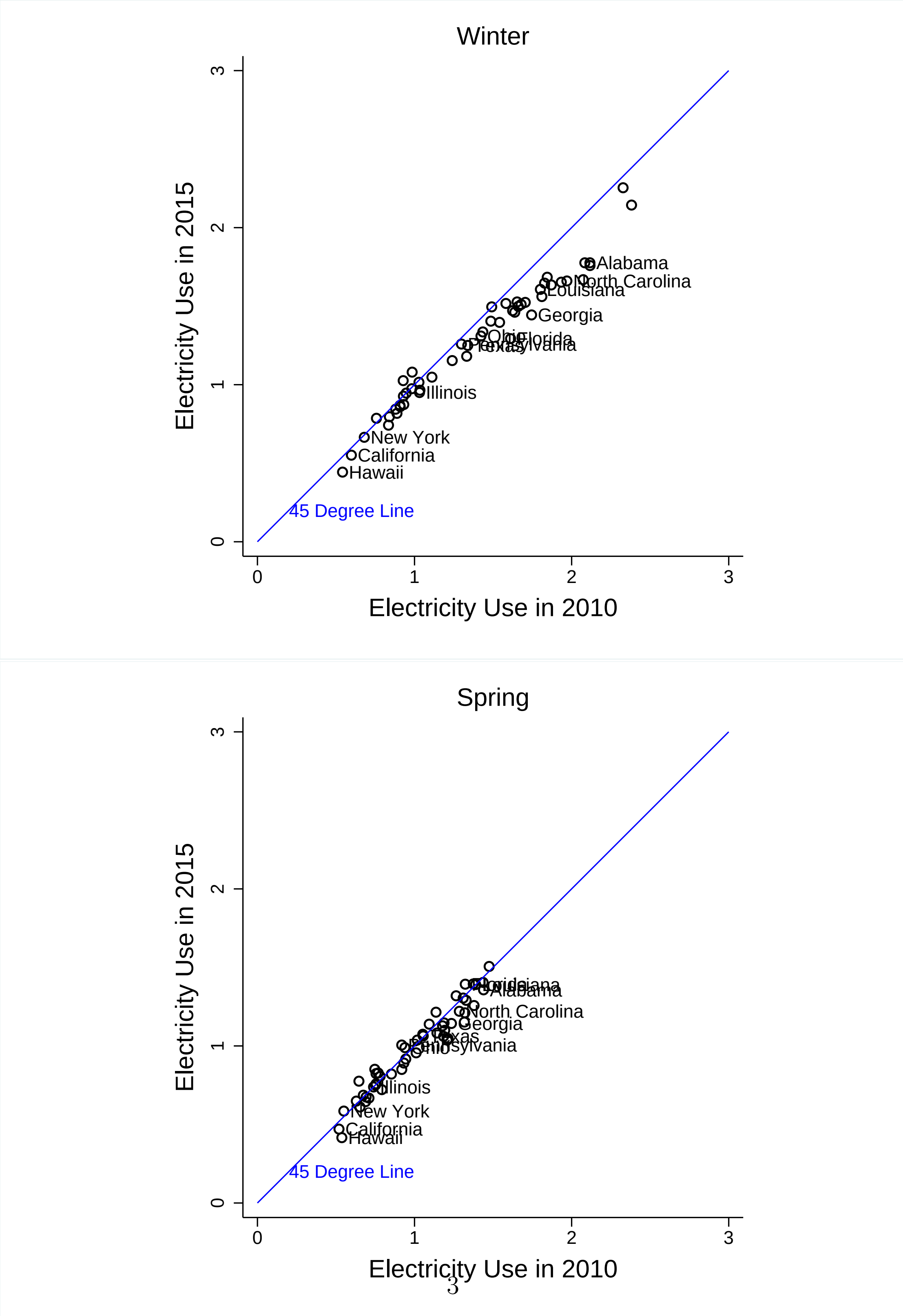
Appendix Figure 1: Total U.S. Household Electricity Use in MWhs



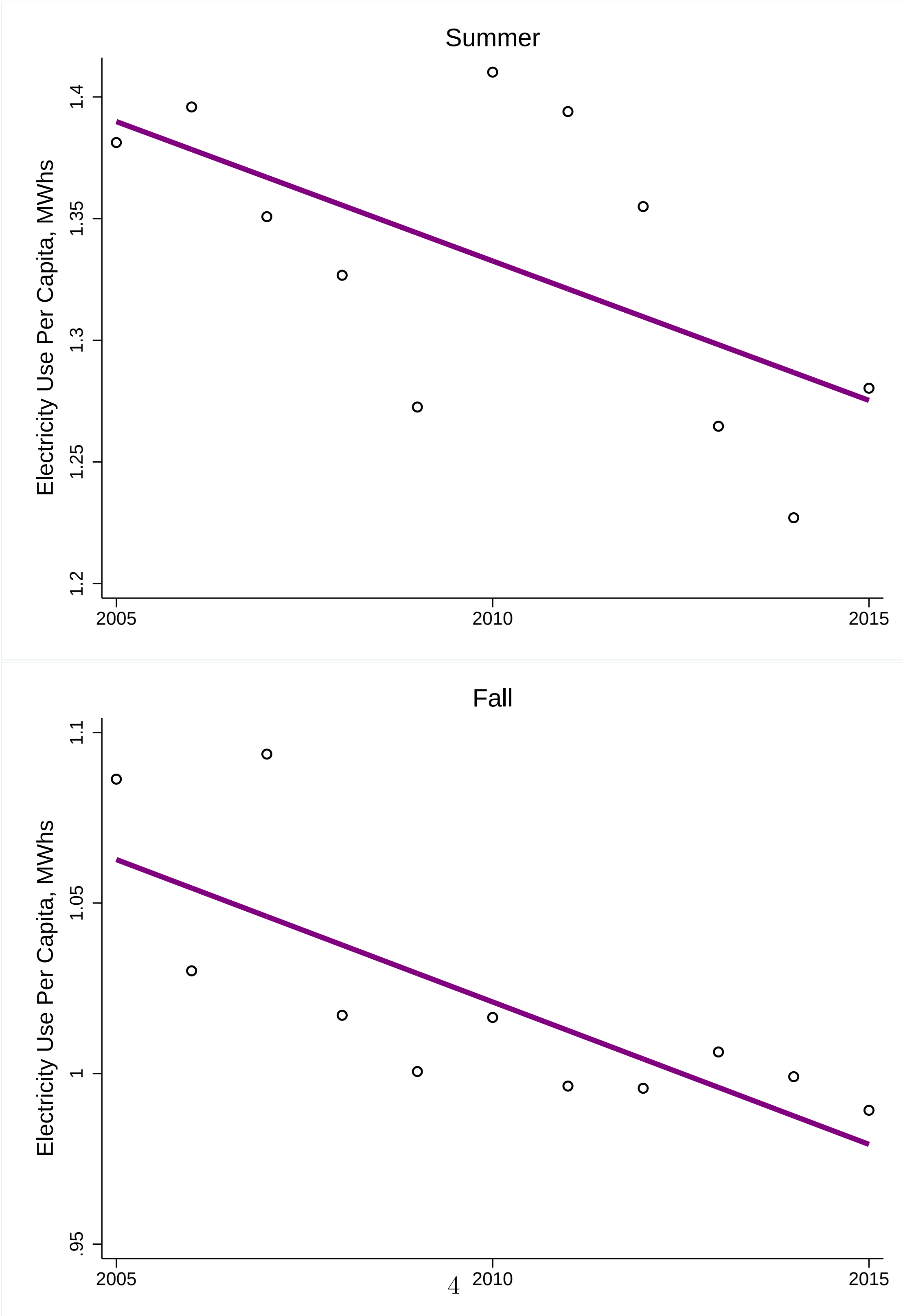
Appendix Figure 2: U.S. Household Electricity Use Per Capita, By Season



Appendix Figure 3: U.S. Household Electricity Use Per Capita, By Season



Appendix Figure 4: Trend By Season 2005-2015



Appendix Figure 5: Trend By Season 2005-2015