ROOFTOP REVOLUTION? THE COMPARATIVE EFFECTIVENESS OF STATE POLICY INCENTIVES FOR SOLAR PHOTOVOLTAIC ADOPTION IN THE RESIDENTIAL SECTOR

by

Virgil Ian Stanford
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Abstract

ROOFTOP REVOLUTION? THE COMPARATIVE EFFECTIVENESS OF STATE POLICY INCENTIVES FOR SOLAR PHOTOVOLTAIC ADOPTION IN THE RESIDENTIAL SECTOR

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Against the backdrop of increasingly vigorous debates in state legislatures over climate change mitigation strategies, this dissertation examines the effectiveness of policy incentives designed to encourage the adoption of solar photovoltaic systems in the residential sector. Utilizing panel data from all 50 states and the District of Columbia from 2007 to 2012, this study controls for critical non-policy covariates including economic, environmental, and socio-demographic factors as well as an array of solar market factors including marketing effort, the number of solar installers within a state, and the support of utilities for renewable energy. Moreover, instrumental variables are used to address possible endogeneity. The results indicate that although financial incentives generally have a statistically significant, positive effect on solar PV installation rates, high electricity prices and the falling retail price of solar PV equipment have a stronger influence on solar technology diffusion at the state-level.

1. Introduction

During 2013, Arizona utility companies confronted solar panel installers in the culmination of a long running debate that received limited national media attention (Wilson, 2013). The argument was over Arizona's net metering policy, a law that provides a financial incentive to encourage individuals and businesses to place solar panels or other renewable energy technologies on their private property by requiring that utilities purchase the excess power generated.

When the policy was introduced in 2009, Arizona had very few residential solar power users; therefore, utilities were relatively unconcerned with the rates they were paying for solar power. Unlike electricity purchased from large power plants at the wholesale electricity rate, net metering in Arizona requires that utilities purchase power from residential solar installers at the retail rate, providing potential installers with an additional financial incentive. However, as the number of households adopting solar power systems continues to grow, especially at the rapid rate depicted in Figure 1.1, utility companies argued that they would be increasingly burdened by the large amount of money they were required to pay and that this would also have an adverse affect on electricity rates impacting every consumer, not just those choosing solar power. Thus, the utility industry proposed that the Arizona Corporation Commission (ACC), the body that regulates utilities in the state, decrease the rate that utilities are required to pay for net metered power and allow utilities to impose additional monthly or yearly fees on homes with net metering.

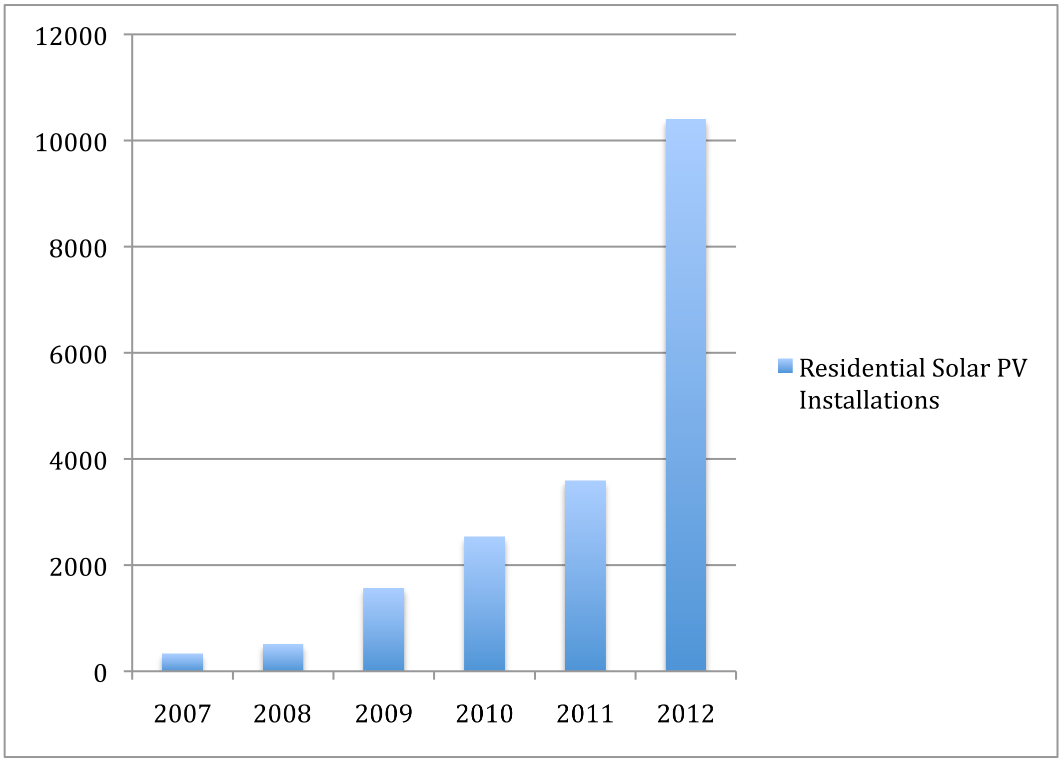


Figure 1.1: Number of Residential Solar Installations in Arizona, 2007 – 2012

The solar industry's response to this policy proposal was clear and simple. Decreasing financial incentives or imposing additional fees for net metering would make fewer people adopt solar power just as solar panels were becoming a popular clean energy alternative. This decision would benefit the fossil fuel industry and harm the environment at the expense of all consumers.

Ultimately, the ACC decided to impose a $0.70 per kilowatt fee on solar systems with net metering, a fee substantially lower than the $8.00 per kilowatt fee proposed by the utility companies (Trabish, 2013a). Recently, this debate over net metering has spread to a number of other states including Colorado, Wyoming, and Oklahoma and belies a greater debate over the value, efficacy, and legitimacy of government incentives aimed at promoting renewable energy generally and solar power in particular (Trabish, 2013b).

Little federal policy for solar power is aimed directly at residential consumers; instead, most federal money goes toward research and development and supply-side incentives for solar panel and module manufacturers. Federal incentives aimed at increasing consumer demand for solar power were available in the late 1970s and early 1980s following the Middle East Oil Crisis but were only reintroduced in the Energy Policy Act of 2005 (Geri and McNabb, 2011). Meanwhile, many states and local governments have been engaged on some level over the last decade at providing a variety of financial incentives for residential customers to decrease the overall cost of adopting solar photovoltaic power systems or other renewable energy technology.

Renewable energy is also at the heart of a number of important political debates in the United States. Politicians argue that developing renewable energy sources decreases dependence on foreign energy sources, particularly in the tumultuous Middle East.

Additionally, increasing the amount of energy produced from renewable sources like solar mitigates the externalities associated with heavy dependence on fossil fuels. Renewable energy preserves natural resources and decreases emissions from fossil fuels that contribute to air pollution and global climate change. In fact, mitigating climate change has become an important reason for renewable development, especially in recent years (Geri and McNabb, 2011). In the United States, federal policy to address climate change faces a number of political and institutional barriers. As a result, much of the public policy aimed at mitigating or adapting to climate change occurs at the state level. Thus, examining these state policies, such as solar adoption incentives, is critical to evaluating how the United States is responding to the threat of global climate change.

Solar photovoltaic power is a key component of the renewable energy mix in the United States. Photovoltaic cells generate electricity directly from sunlight. There are a number of advantages that solar photovoltaic cells possess over other forms of renewable energy. They provide more electricity during peak periods. Also, solar resources (i.e. sunlight) are more widespread throughout the U.S. than wind, geothermal, and hydroelectric sources of power.

Solar power has advanced substantially over the last decade both in terms of deployment and efficiency. At the same time, the cost has also been rapidly decreasing due to improvements in efficiency and increasing economies of scale. While overall adoption of solar power is increasing in three distinct market segments (Residential, Commercial, and Utility), adoption rates are not uniform across the country. The distribution of solar installations varies widely by geography. While scholars and policy makers have investigated reasons for these differences between states and localities, debates over the reasons behind these differences in adoption rates continue to rage.

The high cost of solar photovoltaic systems is one of the key factors that scholars argue prevent the widespread adoption of residential solar power systems. During the last decade, state governments have come up with an array of different financial and policy incentives to bring down both the short and long-term costs of installing solar power systems. These include a variety of tax incentives (income, property, and sales taxes), subsidized loans, grants, rebates, performance-based incentives, renewable portfolio standards, and net metering. Still, solar resources and incentives vary widely between the states. Moreover, past studies of residential renewable power adoption have identified a variety of environmental, economic, and social factors that influence adoption rates. Additional information is needed to determine which of these incentives or combination of incentives is most effective, especially when controlling for several key factors including the availability of solar radiation and state economic conditions.

This dissertation seeks to add to the body of literature on the effectiveness of public policy for influencing pro-environmental behavior. Particularly, it focuses on whether financial incentives are effective policy mechanisms for influencing the adoption of solar photovoltaic energy in residential neighborhoods. To this end, it compares the policy approaches undertaken by the 50 states of the United States of America as well as the District of Columbia. The goal of this research is to answer the following three questions:

1. **Are financial incentives an effective mechanism for influencing solar photovoltaic adoption?**
2. **Are some policy incentives more effective than others in encouraging solar photovoltaic adoption?**
3. **Do economic considerations or socio-demographic characteristics have a larger influence over solar photovoltaic adoption behavior than policy incentives?**

The remainder of this dissertation will be laid out in the following chapters. Chapter 2 will examine the history and current state of the solar market in the United States, specifically in the residential sector. Chapter 3 will examine the scholarly literature relevant to this topic. It will investigate the economic and behavioral theories that explain how people decide to adopt new technologies like solar photovoltaic panels as well as why financial incentives can be effective public policy tools to influence behavior. Furthermore, it will survey the empirical work that has already been done in this area, highlighting existing gaps in the literature that this dissertation seeks to fill. Chapter 4 will explain the methodology used in this study, particularly the quantitative techniques that will be used to model aggregate adoption behavior at the state level. Chapters 5 and 6 will report the characteristics of the data and the results of the quantitative model that will compare solar adoption rates between all states. Chapter 7 Finally, Chapter 8 will discuss the results of the study in the broader public policy context discussed above and provide recommendations for policy makers looking to enact of adjust laws providing incentives for residential solar power.

The following research has substantial relevance for policy makers at the state and federal levels. Integrating renewable energy resources into the United States' energy mix has been a stated goal of politicians of both parties pursuing an "all of the above" energy strategy. Though they may differ on the role that renewable sources like solar will play, better understanding the effectiveness of policy incentives in the presence of real-world social and economic factors will potentially lead to better, more effective policymaking. Moreover, states continue to debate whether to implement more incentives, let incentives expire, or eliminate them back altogether. By weighing in on which incentives are most effective, this dissertation will provide valuable evidence in the political debates occurring in states like Arizona. In an era where lofty goals for the future are constantly confronting the reality of constrained budgets, this research has the potential to contribute to cost-effective, results-maximizing public policy for residential solar development.

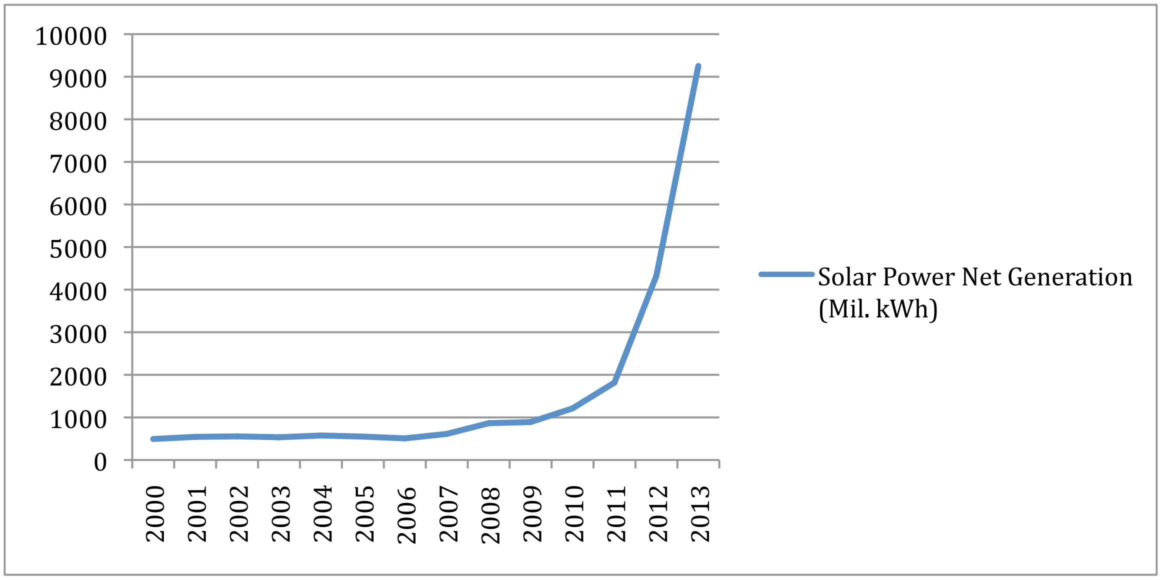
Are state policy incentives effective tools for encouraging private citizens to invest in their own solar power generation systems? Have the efforts of state governments over the last decade been successful in igniting a rooftop revolution, or is their effectiveness limited by the multitude of intervening factors including politics, environmental conditions, economic conditions, and various other social forces? This dissertation seeks to add to the growing literature about the diffusion of renewable energy technology by investigating which state-level policy incentives are most effective in promoting the adoption of residential solar photovoltaic power systems.

2. Policy History of Solar Photovoltaic Incentives

Solar photovoltaic technology is one of the most recognizable forms of renewable energy technology in the world. For decades, solar cells have been used to operate watches and calculators. Traffic lights and street lamps are increasingly powered by a battery charged during the day by solar electricity. They sit on the roofs of houses in residential neighborhoods, and in some areas of the country, gigantic solar arrays take up entire fields just off the highway. In recent years, researchers have even developed prototypes for solar powered automobiles and airplanes. Along with large wind turbines that dot the American landscape, solar photovoltaics have recently become more commonplace in the United States.

Despite their high profile, visibility, and ability to spark the human imagination of what the future might be like, solar photovoltaic power makes up a tiny portion of the total electricity generating capacity in the United States. According to Geri and McNabb (2011), solar energy makes up less than 1 percent of all electricity generation in the U.S. and renewable energy sources (excluding hydroelectric power) together make up only 3 percent.

While the reality of renewable energy generation in some people's minds may not currently meet the ideal, there is no doubt that the deployment of renewable energy technology has also been increasing dramatically over the last decade. As Figure 2.2 illustrates, between 2000 and 2006, total solar net electricity generation in the United States remained relatively constant, yet the growth rate since 2007 has been exponential going from 612 million kilowatt-hours to over 9 billion kilowatt-hours in 2013. Some analysts would attribute this rapid growth to the vast array of government policies that exist to fund research, encourage technology innovation, and incentivize adoption.



Source: Energy Information Administration, 2013

Figure 2.1: Total Solar Power Net Electricity Generation in the United States, 2000 - 2013

Regardless of the role that public policy may have played in the recent growth of solar photovoltaic power, any analysis of current solar growth must take into account the history of the technology itself as well as the history of government intervention into the market for solar energy. This chapter will begin with a brief historical overview of the development solar technology, examining how it has changed over time. Particularly, increases in efficiency over time have produced a power source that now has the capability of competing with other forms of renewable energy and even fossil fuels in some cases.

Obviously, the development of solar power technology did not occur in a vacuum. This chapter will continue by examining the role that key historical events and public policy interventions have played in promoting or stifling solar deployment. Next, it will explain a number of different policy approaches to promoting solar power that have been pursued by different countries around the world and delineate the approach currently pursued by the United States and many of its political subdivisions. Finally, this chapter will examine the current market for solar power in the U.S. with a particular focus on the growth that has occurred over the last decade and how experts project solar power to grow into the future.

2.1 History of Solar Technology

Although solar technology is often considered to be a relatively new development, French scientist Edmond Becquerel first discovered the photovoltaic effect itself in 1839. He found that when two metal electrodes placed in an electrolytic solution were exposed to sunlight, the electricity generated by the cell increased (Department of Energy, 2013). Several decades later in 1876, William Grylls Adams and Richard Evans Day discovered that, when exposed to direct light rays, the element selenium produced electrically charged particles, though the amount of electricity created was too low to power any useful devices. Still, it was this discovery that prompted work on the first solar power cells.

While scientists continued to expand on photovoltaic principles over the next century, developing the technology for solar electric cells and solar water heaters, the practical uses of solar photovoltaic technology remained limited, particularly in commercial applications (Perlin, 1999). For instance, by the late 1950s, satellites orbiting earth were primarily powered by solar photovoltaic cells, making NASA a leading consumer of the technology. However, average consumer uses for solar photovoltaics tended to be more along the lines of Western Electric, who used the cells to power dollar bill changing machines. By the early 1970s, governments and corporations had found limited used for photovoltaic cells, including powering warning lights on offshore oilrigs, lighthouses, and railroad crossings. Their limited usefulness was due primarily to their high cost, which exceeded $100 per watt until Elliot Berman, with funding from the Exxon Corporation, was able to develop a cheaper silicon solar cell with a cost of $20 per watt.

In contrast, solar heating, both passive room heating and solar thermal water heating, has been more common and commercially applicable (Department of Energy, 2013). In 1891, Clarence Kemp, an inventor in Baltimore, Maryland, patented the first solar water heater. Due to the domestic energy shortage brought about by World War II, the demand for homes employing passive solar heating increased dramatically. Then in the 1950s, architect Frank Bridgers built the world’s first solar-heated office building in Albuquerque, New Mexico. These solar heating applications required no complicated chemistry, instead using the natural heating power of the sun, which architects had been using for centuries prior to the development of heating, ventilating, and air conditioning (HVAC) technology.

The recent development of solar power technologies in the United States was catalyzed by the energy crisis of the 1970s. The massive economic expansion that occurred in the United States after World War II was fueled in large part by cheap petroleum prices. From 1948 to 1970, the price of crude oil fluctuated between \$2.50 and \$3.00 per barrel (Williams, 2011). Adjusted for inflation, this range is equivalent to \$14 to \$19 in 2010 U.S. dollars. In 1973, U.S. support for Israel in the Yom Kippur War resulted in the Organization of Petroleum Exporting Countries (OPEC) placing an embargo on oil shipments to the United States and several European allies. According to Williams (2011), OPEC members reduced crude oil shipments to the U.S. by 5 million barrels per day while U.S. allies were only able to increase production by a total of 1 million barrels per day. The 4 million barrel-per-day shortfall resulted in a shortage that saw the price of refined petroleum products, particularly gasoline, rise rapidly in price. By the time the embargo was lifted in March of 1974, the nominal price of crude oil had risen to four times its pre-war price, from \$3.00 to \$12.00 per barrel.

At the time, crude oil filled a variety of energy needs in the United States including being the dominant source of transportation fuel and heating fuel as well as supplying 10 percent of electricity generation fuel; thus all sectors of the economy were under threat from increased petroleum prices (Energy Information Administration, 2014).

2.2 History of U.S. Solar Policy

With crude oil prices at all-time highs during the 1970s, the U.S. government began looking for ways to incentivize either increasing energy efficiency or developing alternative energy sources, thus beginning a long and complicated relationship between the adoption of solar energy technology and public policy. During President Carter's so called "war on energy," the federal government issued energy bonds, instituted energy efficiency and conservation tax credits, and created an energy mobilization board to facilitate the transition to renewable energy (Zahran et al., 2008). All of these efforts were geared toward increasing investment in the research and development of renewable energy and making renewable energy more affordable for the end user. One such law was the Energy Tax Act of 1978. This law provided income tax credits for investments in energy efficiency technology including solar, wind, and geothermal power generation with a maximum credit valued at $2,500 (Crandall-Hollick and Sherlock, 2012). In 1980, the Crude Oil Windfall Profit Tax Act increased the incentive for renewable energy to bring the total tax credit value to $4,000. However, due to both falling oil prices and a general policy of deregulation, the Reagan administration allowed the tax credits to expire in 1985, and it was not until 2005 that federal tax credits for energy efficiency and renewable energy generation were reinstated as part of the Energy Policy Act of 2005.

With the Reagan administration's decision to eliminate the federal government's role in incentivizing alternative energy technology and energy efficiency, several states, particularly those with a high demand for electricity, moved to fill this policy vacuum. One such state was California. During the late 1980s, California shifted its focus from providing incentives for small-scale residential and commercial solar installations to developing utility-scale applications of solar technology (State of California, 2013). In 1986, the LUZ Solar Generating Station, the world's largest concentrated solar power plant, was constructed in the Mojave Desert, providing 300 megawatts of power capacity. By 1993, Pacific Gas and Electric, one of the largest power companies in California, constructed the first grid-supported solar photovoltaic power installation.

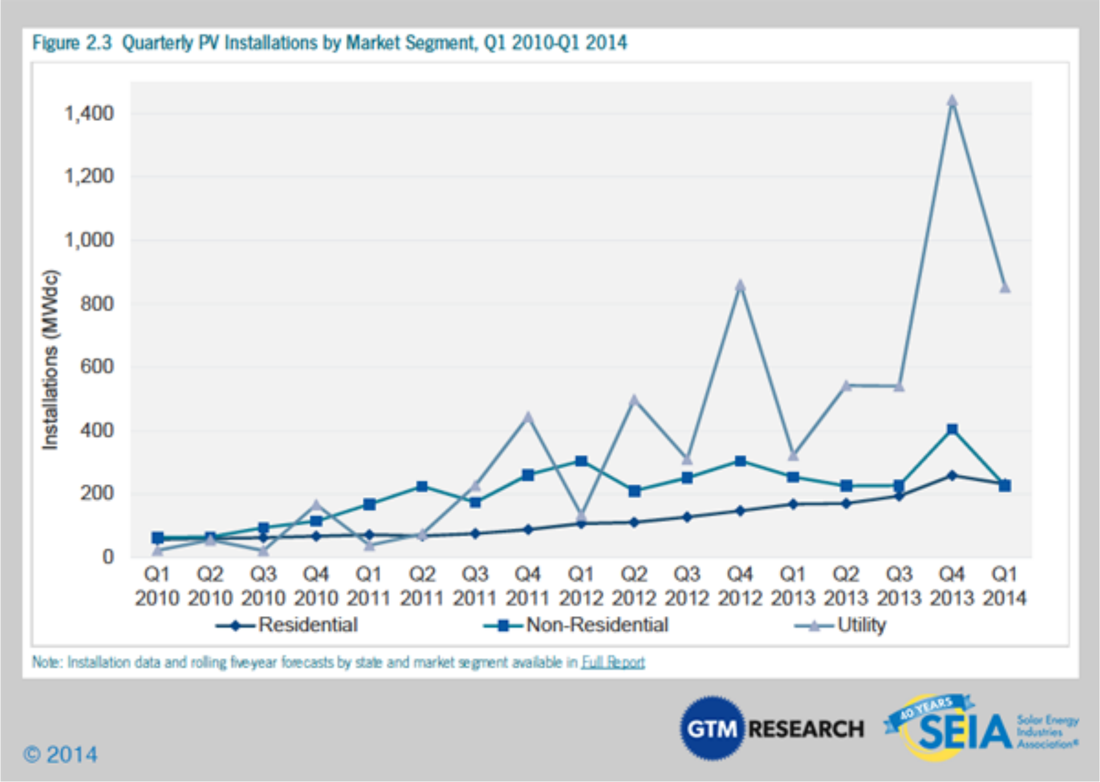
Of course, these advancements in utility scale power did not mean that California abandoned small-scale renewable energy incentives. For example, Assembly Bill 1890 created the Emerging Renewables Program, which offered rebates as an incentive to reduce the up-front cost of qualifying renewable energy power systems, including solar photovoltaic arrays. After the institution of this program along with several others, California experienced the creation of 150 megawatts of solar electric capacity. It is important to recognize that California may not constitute a representative example of how the average state reacted to the absence of federal policy to incentivize solar power development. Still, by 1984, forty–one (41) states had some sort of policy incentive for the installation of equipment that harnessed solar power for heating water, heating the air, or providing electricity (Durham, Colby, and Longstreth, 1988). Currently, Mississippi is the only state without any state-level policy incentives for solar power installations (DSIRE, 2013). Overall, a report by the Bipartisan Policy Center (2011) notes, "The expansion that occurred in the [last] decade would likely not have been possible in the absence of state-based regulatory requirements and/or incentives," (p. 5).

Solar energy comes in many forms. Along with other renewable sources such as wind and hydroelectric power, it has contributed an increasing amount of electricity to the American electric grid over the last thirty years, either in the form of solar photovoltaic panels or concentrated solar electricity plants (National Academy of Sciences, 2010). It is important to differentiate between these two types of solar power generation. Solar photovoltaic power involves the direct conversion of solar rays into electricity while concentrated solar uses the sun's heat to convert liquids to steam that generate electricity by turning a large turbine. While concentrated solar electricity generation requires a large industrial facility to generate power, solar photovoltaic cells can be deployed either *en masse* at a power plant or in smaller settings such as on the roofs of homes and businesses.

Though the number of solar photovoltaic systems deployed in the United States has increased overall throughout the last decade, residential installations still account for only a small percentage of the electricity generated by solar power. In 2012, residential solar installations accounted for 488 megawatts of the 3313 total megawatts of solar energy generated in the United States (SEIA, 2013). This discrepancy in generated electricity comes primarily from the fact that residential Solar PV systems are typically smaller than systems installed at commercial properties or by utilities. Moreover, solar photovoltaic systems are often expensive to install, require trained professionals to install and connect the systems to the power grid, and have fluctuating payback periods due to the volatility of the price for electricity and the fact that solar resources fluctuate with the location, time of day, and season.

Still, the number of residential solar installations continues to increase at a steady rate every quarter, according to Figure 2.2, which cannot be said for the commercial and utility sectors that experience substantial quarterly volatility. In fact, the majority of individual installations occur in the residential sector even though total increases in capacity are driven by growth in the commercial and utility sectors (SEIA, 2013).

Residential sector growth has continued for a number of potential reasons. First, solar power is clean and effectively displaces power generated using fossil fuels, which pollutes the atmosphere and contributes to climate change by emitting carbon dioxide (Tsoutsos, Frantzeskaki, and Gekas, 2005). Second, solar photovoltaic arrays are effective at reducing long-term household electricity costs by displacing power normally purchased from the grid. Third, states are increasingly requiring electric utilities to draw more of their electricity from renewable sources through the implementation of renewable portfolio standards. Rather than invest substantial sums of money in new large-scale solar power plants, some power companies are content to buy excess solar-generated power from many small residential installations, especially where the homeowner pays most or all of the installation costs. Thus, the state and electric utilities have an interest in encouraging the adoption of residential solar photovoltaic systems through policy incentives aimed at reducing the overall cost and shortening the time period to realize a return on investment.



Source: Solar Energy Industry Association, 2014; http://www.seia.org/news/us-residential-solar-pv-installations-exceeded-commercial-installations-first-time-q1-2014)

Figure 2.2: Quarterly Solar Photovoltaic Installations by Market Sector, 2010 – 2014

2.3 Conceptual Frameworks for Solar Policy

There are a variety of policy approaches that governments can use to directly and indirectly influence the deployment of solar PV technology within a particular jurisdiction. A number of scholars have attempted to categorize these policies within an analytical framework that can be useful for future research. Beck and Martinot (2004) arrange renewable energy support policies into three groups based on how they address cost-related barriers to renewable energy development. The first category includes policies that focus on cost setting and quantity-forcing that seek to reduce cost barriers by mandating certain levels of production and distribution. The second group is investment cost-reduction policies, which offer financial support to end users of the renewable energy systems to lower the high initial investment costs. And third, Beck and Martinot identify policies that include public investments and market facilitation activities where governments lower cost barriers by becoming participants in the renewable energy market. While this conceptual framework highlights the importance of cost reduction strategies in renewable energy policymaking, the framework itself is somewhat unwieldy and difficult to use in practice.

As an alternative, Menz (2005) utilizes both geographic and administrative criteria to categorize renewable energy support policies. According to this system, federal policies serve a range of functions including regulating energy markets, funding research and development activities, and providing financial incentives, generally in order of importance. Meanwhile, state and local policies favor financial incentives, rules and regulations, and voluntary programs. Despite the fact that there is some usefulness in analyzing policies at different administrative levels, the primary problem of this particular framework is that there is tremendous overlap between the types of policy options pursued at each level. Thus a study of a particular policy type, financial incentives for instance, will be forced to look across government types, negating the primary advantage of this framework.

Specific to renewable energy financing strategies, Toke and Lauber (2007) contrast two different approaches that they refer to as “market-based” and “command and control.” Their research compares the approaches taken by the United Kingdom and Germany and notes that UK approaches to finance tend to be decentralized and market-based while German approaches tend to be more centrally planned using extensive regulation that requires mandatory participation. Still, the authors note the blurred line that exists between these to categories of financing approaches and even add to the confusion by suggesting that the German Feed-In Tariff (FIT) system is a prime example of command and control policy. Though explained in more detail below, a FIT incentivizes renewable energy adoption by guaranteeing purchasers of renewable energy systems an above-market price for power that they sell back to the grid. While the government sets the premium level, the program still relies on the proper functioning of the market for renewable energy where power is bought and sold. Proper functioning of a FIT also requires that solar power providers choose to enter the market rather than have participation forced upon them. Thus, to describe a FIT as a “command and control” policy can be confusing.

Sovacool (2009) takes a slightly different approach by categorizing barriers to renewable energy adoption, and then drawing from interviews with energy industry experts, he identifies four policies most likely to address each barrier. He claims that the barriers to adoption can generally be grouped as financial, political, cultural, and aesthetic. Meanwhile, the policies that experts favor to address these impediments are "eliminating subsidies for conventional and mature electricity technologies, accurately pricing electricity, passing a nationwide feed-in tariff, and implementing a national systems benefit fund […]," (p. 1529). Interestingly, each of these proposed policies address the financial barriers directly or indirectly, either by making renewable energy cheaper to produce or making renewable energy technology easier to finance.

Zhai (2013) provides the most useful framework for thinking about solar energy policies. The researcher proposes a three-tiered model. While each tier is a different type of policy program, the tiered structure allows each policy to interact with others. Rather than emphasizing the difference in solar policy types, Zhai's model illustrates how they work together in a system. The first tier consists of rules and regulations that set the goals for production and consumption and lay down the rules for the solar energy market and its interaction with the conventional energy market. The second tier comprises financial incentives, or "financial support mechanisms," that encourage individuals and businesses to produce or adopt the technology in order to meet the objectives set by the rules and regulations. The third and final tier includes funding sources such as the creation of public benefit funds that provide financial support for the incentive programs. In this model, each component is necessary for a successful program. Therefore, evaluating the success of solar energy program requires accounting for each individual policy part.

A common thread of each of the frameworks highlighted above is the important role played by financial incentives in the policy mix. Each framework notes, either explicitly or implicitly, that financial barriers provide a significant impediment to solar energy adoption. Even in the absence of federal financial incentives for solar power, states have continuously implemented incentive programs and provided the primary source for policy action and innovation in this area.

Yet, it is also important to note two additional conclusions that can be drawn from the conceptual models evaluated so far. First, Toke and Lauber (2007) point out that not all financial incentives or financing mechanism are created equal. In fact, many have important differences in both technical details and underlying ideological assumptions. Second, Zhai (2013) notes that financial incentives are part of a greater policy system where each policy interacts with the others. A proper study of solar financial incentives should therefore have two characteristics. It should highlight the different types of financial incentive offered, making allowances for how the programs exist in reality and dispensing with the assumption that all incentive programs are created equal. Additionally, a proper study will account for policies that encourage solar adoption indirectly through rules and regulations, not exclusively by offering financial resources. The remainder of this chapter will compare and contrast several solar energy policies commonly found in the United States at the state level. Many will be financial incentives, but two indirect incentive policy programs will also be described, specifically net metering and renewable portfolio standards.

2.4 Common Types of Solar Policy

There are a variety of extant state-level policy initiatives under implementation in the United States that use different mechanisms to incentivize the purchase and installation of solar photovoltaic systems. As described above by Zhai (2013), these policy incentives can take the form of financial incentives that offer monetary benefits directly to consumers in an effort to lower the cost of solar equipment, or they may take the form of indirect policy incentives such as rules or regulations that bolster the markets for renewable energy technology, often but not always resulting in lower costs for consumers and efficiency gains for producers.

Although Toke and Lauber (2007) illustrate definitively that there are important differences in the types of financial incentives that need to be taken into account in any study of their effectiveness, the limitations of their conceptual framework, including the heavy focus on the ideological assumptions of each policy and the overlap between what the authors describe as “market based” and “command and control” policies, make it less than ideal in practice. Sarzynski (2012) provides an alternative conceptual framework for evaluating the different types of financial incentives that overcomes some of these limitations. In an empirical analysis of the effectiveness of financial incentives for the entire solar market (residential, commercial, and utility), she divides the incentives into four groups based on the technical details of the program and the length of time required to achieve a payback. The first group, cash incentives, includes rebates and grants. While these types of programs have wildly different technical details, they are linked by the fact that they offer the most immediate payback for an investment in solar technology. The other three groups are sale tax, income tax, and property tax policies. The technical details of programs may differ slightly from state to state depending on the various tax laws and preferences, such as whether the state prefers an exemption-based or credit-based tax code, but they are unified in that they target a particular type of taxation. Additionally, these tax-based financial incentives vary in both their payback periods (typically less immediate than cash incentives) and complexity.

Unfortunately, she leaves out two types of incentive programs sometimes employed at the state-level, namely low interest loan programs and performance-based incentives. Concerning loan programs, it is possible that this oversight occurs because loan programs don’t quite fit conceptually with these other incentive programs. Instead of decreasing the overall cost of a system, loans, even those where part of the interest is subsidized by the government, actually increase the total cost of a solar system by adding on the cost of interest payments. Still, they allow the consumer to trade-off a slightly higher overall cost with immediate access to capital, serving at least conceptually, as an incentive particularly for low liquidity, less-price conscious consumers. As for performance-based incentives, these programs, such as feed-in tariffs and sales of renewable energy certificates, were not particularly common at the time of her study, though even she notes their recent increase in popularity.

Lastly, Sarzynski also makes an allowance in her study for different types of indirect policy incentives including net metering and solar renewable portfolio standards and carve-outs, treating each of these as an individual type of policy incentive.

Utilizing Sarzynski's basic framework and including loan programs, each category of policy incentive will be described below. The different types of financial incentives will be examined first, followed by the indirect policy incentives. Aside from describing their technical details, this section will also depict some of the different ways that they are currently implemented at the state level.

Cash Incentives

Cash incentives, sometimes referred to as government buy-downs (Gouchoe et al., 2002), include programs like rebates and grants where the government offers direct cash payments to purchasers in order to reduce the initial investment costs for renewable energy technology. Rebates and grant programs have some slight but important differences in their technical details that must be explained. For rebates, purchasers of solar equipment receive a cash payment from a government agency or utility once the renewable energy equipment is installed and certified by a government agency or private certifier. Rebate amounts can vary substantially from state to state and often are distributed over the course of multiple years, which could potentially diminish the effectiveness of the cost reduction effort. On the other hand, renewable energy grants provide small amounts of money before a system is purchased to defray the upfront costs. Generally, grant programs are rare and place strict limits individuals with the potential to qualify, such as income limits.

Cash incentive programs provide a number of distinct advantages over other types of financial incentives. They are often easier to understand and access than tax incentives (Gouchoe et al., 2002). Cash incentives often base their payouts on the size of the system; for example, Connecticut's Residential Solar Investment Program offers a rebate of $1.25 per watt for solar photovoltaic systems up to 5 kW resulting in a total cash rebate of $1,250 for a 1 kW system ($1.25/W x 1000 W). In contrast, most tax incentives require the purchaser to have some knowledge of the tax code in order to fully understand the value offered by the financial incentive. Moreover, it is important to recognize that cash incentives play a role in shortening the time required to realize a return on investment (ROI) for grid-connected systems where net metering is allowed and in comparison to performance-based incentives. Additionally, they represent a guaranteed amount of payment, unlike performance-based incentives, where the amount of money paid to the solar power system owner is dependent on the level of production in any given year and market conditions beyond an individual's control.

The downside of cash incentives is that they tend to be particularly politically vulnerable (Gouchoe et al., 2002). As direct cash payments, they often require and explicit funding mechanism that can be targeted when declining economic conditions or political upheaval in the state legislatures result in a propensity toward budget cuts. Furthermore, the popularity and accessibility of these programs require that the amount of rebate or grant be set carefully so demand does not outpace and overwhelm producers' ability to supply the technology.

Currently, there are 18 government-sponsored rebate programs for renewable energy in states around the country. This number is up from 11 in 2002 (Gouchoe et al., 2002). There are slightly fewer grant programs, 15, though most of these do not cover the residential market sector. In fact, only 3 grant programs were available for the residential solar energy sector by the end of 2012.

Tax Incentives

The tax code can be used many different ways to incentivize the purchase of Solar PV systems. In some states, an exemption from some or all of the state sales tax is available for the purchase of new photovoltaic power systems. Alternatively, a state may decide to offer a personal income tax credit that decreases the installer's overall tax liability over a particular time period. Finally, states could also provide a property tax exemption for the increased value of a property due to solar equipment installation. The type of tax incentive offered by a particular state depends heavily on the tax structure within the state. For instance, several states, such as Florida and Texas, collect little or no income tax, making sales and property tax incentives more likely.

Ultimately, the purpose of these tax incentives is to reduce the overall cost of solar power systems, yet they require the installer to pay all of the cost upfront and thus do little to reduce the initial investment required. Still, they are potentially more politically viable than other types of financial incentives because they do not require annual appropriations. However, if the primary goal of the tax incentive is to encourage maximum public use, tax incentives have an important limitation. As Gouchoe et al. (2002) note, many tax incentives go unclaimed or under-claimed due to their complexity or obscurity.

Some other studies have shown that tax incentives might not be as effective as other types of policies. A study about federal renewable energy subsidies by the

Bipartisan Policy Center (2011) compared renewable energy tax incentives to similar cash incentives. They concluded that upfront cash incentives were more cost-effective than tax incentives by approximately a factor of 2 (p. 13). This is probably due to the fact that cash incentives are paid directly to project developers compared to tax incentives, which typically benefit equity investors. The report also points out that cash incentives do have some limitations, such as the fact that they encourage capital investment and not necessarily energy production or innovation. In contrast, several other studies have shown that state and federal tax incentives are effective at increasing the likelihood of purchasing and installing solar equipment (Durham et al., 1988, Hassett and Metcalf, 1995).

Despite questions of effectiveness, tax incentive programs remain popular and widespread. Property tax exemptions are the most popular with 39 states offering some sort of property tax incentive for renewable energy. This trend is likely due to the fact that while some states do not have income taxes and some do not have sales taxes, most states has some form of property tax that constitutes an important source of sub-state government revenues. Income tax and sales tax incentives are available in 23 and 28 states respectively. Moreover, 11 states offer some version of all three tax incentives, though they do not always apply to solar photovoltaics.

Low Interest Loan Programs

Although they may actually increase the total cost of a solar photovoltaic system, loan programs are aimed specifically at injecting liquidity into the residential market for solar installations. States will often provide subsidized or guaranteed loan programs that allow easier access to the initial investment capital and lock in low interest rates over the term of the loan. Subsidized programs decrease the total interest rate paid by the loan recipient while guaranteed loan programs promise the financial institution making the loan that the government will pay the balance if the recipient of the loan defaults. Loan terms and maximum borrowing limits vary from state to state and even sometimes within states if different private lending institutions administer the program. Moreover, some states and localities have a unique loan program know as Property Assessed Clean Energy (PACE), where the government directly loans the money and payments are collected through property tax revenue. However, due to the scarcity of state funds in the wake of the 2007 recession, most state-level PACE programs have either been suspended or relinquished funding authority to local governments (DSIRE, 2013).

Forty-five (45) states offer subsidized or guaranteed loan programs for renewable energy, but few of these programs apply to solar photovoltaics in the residential sector. Loan programs instead tend to apply to commercial and utility scale installations because of their greater ability to generate profits to pay back the loans. From 2007 to 2012, 13 different states had active loan programs for residential sector solar photovoltaic equipment.

Performance-Based Incentives

Performance-based Incentives are market-based tools designed to increase the amount of money that solar power providers receive for selling their power back to the grid. There are a number of different types of performance-based incentives with feed-in tariffs (FIT) and solar renewable energy credits (SREC) being the most common. FITs often involve long-term contracts (15 – 20 years) guaranteeing a price slightly above market rates for the electricity generated by residential solar PV arrays. SREC programs, on the other hand, provide solar energy producers with credits for every megawatt hour of electricity they produce. Then, within a particular time frame such as 3 years, the producer can sell the credit in a market to an electric utility that does not produce enough clean energy according to state regulations. After the 3-year life span for the SREC, it is retired if it is not sold. The purpose of both of these policies is to provide power companies with an adequate supply of renewable energy to purchase in states with renewable portfolio standards, an indirect policy incentive that will be explained in a later section.

Because FITs and SRECs are two substantially different types of policies, it is difficult to make sweeping generalizations about their advantages or disadvantages. As policy options that rely on the organizing power of markets and pay for actual production of electricity rather than potential production, these programs tend to be popular among economically conservative politicians, at least in theory. However, opponents of FIT programs say that these policies distort the market for electricity where higher rates paid for renewable energy tariffs are passed on to the consumer resulting in higher retail electricity prices. As for SRECs, the costs of setting up and regulating markets for trading credits are initially expensive. Moreover, it is unclear whether the small amount of electricity generated by most residential solar systems results in enough SRECs worth selling on the market. Lastly, as with many financial markets, the market price of SRECs in practice is volatile and depends on a number of factors outside of an individual producer's control. Especially during seasons where solar power is abundant, the large number of people attempting to sell SRECs could cause the price to crash resulting in a lower net financial benefit for solar energy producers.

Performance-based incentives have only recently become popular in the United States; however, they have enjoyed substantial success in European nations like Germany. In fact, Germany's successful deployment of solar technology despite low average solar radiation levels speaks to the potential power of a FIT program. Recent evidence from Europe also highlights a potential political vulnerability of FIT programs. For example, the government of Bulgaria that recently implemented a FIT was removed from power in the subsequent election when electricity prices began to rapidly increase (Bivol, 2013). The replacement government immediately lowered the FIT. Still, states have begun experimenting with performance-based incentives. Currently, 19 states sponsor a performance-based incentive for renewable energy and 18 states have at least one electric utility that offers a performance-based incentive program, even with no government support.

Net Metering

Net metering is an indirect policy incentive that allows residential solar power producers to sell their excess power back to the grid, often at retail rather than wholesale rates. It is by far the most ubiquitous indirect policy incentive. While it guarantees no specific amount of money, it is often a prerequisite to other incentives that hinge on the producer's ability to sell power back to the grid such as a feed-in tariff or loan program. The details of net metering policies at the state-level differ widely. In some states, the size of eligible solar photovoltaic systems is restricted, as low as 1 kilowatt. Alternatively, some states decide to restrict the aggregate capacity of an eligible solar system to a percentage of the average peak load, among other ways. Some states even impose an additional fee on net metering customers to reimburse electric utilities for installing two-way meters and performing electricity grid maintenance. In states with lax limits and low fees that require the electric utilities to shoulder much of the cost burden, political opposition to net metering programs has grown, yet, net metering proves to be quite popular in the United States with only 5 states having no policy for net metering.

Renewable Portfolio Standards

Renewable portfolio standards (RPS) are a set of regulations that require utilities within a state to produce a specific portion of their electricity from renewable resources like wind or solar (SEIA, 2014). Though aimed at utilities, RPS programs often indirectly support residential renewable power by encouraging utilities to purchase excess electricity from residential producers.

The specific details of RPS programs vary widely between states including different total targets, yearly targets, and deadlines. Moreover, some states have specific requirements for electricity produced from solar sources known as “carve-outs.” Despite the additional regulations imposed on utilities in states that have RPS programs, one benefit of the program is that it allows utilities a large amount of flexibility in determining how they meet their standards. As a result, RPS programs are increasing in popularity with 27 states having an RPS program, 19 of which include a specific solar carve-out.

2.5 Summary

In his study of how public policy change occurs over time, John Kingdon (2003) defines three streams of activity: problem, policy, and politics. Each of these streams develops independently over time; only when they coincide does policy change have a high probability of happening. Although at times discussing renewable energy can seem like describing some far-off future, this chapter has set out to illustrate that all three of these streams have existed in renewable energy policy for quite some time. The problems associated with building a society based on non-renewable, high pollution resources have been identified for quite some time. Meanwhile, the science of the photovoltaic effect was discovered over a century ago, and technology harnessing this scientific knowledge continues to be refined. While the problem stream continues to be updated as more information becomes known about the problems associated with carbon pollution and global climate change, these developments in the problem stream only serve to raise the profile of renewable energy generally, and solar energy specifically, as a possible solution.

Moreover, policy solutions to bring solar energy into mainstream use have been debated and realistically attempted at least since the 1970s. While many barriers exist that prevent the widespread adoption of solar power, a key barrier is the cost. Thus, policymakers have attempted a variety of strategies from market manipulation to regulation in order to lower the cost of solar technology and make solar energy competitive with incumbent energy technologies, with varying degrees of success. Still, there remain important questions to answer along this stream including why individuals choose to adopt solar technology in the first place? Is price all that matters, or do other factors, such as demographics, make people more likely to invest in solar technology? Is one type of policy more effective at spurring adoption than another?

Although the politics stream has not received as much attention in this chapter, it is important to note that each alternative has its own political advantages and disadvantages. These policies are enacted by elected officials who may have political reasons to believe or disbelieve claims from the problem stream. Political favorability toward more or less government intervention in markets may also constrain which policy alternatives are chosen in a particular state. Powerful political interests including utilities, political parties, fossil fuel companies, and solar component manufacturers may seek to further their own interests by opposing or supporting policies for solar development. Yet, the key question here is not why these policies are enacted but whether, once enacted, are these policies successful in their intended goal of expanding solar development in the residential sector?

Certainly, another objective of this chapter has been to convince the reader that residential solar is "an idea whose time has come" (Kingdon, 2003; 1) in our current political system, and therefore policies surrounding the issue deserve academic scrutiny now. Although solar PV installations in the residential sector make up a small portion of overall capacity, they are also currently the largest number of total installations every year and continue to grow at a rapid pace. Solar industry experts agree that the time for addressing policy in the residential sector is now. Shayle Kann, author of an annual report on the state of the U.S. solar market conducted for the Solar Energy Industry Association was quoted in a *Bloomberg News* article saying:

> “’Distributed generation is the big story in the U.S. solar market this year,’ Kann said in the statement. ‘We expect significant growth, especially in the residential sector, but the future will be dictated by the increasingly-complex nexus between the solar industry and utilities.’” (Goossens, 2013)

Lastly, this chapter highlights the different types of incentives for solar development commonly found in the United States at the state level. States have been the hub of solar policy innovation in the United States while federal intervention has generally been weak and inconsistent. Thus, any question as to the effectiveness of particular types of solar policy must look closely at the states. However, a piece of the story remains untold. An underlying assumption behind the existence of these solar policy incentives is that they are an effective means for directing human behavior related to adopting such a technology innovation, yet this proposition cannot be taken for granted. The next chapter will explore the theory behind how public policy can aid the adoption of innovative technologies and encourage pro-environmental behavior. Additionally, it will lay the foundation for the present study by examining how researchers have studied the problem of solar technology adoption in the past.

3. Literature Review

A variety of theoretical approaches have been used in the social sciences to model the decision to adopt new technology. As is typically the case, individual theoretical approaches tend to be favored in particular fields, such as economics or sociology, and each comes with its own underlying assumptions that must be evaluated in the particular context of this paper, solar photovoltaic adoption. This chapter will compare three useful theoretical approaches to understanding technology adoption, moving from the Diffusion of Innovation Theory commonly used in sociological studies to the utility-based Consumer Choice Theory of economics to the Theory of Environmentally Significant Behavior rooted in environmental psychology. Each theory will provide insights into potentially critical factors that shape the decision-making process relevant to solar photovoltaic adoption. After contrasting these behavior theories, this chapter will pivot to evaluate the theoretical justification for policy action that stems from the government's role of addressing market failures and negative externalities cause by the socialized costs of pollution and climate change. Finally, this chapter will explore the extant empirical work on solar adoption to highlight areas where new empirical research might substantially add to the body of literature on this topic.

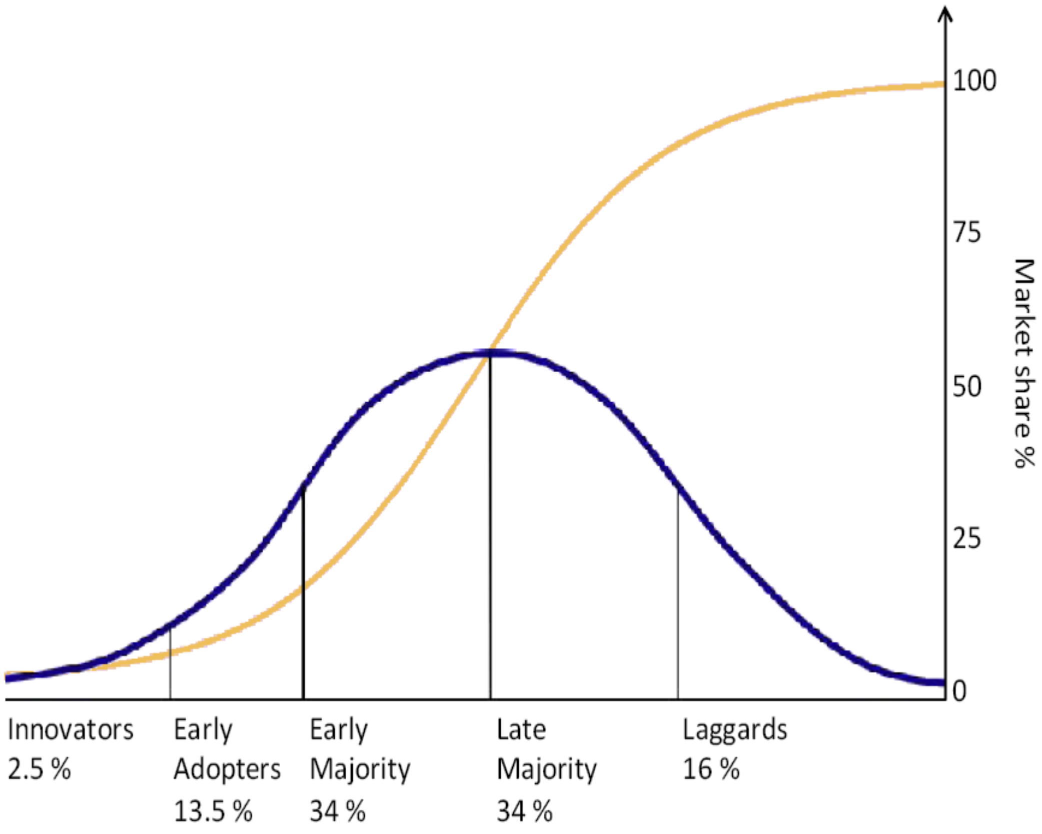
3.1 Theories of Technology Adoption

Solar photovoltaic panels belong to a category of technology innovations commonly known as Energy Efficiency and Renewable Energy (EE/RE) technologies (Stern, 2000; Diamond, 2008). These technologies vary widely in both their characteristics and applications but are similar in the fact that they either reduce or displace fossil fuel consumption. Such technological innovations include hybrid electric vehicles (HEV), compact florescent light bulbs (CFL), Energy Star appliances, and wind turbines to name a few.

As with other technological innovations, Schumpeter's technology development framework provides a useful beginning model for understanding the progression of EE/RE technologies over time. In this model, technological development passes through three stages: discovery, innovation, and diffusion (Jaffe, Newell, and Stavins, 2002). It is important to recognize that these stages often overlap and receive feedbacks from the other stages of development. The previous chapter described the early stages of knowledge discovery and innovation relevant to solar photovoltaic technology, both of which continue to go on in the present, but the most important stage to understand for this research project is diffusion. The diffusion stage is where the individual makes a decision about whether or not to purchase the technology or adopt the idea. The underlying assumption behind the existence of policy incentives for solar technology is that these policies will aid the diffusion of this technology throughout society, but is this assumption, along with the government's policy intervention, justified?

Before progressing into a discussion of diffusion, it is important to elucidate the term *innovation*. Confusion derives from the fact that is can refer to a stage in the overall process of technological development (as above) or as the technology itself. Innovations are reference dependent, meaning that they are any "idea, practice, or technology" that are perceived as a new alternative to some incumbent idea, practice, or technology (Wilson and Dowlatabadi, 2007). Understanding the nature of the innovation and evaluating its potential to progress through diffusion requires understanding both the characteristics of the innovation as well as the characteristics of the incumbent technology it seeks to replace.

Much is known about how technological innovations diffuse throughout society. Everett Rogers (1962) first introduced his theories on the diffusion of innovation more than 50 years ago. He proposed that new innovations diffused through society in a sigmoid patter, or S-shaped curve. This means that early adoption is slow but gradually picks up speed as more and more people adopt the technology. The greatest rate of adoption occurs in the middle of the curve, but as the technology becomes mainstream, the rate of adoption continues to slowly decline. He also classified different groups of people based on what stage along the curve they were most likely to adopt the innovation. As shown in Figure 3.1, these groups include innovators, early adopters, early majority, late majority, and laggards.



Source: Wikimedia Commons, 2009

Figure 3.1: Roger's Diffusion of Innovations Model

According to this theory, there are four elements to any innovation (technological or otherwise) that help predict how fast that innovation will disseminate through a society or culture: the characteristics of the innovation, the communication channels, time, and the social system. First, it is important that the technological innovation presents some sort of comparative advantage over the incumbent technology, solves some sort of problem that the consumer has, and is easy for the consumer to find and use.

Rogers also notes the central role that communication plays in diffusion. Individuals must know that a technology exists either by receiving messages from the technology producer or seeing other members of society demonstrate the use of the technology. While this communication can occur through mass media channels, the presence of social networks is also important. An individual's decision to adopt a new technology is often the product of social processes that include the presence of social networks of many individuals and the interaction of these networks with social structures, private organizations, and the government.

Also, diffusion cannot occur instantaneously but must occur over some period of real time, though this time may vary substantially for different innovations. Much diffusion of innovation research has been focused on comparing the speed with which different types of innovations diffuse throughout society. For instance, communication scholars have noted that mass media technologies have diffused through society at different rates, with later technologies such as the Internet and personal computers diffusing substantially faster than television or radio.

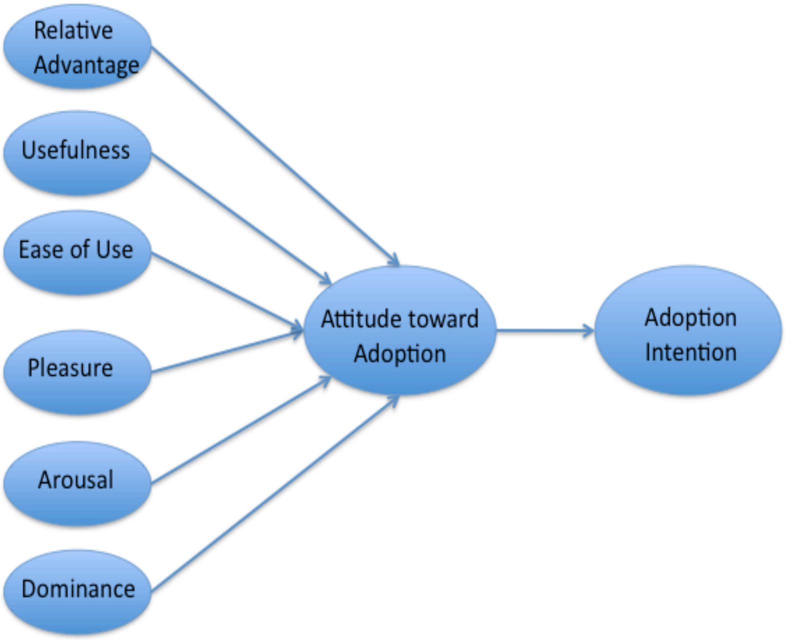
Finally, social and cultural characteristics can speed or slow diffusion. For instance, the diffusion of new forms of contraception will be slower in a more sexually repressive society compared to one that is less sexually repressive. Previous studies of diffusion have focused on one or more of these characteristics.

Research into technology diffusion has found that five characteristics of the innovation explain most of the variation in the speed of adoption: relative advantage, compatibility with existing needs and problems, complexity, trialability, and observability (Wilson and Dowlatabadi, 2007). Applying these characteristics to solar panels, certain strengths and weaknesses of the technology become apparent. Solar photovoltaic panels are compatible with a solution to the problem of carbon pollution, though it is unclear the extent to which that is seen as a problem or need in the United States, and are highly observable. Meanwhile, questions remain about their comparative advantage compared to the incumbent electrical system where power is generated by electric utilities and simply purchased by the consumer. Additionally, the technology is complex, requiring specialists to sell, install, and service the equipment. Lastly, solar panels are difficult to use on a trial basis because of the high capital investment required to purchase and install. However, technological advances including small, lightweight thinfilm solar panels and business advances including group purchase and leasing programs are addressing many of these issues, resulting in an environment more favorable to diffusion.

While much of the discussion of Diffusion of Innovation Theory to this point has emphasized the innovation and the social context of the innovation, it is important to return the focus to the individual. The theory predicts that once an individual with a certain knowledge set is made aware of an innovation and its attributes, that individual will form a set of product-specific attitudes leading to an intention to obtain the innovation and finally a behavioral decision to adopt the innovation. However, it is not clear that product knowledge and awareness are the only factors that influence attitude formation. Building on this procession from knowledge to attitude to behavior, several scholars have attempted to refine the explanation of the individual's innovation adoption decision process.

Instead of characterizing attitude formation as the exclusive result of increased awareness, the Technological Acceptance Model (TAM) describes the cognitive components of adoption decisions and behaviors. TAM theorizes that usage behavior is primarily a factor of the individual's attitude toward the new technology, which in turn is determined by two components: perceived usefulness and perceived ease of use (Davis, 1989; Kulviwat et al., 2007). Created to explain technological adoption in an organizational environment, TAM focused primarily on the cognitive components of adoption decisions while eschewing the affective.

As Kulviwat et al. (2007) point out, TAM does not sufficiently explain adoption intention in a consumer context where individuals have more leeway to decide what technologies they will adopt. Building on TAM, they propose the creation of the Consumer Acceptance of Technology (CAT) model. The CAT model takes into account both cognitive and affective determinates of the product specific attitudes. Including the two cognitive components of TAM, perceived usefulness and perceived ease of use, Kulviwat et al. (2007) add a third cognitive component, relative advantage. Not only must a new technology meet a specific need and be easy to use, but it must also be a better option than any other new technology or the status quo. Next, the CAT model incorporates elements of the Pleasure, Arousal, and Dominance (PAD) model proposed by Mehrabian and Russell (1974). PAD is a three-dimensional affective model that suggests that every emotional state is some combination of pleasure, arousal, and dominance. CAT assumes that an individual's attitude about a new technology and their usage behavior are influenced by their thoughts and feelings about that technology. Figure 1, adapted from Kulviwat et al., shows the components and directional flow of the CAT model.



Source: Kulviwat et al., 2007

Figure 3.2: Consumer Acceptance of Technology Model

A further empirical study of the CAT model using the intention to adopt a personal digital assistant (PDA) found that it predicted adoption intention better than the original TAM (Kulviwat et al., 2007). Still, the CAT only accounted for 50 percent of the variance in the adoption intention meaning that a substantial amount of the variance was not explained by these cognitive and affective measures alone. Other individual measures as well as external variables may be at play, but the experience with the CAT model does confirm that adoption decisions are far more complex than the literature originally suggested. It is also unclear whether the CAT would sufficiently capture the affective components of emotions related to environmental issues. In the case of solar power adoption, personal financial considerations are likely to interact with emotions related to protecting the environment or preventing the destructive impacts of climate change, emotions far more complex than the feelings of pleasure brought by purchasing a new PDA.

The common weakness of each of these approaches is that the progression from awareness to attitude to behavior is modeled as a linear pattern. As a result, Wilson and Dowlatabadi (2007) point out that the explanatory power of the models at the individual level breaks down. For instance, individuals with favorable attitudes toward and innovation can still fail to acquire it because they lack resources (monetary, physical, or mental) or in the case of technology, because it is unavailable due to legal, cultural, or physical barriers.

Other social science fields have offered alternative explanations of the diffusion of technology from the individual perspective. Perhaps because of its focus on individuals and their preferences for adopting new technological innovations, variations on Consumer Choice Theory have been the dominant paradigm upon which economists have attempted to explain innovation adoption and diffusion. This paradigm is well expressed by the words of Hall and Khan (2002) who explain diffusion from an economic perspective saying,

> "Diffusion can be seen as the cumulative or aggregate result of a series of individual calculations that weigh the incremental benefits of adopting a new technology against the cost of change, often in an environment characterized by uncertainty (as to the future evolution of technology and its benefits) and by limited information (about both the benefits and costs and even about the very existence of the technology)." (p. 3)

As with Diffusion of Innovation Theory, Consumer Choice Theory contains built-in assumptions about individuals that affect the explanatory power of the model. Most notably, this theory characterizes the individual as a rational individual with a fixed set of preferences. For such an individual, consumption decisions are based on a calculation and maximization of utility subject to a budget constraint. Because of the easily quantifiable nature of financial costs and benefits, this theory often relies on these monetary measures as proxies for utility.

Hall and Kahn (2002) go on to point out that while the final adoption decision is based on considerations falling on the demand side of the economic transaction, the cost and benefit calculations are often affected by both supply side activity and environmental factors outside of the individual consumer's control. Often, the adopter's choice in the economic paradigm is not characterized as a decision to adopt or not adopt; rather, it is thought of as the decision to adopt the technology now or adopt it later. Typically, the benefits of a new technology over an old one are taken as a given and the only remaining question that explains how a new technology will diffuse is whether the individual perceives that those benefits will outweigh the costs now or some time in the future.

The heterogeneity model (Hall and Kahn, 2002) proposes that individuals have heterogeneous preferences and thus come to individual valuations of the benefits of the innovation. According to this model, three assumptions will lead to a logistic (S-shaped) diffusion curve. First, the distribution of benefit valuations is normally distributed. Second, the cost of the innovation does not increase as more individuals adopt it. And third, consumers will always adopt the new technology when they perceive its benefits as outweighing its costs. Here, it is the variation of consumers' preferences and evaluations that result in the difference in diffusion rates. Individuals are seen exclusively as rational actors motivated primarily by economic factors.

Empirical economic studies have identified a number of common barriers to technology adoption that conform to the prediction of the heterogeneity model. These barriers include high initial unit costs, gaps in knowledge, uncertainty in payback periods, low consumer risk tolerance, and high discount rates (Jaffe and Stavins, 1994; Stoneman and Diederen, 1994; Argote and Epple, 1990; Diamond, 2008). Certainly, it is arguable that solar PV technology suffers from all of these issues to some degree. Despite the fact that costs have declined substantially over time, the initial investment in solar technology is high and will always be high when compared with the primary competing option to purchase power generated by the electric utility, which requires no initial capital investment.

Moreover, consumer choice models also assume that individuals have perfect information about the chosen product and its alternative; however, knowledge and awareness gaps occur at multiple levels. Solar PV is a complicated technology that requires experts to install and maintain systems. Consumers may be intimidated and reluctant to adopt new technology that they do not understand. Still, working knowledge of the photovoltaic effect may not be necessary for solar PV technology to gain widespread diffusion, just as fully understanding the workings of the internal combustion engine isn't necessary for people to purchase automobiles. Potential purchasers must also be made aware of solar panel dealers and the incentives available to reduce the cost or shorten the payback period. A number of scholars have noted that creatively and strongly marketing these programs is essential for their success (Stern et al., 2010; Vandenbergh et al., 2010). They suggest that such marketing efforts should go beyond merely advertising in mass media channels and incorporate informal marketing channels such as individuals' social networks. Put simply, individuals cannot take advantage of programs or purchase products that they don't know exist.

Furthermore, the payback period for solar PV technology is dependent on a number of factors outside of the control of the adopting individuals, particularly the market price of electricity, which is influenced by a number of complicated factors. Consumers may be unwilling to risk paying large amounts of money for future potential gains. This thought process involves understanding the consumer's discount rate. The higher the individual's discount rate, the less likely that individual is to pay large amounts of money upfront to accrue benefits in the future. Studies have found that lower income individuals often have higher discount rates than higher income individuals. Jaffe and Stavins (1994) found that on average individuals were only willing to pay for energy savings technologies that have a payback period of three years or less; although, Sperling et al. (2004) provide contradictory evidence in the form of in-depth household interviews that show many individuals do not base their energy efficiency decisions on any type of payback calculation.

The overreliance on monetary measures of utility, imperfect information, and the existence of fluctuating discount rates, among other factors, challenge the underlying assumptions of rationality and fixed preferences inherent in classical economic consumption models when attempting to explain solar photovoltaic diffusion. While economic considerations are clearly extremely important to adoption decisions and diffusion research, a growing body of evidence has identified other important factors. Much of what we know about how public policy can be used to influence behavior comes from the field of behavioral economics. As a field, behavioral economics combines research from psychology and economics, and when applied to the field of public policy, it attempts to explain how people react to changes in policy designed to incentivize or disincentivize particular behaviors.

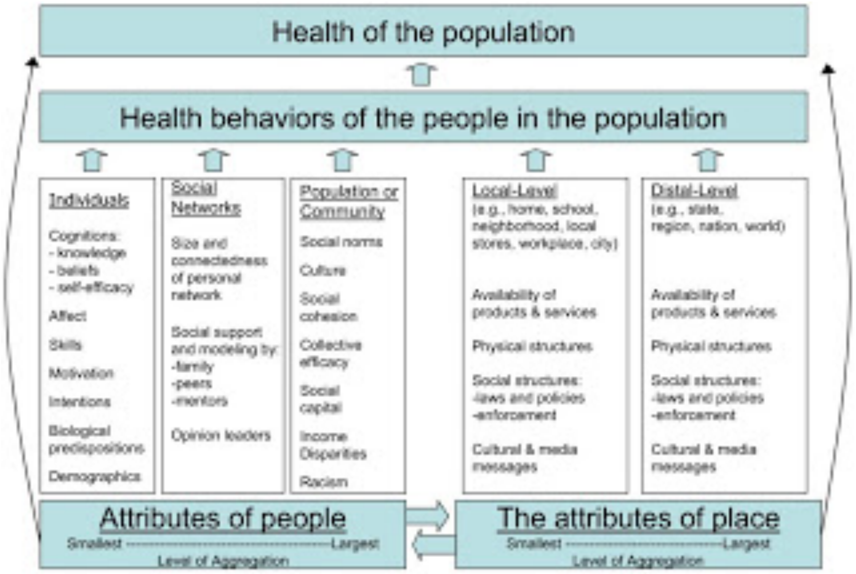
According to Dolan et al. (2013), there are two contrasting models for behavioral change from the policymaker's perspective. The first suggests that government's primary role is to supply information about important policy issues, and with all the important information in hand, citizens will be able to make the right decisions. This is known as the cognitive model. One of the cognitive model's most functional tools is the awareness campaign. A substantial amount of policymaking in education, public health, and election campaigns contains underlying assumptions rooted in the cognitive model. Take, for example, the nutrition labels required for all packaged food by the Food and Drug Administration. The goal of this policy is to provide individuals with accurate and relevant health information about the food they consume. The underlying assumption behind the policy is that, when equipped with that information, individuals will make the rational choice to consume the healthy options. Unfortunately, human beings do not always behave in the most rational way so sometimes more than just information is needed.

The alternative model of behavioral change "focuses on the more automatic processes of judgment and influence…altering the context within which people act," (Dolan et al., 2013; 4). The context model suggests that because people don't always act rationally, policymakers should change the context of the environment to encourage certain decision-making outcomes. The types of public policies that embrace the context model of behavior change include regulation, tax incentives, and price floors and ceilings to name a few.

The context of decision-making is more complex, though, than simply implementing a particular policy incentive. Context also applies to the social context in which decisions are made including who the messenger is, what the norms and culture of the society in which the decisions are being made, and preexisting emotional associations with both the policy and the proposed solution. For instance, the people of the United States have a strong cultural aversion to policies whose primary mechanism is increasing taxes. When a policy to cap carbon emissions and set up a tradable pollution permits market, known as a cap-and-trade system, was proposed in 2009, opponents of the policy were quick to reframe it as “cap-and-tax,” tapping into both the cultural aversion as well as negative affective associations with taxation. The focus on taxation was successful obscuring the true market-oriented nature of the program (the trade) as well as derailing the policy before it became law.

While the cognitive and context models offer alternative understandings for the inducement of behavior change, it is important to note that they are not mutually exclusive, and in fact might be mutually reinforcing. An alternate way to think about the dual nature of information and context can be found in a framework commonly used in the field of Public Health to understand decision-making but rarely applied to environmental issues, the People and Places Framework.

The People and Places Framework organizes the factors that influence behavior into two broad groups, those aimed at the individual and those aimed at the policy environment. The goal of this framework is to assist practitioners in developing behavior change interventions that operate at multiple levels of influence. Figure 3.2 illustrates how the People and Places Framework identifies five domains for behavioral change. The first is the individual. Interventions focusing on the individual may address a number of individual traits that influence behavior including both cognitive and affective components. Second, the framework recognizes that people don't make decisions in a vacuum and are influenced by other people around them; therefore, behavior change interventions should also focus on people's social networks. Third, behavior can even be influenced by people in the wider community. The People and Places Framework also suggests community-level interventions that build trust, cooperation, and social cohesion. Finally, the framework also suggests altering the environment in order to induce behavior change by implementing policy changes at the local-level (i.e. neighborhood, town, workplace) and distal-level (i.e. state, nation).



Source: Maibach et al., 2007

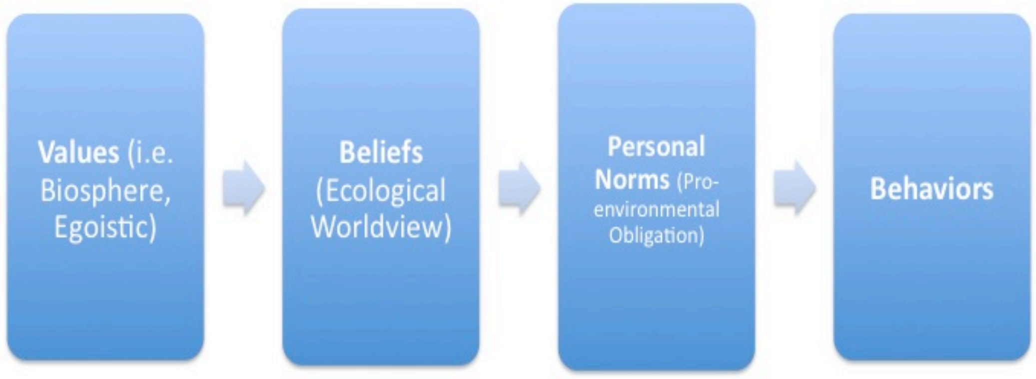
Figure 3.3: People and Places Framework

While the People and Places Framework has been applied extensively in a public health context, several scholars have suggested that applications exist for environmental behavior. Maibach, Abroms, and Marosits (2007) and Maibach, Roser-Renouf, and Leiserowitz (2008) proposed the application of the framework to the problem of global climate change, suggesting that combining communications and marketing assets could influence behavior at the level of personal attributes and important attributes of place including policy change. It is important to note that the People and Places Framework is just one of many ways that cognitive and context aspects can be combined to produce a practical model for behavior change interventions. It does show, however, that the lessons of behavioral economics can be combined with lessons from other social science disciplines to produce models with practical applications across multiple fields.

Classic economic theory models consumer preferences as the result either rational calculations of utility based on the cost and price or as the level of cognitive awareness present in a society. Further models in the area of behavioral economics have attempted to account for the role that affect and emotion play in the adoption decision and how factors such as pleasure and arousal moderate purely rational economic thinking. In the case of the adoption of solar photovoltaic technology, there is still a high degree of uncertainty whether individuals who adopt the technology are responding primarily to economic conditions or whether they are influenced by psychographic, demographic, and affective factors, such as a high level of concern for the environment, that outweigh economic considerations.

Alternative theories address this uncertainty directly. Relying on evidence gained in the field of environmental psychology, Paul Stern (2000) proposes the Theory of Environmentally Significant Behavior, which conceptualizes environmental behavior as distinct from other types of behavior. Stern defines environmentally significant behavior as any behavior "undertaken with the intention to change (normally benefit) the environment," (408). It is important to note that the definition is intent-based and not impact-based; therefore, the behavior can still be environmentally significant even if no actual impact on the environment occurs. Stern also identifies three important types of environmentally significant behavior including activism (i.e. protesting), non-activist political behavior (i.e. signing petitions), and private sphere environmentalism (i.e. purchasing environmentally friendly products). In this case, purchasing solar panels would fall under private sphere environmentalism.

Stern also stresses the importance of individual environmentalism in determining environmental behavior. He conceptualizes environmentalism as being a product of pro-environmental values, beliefs, and norms. Figure 3.4 describes how values progress to enforce beliefs and subsequently result in pro-environmental personal norms. Behavior is a product of these attitudinal variables and context; however, Stern notes that the influence of attitudinal considerations and context are dynamic, shifting with the characteristics of the environmentally significant behavior. As an activity becomes more costly in terms of money and effort, context becomes more important while attitude becomes less important. In the case of solar panels, individuals will become less influenced by environmental concerns and more sensitive to financial costs. The implication that can be drawn from this statement is that policy incentives designed to reduce the monetary and effort costs of large should be effective for high cost goods like appliances, home renovations, electric vehicles, or renewable power generation technology. Conversely, such incentives may not be as effective at influencing the adoption of low-cost goods like compact florescent light bulbs or environmentally friendly cleaning products. For these products, an appeal to environmental values and beliefs might be more effective, though Stern provides no empirical evidence of this implication.



Source: Adapted from Stern, 2000

Figure 3.4: Value-Belief-Norm Theory of Environmentalism

When it comes to defining contextual factors that might environmentally significant behavior, Stern (2000) does not limit his discussion to exclusively economic factors. He lists a number of possible external factors that could influence decision-making including persuasion, modeling, community expectations, advertising, policy, monetary incentives, difficulty, and broad social, political, and economic factors. An important factor highlighted in this discussion is public awareness of the product and the incentive programs. As Stern explains, "[Financial] incentives may favor behaviors that nevertheless do not occur unless information makes individuals aware that the incentive is available," (418). Moreover, different types of behavior might be influenced by different sets of these factors, meaning that the most effective government programs "involve combinations of intervention types," (419).

Stern's (2000) article provides a testable prediction about how individuals might react to policy intervention when it comes to adopting solar photovoltaic panels. If individuals respond primarily to economic incentives, then policymakers have a diverse toolkit of policy options to influence individual decision-making. On the other hand, if individuals non-economic concerns play a greater role, the government's efforts to provide a diverse array of policy incentives might not be warranted, and instead governments might focus more on supply-side policies or public information campaigns.

3.2 Justification of Policy Intervention

Despite the fact that there is a strong body of evidence that governments have the capability to aid the diffusion of innovation with policy interventions, there persists a normative question about whether these policy interventions are justified. On one hand, there exists a market for distributed solar PV technology, and markets often operate efficiently without government intervention (Krugman and Wells, 2009). On the other hand, there exists a set of circumstances, known as market failure, where government intervention into a market is justified.

One such case involves the presence of negative externalities. Solar PV technology is a substitute good for traditional electricity generation where the consumer purchases electricity from a utility company who produces the electricity through a combination of fuels heavily reliant on various types of fossil fuels including coal, oil, and natural gas. Coal makes up approximately 45 percent of the fuels used to produce electricity in the United States (Geri and McNabb, 2011) and natural gas another 23 percent (oil only accounts for about 2 percent of fuels used for electricity generation, though in the past it was as high as 10 percent). Either through the process of electricity production, mining, or transportation, these fuels, especially coal, contribute substantially to air pollution and greenhouse gas (GHG) emissions that impose substantial social costs, or externalities, to society as a whole. These externalities include increased healthcare costs, droughts that impact farm yields, pollution remediation programs, and programs to adapt to rising sea levels. Because the benefits of electricity production accrue privately to the electric utility companies but the costs of pollution are imposed on the public, electricity producers have little incentive to adopt low pollution and emission reduction technologies. In the case of market failure due to negative externalities, governments are justified in intervening into the market to correct the failure.

There are many strategies that a government can employ to address a market failure like the one described above. The most obvious strategy is to adjust the price of the polluting technology to factor in the real social costs not borne by the polluting company. This goal could be achieved by placing a price in the form of a tax on carbon. Tax revenues could then be used to pay for the social costs of GHG emission. Utilities could also be forced to pay into pollution remediation funds. While this strategy has been pursued in Europe and several other locations, American political opposition to taxation makes imposing a carbon tax an unlikely solution in this case.

An alternative to imposing a price on pollutants is to provide subsidies to support competitive technologies that do not have the same externalities as the incumbent technology. While these subsidy programs do nothing to directly shift the cost structure that incentivizes the polluting behavior in the present, they could reduce social costs in the future by making the current polluting technology noncompetitive in the market. These subsidies could take the form of incentives for solar panel producers to expand capacity and reap the cost benefits of returns to scale. They could also include increased spending on research and development to create more efficient solar panels. Lastly, they could be demand-side incentives that lower the retail cost of solar PV technology.

Additionally, governments could impose regulations that limit the amount of pollution that an electric power plant can emit or that require electric utilities to produce a certain amount of their electricity from low-emission sources like renewables and nuclear power. The current policy approach of the United States is to combine regulation and subsidization to increase the market competitiveness of alternatives to fossil fuels.

The previous models of the technology adoption process do not explicitly define the role of policy and policy makers; instead, they imply that the role of policy is to address the identified barriers to adoption such as lowering initial costs, providing certainty in the market, or solving communication problems, depending on which model is followed. Mutingi and Matope (2013) propose a conceptual model for the adoption of renewable energy technology that specifically identifies the role of policy makers. They conceptualize renewable energy adoption as a product of the "dynamic interaction of adoption related factors" (p. 1512). Broadly, they identify three groups of factors pertaining to technology adopters, policy makers, and the policies themselves. More specifically, these factors include promotional efforts, communication networks, market factors, and experiential learning. Their study creates a speculative, computer-based model that takes a set of individuals from a pre-adoption phase through adoption and possibly termination. By running sensitivity and "what-if" analyses, they conclude that promotional efforts and favorable market factors (mostly decreasing cost) are the most effective at turning a pre-adopter into an adopter. To the extent to which policy makers can influence these considerations through public awareness campaigns or policies that reduce the cost of the technology, this model predicts that they will be successful at influencing the adoption of renewable energy technology. Despite the absence of empirical analysis, this study represents an important theoretical approach to understanding the entire system that influences the adoption of renewable energy technology.

The role of public policy in the adoption of technological innovation remains in need of further study. Most of the theories that explain the adoption and diffusion of innovation skim over the policy environment in favor of a focus on the individual decision making process; however, some public policy initiatives can create strong signals and incentives for particular types of behavior, affecting both the supply and demand for certain goods or services. As previously described, many state governments have attempted to influence the adoption of residential solar power through just such incentive programs and policy initiatives influencing the overall market characteristics for solar power.

The previous theoretical work on adoption and diffusion of innovation yields two important lessons. First, the economic factors affecting the demand for residential solar photovoltaic systems, while important, are not the only critical factors influencing adoption. Other contextual factors such as social conditions, environmental factors, communication strategy, and market conditions are critical to understanding how, why, and when people adopt a particular technology. Second, the work of Mutingi and Matope (2013) highlights the fact that renewable energy adoption is a dynamic system with component parts that are constantly changing and interacting. As a result, cross-sectional approaches looking at a single year tell researchers very little about how the mechanisms influencing adoption actually work together or against each other.

3.3 Empirical Studies of Solar Adoption

The individual decision to adopt solar energy technology is complex and influenced by a number of different exogenous and endogenous factors. These factors can interact with or moderate the effects of policies intended to incentivize adoption behavior. Past empirical research about renewable energy deployment has examined many of these factors and come to different conclusions about their relative importance. Additionally, these studies have employed differing methodologies making direct comparisons difficult.

Studies of solar photovoltaic adoption are relatively new in the literature as technology has improved and actual deployments have increased. Research into the effectiveness of government incentives on the adoption of any type of solar technology exist in the literature going back to the early 1980s, but these focus mostly on solar water heating and passive solar heating. Still, they can provide valuable lessons, just as research on the deployment of other types of renewable energy technologies such as wind or geothermal heating, both of which have applications in the residential sector.

Generally, studies of renewable energy deployment grounded in a consumer theory perspective fall into two research tracks. The first group is surveys of renewable energy consumers or potential consumers. These studies ask individuals to identify whether they have purchased or intend to purchase renewable energy technology and examine trends in socio-demographic and economic factors. The second group aggregate adoptions of renewable technology at various geographic levels (country, state, county, zip code) and look for trends in aggregate variables identifying important factors predicting or explaining the overall adoption rates. Both of these types of studies are valuable to examine in order to understand what factors might lead people to purchase solar photovoltaic systems, particularly in the presence of policy incentives.

Studies examining the effect of policy on consumer behavior also must select a variety of variables to control for in their models. These are factors that could impact adoption rates or adoption intent outside of the government's policies. When all empirical studies of renewable energy are taken into account, critical control variables generally fall into three groups of factors: environmental, economic, and socio-demographic. The justifications for incorporating these controls into renewable energy adoption models, as well as the results of previous research using those controls, are reported below.

Environmental Factors

One of the most commonly identified explanatory factors for renewable energy system distribution identified in the academic literature is the availability of solar resources. It follows logically that because most renewable resources are non-transportable (i.e. one cannot move wind or sunlight from one area with an abundance to another area with a scarcity) areas with large amounts of those resources could potentially have higher adoption rates regardless of what policies were instituted by the government. In the case of solar, the variability in solar radiation, also known as insolation, can also influence the total level of savings from the adoption of solar technology. Gadsden, Rylatt, and Lomas (2003) used a GIS-based urban planning tool to calculate areas of Leicester, UK where economic savings from using solar power for domestic hot water could be maximized. They found that several natural and human environmental factors were critical in accurately predicting the best locations for solar water heating systems including levels of solar irradiation, temperature, and roof orientation. Feder (2004) also notes the importance of available solar resources for meeting aggregate energy demand. In cases where solar resources are not extensive, solar power can be expected to make up a lower portion of the energy mix than other forms of renewable or non-renewable power.

Only a limited number of studies have examined how the availability of solar resources impacts the actual decision to install solar energy systems. Sawyer, Sorrentino, and Wirtshafter (1984) used state-level data on solar installations to determine that high solar radiation increased adoption rates. More recent studies on household solar photovoltaic adoption at the county (Zahran et al., 2008) and ZIP Code levels (Kwan, 2012) indicate that insolation has a consistent, positive effect on installations. On the other hand, two studies examining data taken at the household level discovered that solar resources were insignificant predictors of adoption decisions, and instead economic factors such as the energy price, household income, and the availability of tax credits increased the probability of adoption (Fujii and Mak, 1984; Durham, Colby, and Longstreth, 1988).

From a purely theoretical standpoint, it is clear that the inclusion of insolation in a model analyzing solar photovoltaic deployment is essential. While the inconsistent results highlighted above might seem troubling, the purpose of policy incentives is to lower the technology price so that areas with limited solar radiation might still achieve some level of return on investment despite producing less total electricity than someone in an area with more insolation. If solar radiation is insignificant in a multiple variable model, it might signal that incentives or some other factors negate the influence of the amount of solar resources. Even if the variable is significant, policy could still potentially be having an effect in areas where adoption is high but solar radiation is low. Regardless of the result, it is clear that insolation is the most important environmental control variable used in extant research.

Economic Factors

Other studies have highlighted the importance that economic factors play in the adoption of solar energy systems. Labay and Kinnear (1981) found a number of key differences between solar adopters and non-adopters. Adopters had higher incomes and perceived less financial risk involved in installing solar water heaters than non-adopters, even those who were knowledgeable about solar power. Additionally, non-adopters rated factors such as initial cost, length of payback period, and availability of government incentives as more important in their decisions than adopters.

Looking at the UK market for solar power, Faiers and Neame (2006) identified economic and financial considerations that served as substantial barriers to adoption, even in the presence of policy initiatives aimed at reducing the cost of solar installations. Comparing attitudes toward solar power between adopters and environmentally concerned non-adopters, their study discovered significantly different attitudes toward the payback period and availability of government grant programs, with non-adopters viewing these much more negatively. It is important to recognize that both of these studies were based on public opinion about adoption of solar power technology rather than actual adoption decisions, yet it does point out the critical role of economic considerations.

More recent work has sought to incorporate economic variables into multiple variable regression models examining aggregate solar adoption. One critical economic characteristic often controlled for is the level of wealth in a particular area. Because of the high cost of solar panels, even with incentives, theory suggests that the wealthy will be more likely to purchase them. Zahran et al. (2008) used median home value as a proxy for wealth. Kwan (2012) accounted for the economic resources of solar adopters by including ordinal variables for the number of residents in specific income groups. Other studies have used per-capita gross domestic product as a control variable (Shrimali and Kniefel, 2011; Sarzynski et al., 2012; Shrimali and Jenner, 2013). However, the results of the models were inconsistent. Zahran et al. and Kwan found that higher wealth levels corresponded to higher adoption rates while per-capita GDP was insignificant for most of the models run by Shrimali and Kniefel and Shrimali and Jenner. The GDP variable was significant but negative in the Sarzynski et al. study suggesting a negative relationship between wealth and solar PV adoption. Even if the relationship is not fully understood, income and wealth remain important economic variables to consider.

Several of the state-level regression models have also considered economic conditions related to markets for energy. Sarzynski et al. (2012) included a variable to control for the retail price of electricity, suggesting that high electricity prices would send individuals in search of alternative electricity products such as solar PV systems.

Shrimali and Kniefel (2011) and Shrimali and Jenner (2013), both of whom also created state-level regression models, included variables for electricity price and natural gas price. Because both of these studies examined the entire market for solar PV, the residential, commercial, and utility sectors, the natural gas price served as an additional potential competitor for solar power, but this variable would likely have less relevance for the residential and commercial distributed power sectors than for the utility sector.

A critical economic factor ignored by all of the previously cited studies is the role of the declining price of solar panels at influencing adoption. Even in the absence of incentives, the retail price of solar panels has been decreasing due to improvements in technology and manufacturing (The Economist, 2012). Sarzynski et al. state the importance of changing PV price but point out that the data was unavailable. They write:

> "The falling price of solar technology will improve the potential return on investment for solar technology. Final installation costs for PV systems vary significantly across states depending on local labor and installation costs (Wiser et al., 2011). Unfortunately, historical PV module and installation costs are […] not included in this model." (554)

Socio-Demographic Factors

While there continues to be an argument over the relative influence of environmental and economic conditions, other studies have also recognized the importance of socio-demographic factors. A standard array of social factors including age, race, and education has been shown to have varying degrees of significance in explaining pro-environmental behavior generally and renewable energy adoption specifically. Zahran et al. (2008) examined age by creating a variable controlling for the proportion of the population at peak consumption age, which he defined as between 40 and 49. Using a zero-inflated negative binomial regression, they found that age was not a significant predictor of whether a county had more than zero installations, but once only counties with at least one installation were examined, the proportion of the population at peak consumption age was positively associated with more installations. Following up on this research, Kwan (2012) included variables for age in ten-year increments (25 – 34, 35 – 44, 45 – 54, 55 – 64, and 65+). His study found that ZIP Codes with a large number of residents in the youngest age group (25 – 34) and an older one (55 – 64) were negatively associated with solar installations; however, he did not find that peak consumption years were positively associated.

Despite the seemingly obvious relationship between education and solar adoption, few studies have included this variable in their models. Previous studies of environmental behavior have found that those behaviors are more likely to be engaged in by individuals with higher education levels. Laidley (2011) used a number of social, cultural, and demographic variables to predict three distinct environmental behaviors (recycling, hybrid car ownership, and environmental group membership) in Massachusetts. His results showed that having a bachelor's degree was a significant positive predictor for both recycling rates and hybrid car ownership. Durham et al. (1988) used a probit model to show that having a higher level of education significantly increased the probability that an individual homeowner would adopt a solar water heater.

Kwan also (2012) included variables for level of education in a study of solar adoption. Using Census Bureau data, he finds that ZIP Codes with high percentages of the population with bachelor's degrees and post bachelor education are associated with higher solar adoption.

Race is another socio-demographic variable that has been considered in studies of pro-environmental behavior and renewable energy adoption. Laidley (2011) found that the percentage of white residents in a Massachusetts municipality was positively associated with higher recycling rates, implying that more diverse communities were less likely to participate in this type of environmentally friendly behavior. Johnson et al. (2004) also investigated whether there were differences in environmental behaviors and overall levels of environmentalism between racial and ethnic groups in the United States. They found that Asian American and U.S.-born Latino environmentalism was most similar to white environmentalism. Moreover, African Americans and foreign-born Latinos were less likely to hold environmental values or participate in environmental behaviors including reading environmental literature, recycling, and participating in nature-based recreation activities. The only area where African Americans resembled whites was in their participation in environmental activist organizations. A number of public opinion polls have also noticed stark differences in opinions between blacks and whites on renewable energy issues, though these results are not necessarily consistent. A 2009 survey by environmental activist group Planet Forward found that blacks were more likely to overestimate the amount of electricity generated from renewable sources in the United States, less willing than whites to "pay more for electricity generated by renewable sources," and less likely to agree that electric companies should be required to produce more electricity from renewable sources if that requirement raises electricity prices in the short term. Yet in the same survey, they were more likely than whites to favor the implementation of a 40-cent gas tax to fund clean and renewable energy alternatives. Additionally, another survey, the 2010 Chicago Council on Global Affairs "Global Views Survey" measured African Americans as substantially more likely to favor government investment in renewable energy, and the May 2012 United Technologies/National Journal Congressional Connection Poll found a higher favorability toward a national clean energy standard among blacks than whites. In the only study to incorporate race into a multivariable quantitative model of solar PV adoption, Kwan (2012) discovered that a high Hispanic population is positively associated with solar installations while high Asian and Black populations are significantly associated with lower rates of solar adoption.

Important social factors for solar adoption go beyond simple demographic measures. Other studies have also discovered that individuals may adopt solar power systems on their homes as a signal of their elevated social status (Sidiras and Koukios, 2004), due to the possession of a liberal political ideology (Zahran et al., 2008, Kwan, 2012), or because of their identification with pro-environmental values and association with environmental protection groups (Sawyer and Wirtshafter, 1985). Of these factors, environmentalism has the most support in the literature; however, the variable used to account for it and its significance has varied from study to study. Zahran et al. attempted to model environmentalism in two ways. They used the number of environmental non-profits registered in a county as well as the presence of cities that are members of the International Council for Local Environmental Initiatives (ICLEI). The results were inconsistent with ICLEI membership being statistically significant but the presence of environmental non-profits failing to achieve significance. Kwan (2012) later found ICLEI membership to be insignificant. Shrimali and Kniefel (2011) and Shrimali and Jenner (2013) conducted state-level analyses of solar policies and used the state's average League of Conservation Voters (LCV) score. The LCV is a political organization that scores members of congress based on how they vote on environmentally friendly legislation. The rationale for using LCV scores as an indicator of a state's environmentalism is that congressional voting is generally representative of the beliefs of the people in the representative's district. If the congressional representative votes counter to the beliefs of his constituents, then there is an increasing likelihood that someone more representative of the constituents' beliefs will replace the incumbent in the subsequent election. Unfortunately, these two studies do not find a statistically significant relationship between environmentalism as measured through average state LCV score and solar adoption. However, this result may not be due to a failure of the LCV variable as an accurate measure of environmentalism. Instead, it could indicate that accounting for differences in solar policy incentives, as done in this study, negates the influence of environmentalism in influencing solar adoption. For instance, it is possible that in the absence of incentives, the higher initial cost of solar PV equipment only appeals to individuals whose utility can be increased by engaging in environmental behavior, namely those individuals that hold pro-environmental beliefs and values.

However, when policy incentives are present and bring down the cost, investing in solar PV systems become more enticing to people without pro-environmental values. This is an issue that clearly deserves more exploration.

Lastly, in examining the geographic distribution of solar photovoltaic adoption in California, Bollinger and Gillingham (2010; 2013) found evidence of geographic clustering within zip codes that they could only explain through the existence of peer effects or localized marketing campaigns. These types of peer effects could be explained by the tendency of solar technology to diffuse through social networks due to modeling (Lutzenhiser, 2003) and information transfer (Warkov and Monnier, 1985). Unfortunately, accounting for peer effects becomes increasingly difficult as the geographical unit of analysis becomes larger. The studies by Bollinger and Gillingham examine neighborhood level and Zip Code level data. As the geographical unit becomes larger, the assumption that subsequent installations in the same area are connected becomes increasingly untenable. For instance, one could reasonably assume that an individual living in the same neighborhood as another who just installed a solar PV array might at least see the equipment when he leaves his house. However, even in the nation's smallest state, Rhode Island, it is unlikely that a resident in Newport is ever even aware when an installation occurs in Providence. Still, each of the above studies provide evidence that important social factors, to the extent that they can be effectively and accurately modeled, should not be ignored.

Though several of the previously cited studies note the import role of tax incentives, few examine the vast array of other policy initiatives designed and implemented at the state level to incentivize the adoption of solar power systems. Moreover, not all of the studies on residential adoption of solar technology examine just the installation of any solar PV technology. In fact, most of the studies focused exclusively on the adoption of solar water heaters, not photovoltaics. Meanwhile, many policy incentives enacted recently are geared specifically toward incentivizing solar photovoltaic adoption. On the other hand, several studies have specifically examined the effectiveness of the variety solar incentive policies that currently exist at the state level, though many of them employ case study research methods instead of quantitative modeling. Still, they have many valuable lessons that can inform the creation of valid and reliable quantitative models.

State Support for Solar Development

Incentives geared toward encouraging the adoption of solar power technology are actually part of a larger trend going on among the states to reduce the share of energy produced by fossil fuels. This set of policies is often grouped together under the name energy efficiency and renewable energy (EERE) (Kubert and Sinclair, 2011). The use of fossil fuels for energy production, especially coal in the eastern United States, has a number of significant environmental consequences, not the least of which is the high amount of carbon dioxide released into the atmosphere, significantly contributing to global climate change. As a whole, Kubert and Sinclair (2011) point out that states spent $5.9 billion on EE/RE programs in 2009 alone, not including state-level spending of federal money included in the 2009 American Recovery and Reinvestment Act. Therefore, it is critical for policy makers to be able to assess the effectiveness of these programs so that they can reduce spending on ineffective programs and shift funding to effective ones. This knowledge is even more valuable now because states are still suffering from the previous decade's recession.

Much of this policy activity in the United States occurs at the state level and not the federal level for a number of reasons. There are a number of specific reasons why this is the case. First, the United States Congress is highly partisan and suffers from gridlock on major, controversial issues, especially those related to climate change. Second, incentives for federal action are low because of limited evidence that environmental policies encourage voters to reelect their representatives, especially compared to enacting policies that risk increasing energy costs. And third, states often act as policy laboratories where experimentation can take place and policies can be crafted to fit the unique characteristics of each state. While one state might prefer a market-oriented approach, others might favor command and control. For all of these reasons, it remains critical to evaluate state-level policies aimed at achieving environmental goals.

The set of state energy policies designed to address climate change and encourage clean energy development take various forms. Although some directly incentivize consumer behavior, others are intended affect the supply side of the market for clean energy technology. Yet, their goal is the same, to create a viable and economically efficient market for various types of renewable energy technology.

Kubert and Sinclair (2011) conducted a cross-state comparison of renewable energy incentives. They used data collected by the Clean Energy States Alliance (CESA), a non-profit organization that promotes clean energy development and provides counseling to states concerning their renewable energy policies. Their study evaluated CESA members based on six criteria: energy generated, cost-effectiveness, avoided greenhouse gas emissions, market growth, funds leveraged, and jobs created. They found that even when accounting for the value of the incentive for solar energy, the cost of the power in a state with moderate solar resources was higher than the average wholesale electricity rate. Only in states with high solar resources were incentives successful in driving the cost of solar power below the average wholesale rate. Still, they argue that other benefits such as avoided greenhouse gas emissions, rapid market growth, and jobs created make up for the fact that incentives have a difficult time in making solar power more cost competitive. As a result, they conclude that direct financial incentives may not be enough to influence adoption alone and should be supplemented with technical support, customer education, and marketing initiatives. It is also important to point out that the CESA data comes from only 18 states, likely those that care most about developing renewable energy. Additionally, this study examines different types of incentive programs but does not come to a clear answer concerning which are most effective. Instead, it concludes that different incentives should be chosen based on the goals set forth in each state.

Sarzynski (2010) examined the impact of solar incentive programs in ten different states. This study used three criteria to judge whether state incentives were meeting their objectives: encouraging adoption, reducing conventional energy demand, and reducing emissions from fossil fuel energy sources. Despite the limited sample size, the study found that states with high population, high incomes, high electricity prices, high solar resources, a more liberal population, and lower domestic energy resources tended to have more solar power adoption. It is important to point out that this study is based on a convenience sample and cross-sectional data and is therefore neither generalizable nor does it indicate causality. The study also reveals that only three of the ten states, namely California, Connecticut, and Hawaii, have residential incentives that create a levelized cost of energy that does not exceed the average price of energy. Ultimately, this is how this study defines an “effective” set of state policy incentives. This study also does not include the value of federal, local, or utility incentives.

Four previous studies employ quantitative models to explain the role of state policy in solar PV adoption. Kwan (2012) creates a model using a multi-year cross-sectional zero-inflated negative binomial regression to conduct a ZIP Code level of analysis study of solar PV adoption. He accounts for solar policy incentives through one variable that aggregates the number of solar PV incentives available in a given state, finding that this variable has a positively statistically significant relationship with installations. However, this approach suffers from a number of limitations. Its multi-year cross-sectional model aggregates all installations over a six-year period from 2005 to 2010 rather than looking at each year individually in a time series fashion. While the total number of incentives in a state represents the number at a particular point in time, it is impossible to tell from this study whether all states had that number of incentives in every year and whether the introduction or expiration of any particular incentive programs affected the installation of solar PV technology. Moreover, this study treats all incentives equally, yet because different types of incentives are intended to act differently with consumer preferences, such as in the immediacy of payment, this equal treatment is probably unwarranted. Still, Kwan's study is important because it controls for a substantial number of economic, environmental, and socio-demographic controls.

Sarzynski et al. (2012) use a panel cross-sectional time series model to account for the effect of different types of solar incentives: cash incentives, income tax credits, sales tax exemptions, and property tax exemptions. It also includes variables for net metering, renewable portfolio standards, and solar RPS carve-outs. The data in this study cover a 13-year period from 1997 to 2009. They discover that cash incentives are the only statistically significant type of financial incentive and that RPS and the RPS solar carve-out are significant while net metering is insignificant. The only controls in their model are for electricity price, per-capita GDP, and population. Electricity price is positively statistically significant while GDP is negatively statistically significant, which is a questionable result. The study acknowledges the importance of leaving out some economic variables like the price of solar equipment yet does not mention the omission of socio-demographic or environmental variables that could be of substantial importance to understanding the effectiveness of policy. While many of these omitted variables are controlled for in the state and year fixed effects terms, approximately one third of the variability remains unexplained. The study also omits several newer policy programs such as performance-based incentives that have been recently implemented at the state level. Lastly, the study's results apply to all sectors of the solar PV market lumping residential, commercial, and utility installations together. As identified earlier, utility installations are currently driving increases in solar PV capacity; thus, the findings of this study may not apply specifically to the residential market.

Finally, two related studies, Shrimali and Kniefel (2011) and Shrimali and Jenner (2013), examine various policies for renewable energy sources including solar PV development at the state level. Shrimali and Kniefel create a 50-state panel model covering the years 1991 to 2007. The dependent variable is a ratio of capacity to net generation of electricity. The policy variables included in this study are related to Renewable Portfolio Standards, State Green Power Purchasing requirements, a Required Green Power Option provided by utilities, and the presence of a Clean Energy Fund. Of these policies, solar PV capacity was only influenced by mandatory capacity requirements (a portion of the RPS) and the presence of a mandatory green power option. No financial incentives were included. Economic and social variables were included as controls but none were statistically significant predictors of solar capacity including electricity price, natural gas price, per-capita GDP, percentage of coal used for electricity in the state, and LCV score. Additionally, the capacity measure used for the dependent variable was also susceptible to influence from utility and commercial scale installations and might not be best for understanding the factors that specifically influence the residential sector. Shrimali and Jenner (2013) are the first researchers to specifically examine the residential solar PV market using a panel model of specific state-level programs. Their data set covers 27 programs in 16 states from 1998 to 2009. Their results for the residential sector generally show weak results for the policy variables, especially financial incentives. Income tax incentives are negatively statistically significant in two of the seven capacity model specifications. Cash incentives are significant in only one model specification. RPS, State Green Power Purchasing, and the presence of solar Interconnection Standards were also significant in one of the models. Moreover, the study did show that cash incentives and property tax incentives were successful in bringing down the cost of PV systems in the residential sector, even if they didn't appear statistically related to capacity.

3.4 Research Questions and Hypotheses

While some previous research has been conducted to determine whether policy incentives are successful at encouraging consumers to adopt solar photovoltaic arrays for electricity generation, these studies still possess several major gaps that must be addressed. For instance, all of the studies mentioned previously fail to account for the change in price of solar panels despite recognizing the role of economic factors in the adoption process. Economic variables included in the models are often proxies for individual wealth such as income level or state gross domestic product or electricity prices, yet the price of solar panels have fluctuated substantially year over year, especially in the last decade. However, this trend has primarily been in the downward direction making solar technology increasingly affordable. Swanson's Law suggests that solar price halves for every 20 percent increase in world manufacturing capacity, which continues to increase at a steady pace (*The Economist*, 2012). It is important to disaggregate the marginal effect of policy incentives on adoption rates from the overall effect of declining prices.

Another glaring gap in the existing research is a lack of time series analysis, which makes causal inference impossible. Due to cross-sectional nature of many previous studies, researchers know a great deal about factors that correlate with high residential solar adoption rates but have yet to establish a chain of causality. So far, only three studies examine changes in solar PV deployment over time, only one of which concentrates on the residential market sector. Of these three, only two make a limited attempt to incorporate social, environmental, and economic factors that the previous cross-sectional models indicate are important predictors of solar adoption. Moreover, some previous studies favor a case study approach instead of quantitative modeling. The case studies examined in this literature review are an important part of the puzzle in understanding individual motivations for solar power adoption, but they come with the important limitation of not being generalizable.

I propose the creation of a longitudinal, quantitative model to determine the effectiveness of state-level policy incentives for influencing residential solar photovoltaic adoption rates at the state level[1]. The results from this model will be used to explore the following research questions and hypotheses.

Effectiveness of Solar PV Incentives

Previous studies show limited evidence that some state financial incentives appear to influence solar PV adoption. Sarzynski et al. (2012) show that the presence of cash

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[1] State and county level analyses each come with their own sets of advantages and disadvantages. The large numbers of counties in the Unites States provide more variation than just 50 states, increasing the robustness of results from a quantitative model. However, the policy incentives are state-level variables, and it may be difficult to assess their effectiveness by examining adoption rates at the county level.

incentives, primarily rebates, are a significant predictor of solar adoption, but their study examines all three market segments of solar rather than just the residential sector. Furthermore, Shrimali and Jenner (2013), by disaggregating residential, commercial, and utility segments demonstrate that cash incentives are a stronger predictor of adoption in the commercial sector than in the residential sector. Still, the balance of evidence points to the efficacy of cash incentives. Therefore, Hypotheses 1a and 1b will cover the role of cash incentives.

Hypothesis 1a: The presence of cash incentives such as rebates and grants will be positively associated with residential solar PV adoption rates, with all other factors held constant.

Hypothesis 1b: The amount of cash incentives such as rebates and grants will be positively associated with residential solar PV adoption rates, with all other factors held constant.

Currently, research is unclear about the effectiveness of other types of financial and policy incentives. Some evidence exists that Renewable Portfolio Standards, Net Metering, Property Tax Exemptions, and Income Tax Credits affect solar adoption rates, but this evidence has so far been inconsistent and sparse. Additionally, the current quantitative studies have so far overlooked a number of incentive programs including feed-in tariffs, solar renewable energy credits, and loan programs. Therefore, the remainder of incentives will be covered under Research Question 1.

Research Question 1: What is the influence of state solar photovoltaic incentives on solar adoption in the residential sector of the United States?

Evidence also suggests that having more policy options in a state is positively associated with higher adoption rates (Kwan, 2012). However, the study responsible for this conclusion is cross-sectional in nature and combines multiple years of adoption data into a single cross-section. Still, the theoretical justification for this expectation remains solid, resulting in Hypotheses 2a and 2b.

Hypothesis 2a: Larger numbers of solar financial incentives in a state will correspond to higher rates of solar photovoltaic adoption in the residential sector.

Hypothesis 2b: Larger total amounts of solar financial incentives in a state will correspond to higher rates of solar photovoltaic adoption in the residential sector.

Intervening Factors

In the current longitudinal quantitative models, the most attention has been paid to economic factors that influence adoption. Theoretically, these factors are particularly important. The adoption literature is rooted firmly in economics and states that the price of solar panels as well as the price of alternatives will matter to consumers who have the potential to adopt solar PV technology. Solar PV represents an alternative to the incumbent power distribution system; therefore, high electricity prices will make adopting solar a more attractive option. A number of studies have examined energy prices and found that high retail electricity prices correspond to higher solar PV adoption rates. Similarly, Diamond (2008; 2009) found that increases in gasoline prices were the most powerful and most consistent predictor of hybrid-electric automobile sales. Even with the addition of new solar financial incentives in the quantitative model, the expectation in Hypothesis 3 is that this relationship will remain positively statistically significant. However, Hypothesis 4, based on similar logic but currently unsupported by evidence, is that as the retail cost of solar installation decreases, installation rates will increase.

Hypothesis 3: The higher the retail cost of electricity within a state, the higher the adoption rate for residential solar PV will be.

Hypothesis 4: The lower the retail installation cost of solar panels within a state, the higher the adoption rate for residential solar PV will be.

The most consistent socio-demographic variable used in studies of solar adoption is environmentalism. This makes sense because if environmentalism were a substantial driver of solar PV adoption, then programs aimed at lowering the cost of solar panels would be ineffective at influencing adoption because the utility generated by them is psychological in nature and not economic. The Theory of Environmentally Significant Behavior suggests that environmental beliefs will be particularly important for low-cost environmental behaviors, but for high cost behaviors such as expensive purchases of environmentally friendly goods and services, the effect of environmentalism should be diminished relative to other important contextual factors. The most recent time series studies have not found that environmentalism is a statistically significant predictor of solar PV adoption when policy and economic variables are taken into account. Thus, Research Question 2 will further explore the nature of the relationship between environmentalism, solar policy incentives, and solar adoption.

Research Question 2: Is the influence of environmentalism on residential solar photovoltaic adoption in the presence of policy incentives direct or indirect in nature?

Lastly, research in this area has yet to completely identify or explain all of the factors that influence solar adoption. At least one-third of the explanatory factors remain a mystery. Several conceptual studies of renewable energy development have suggested the importance of capacity building in a market including factors such as knowledge, awareness, and marketing efforts. Others have considered whether having solar installers in close proximity may make individuals more likely to adopt solar PV systems. Finally, relating back to the anecdote of Arizona, utilities can either support state efforts to promote renewable energy or oppose them, as in the case of Arizona. All three of these market factors could play a role alongside traditional environmental, economic, and socio-demographic factors. Hypotheses 5 through 7 introduce three new variables to studies of the policy effectiveness of residential solar incentives.

Hypothesis 5: High levels of marketing effort will correspond to higher rates of residential solar photovoltaic adoption, controlling for other factors.

Hypothesis 6: High levels of utility support will correspond with higher residential solar photovoltaic adoption, controlling for other factors.

Hypothesis 7: A higher number of solar photovoltaic installers within a state will correspond to higher rates of residential solar photovoltaic adoption, controlling for other factors.

Hypothesis 8: The presence of a Green Power Option (GPO) will correspond to lower rates of residential solar photovoltaic adoption, controlling for other factors.

3.5 Policy Relevance

The research questions and hypotheses above have significant implications for public policy regarding solar electricity in the United States. Understanding the effectiveness of policy incentives, particularly those that cost states money, is critical toward maximizing the effectiveness of tax dollars and general good governance. Moreover, studies should compare the effect of policy incentives to overall conditions in the market such as declining prices. If a rapid decline in the price of solar panels is more effective at convincing new users to adopt residential photovoltaics, then perhaps policy makers should focus their efforts on supply side policies aimed at lowering the overall cost of the product and not incentives geared toward the consumer. It could also be the case that some, but not all, of the incentive programs are effective. If this is the case, a comparative effectiveness study like the one proposed here will help policy makers select good programs over bad ones.

Most importantly, creating feasible, effective, and affordable renewable energy policy is essential for the future of renewable energy development in the United States. Whether the goal is to reduce pollution, mitigate the effects of global climate change, or provide energy security for the United States, the development of a competitive market for renewable energy is essential. While residential solar power is only a small piece of a complex puzzle, it still represents a key part of the solar energy supply, and beyond the global implications of helping the environment; residential solar power gives individuals the opportunity to lower their energy bills.

4. Methodology

4.1 Introduction

As established in the previous chapter, several previous research studies have attempted to identify and account for factors that influence individuals to adopt solar photovoltaic technology at the residential level. Typically, these studies aggregate many individual behaviors to some larger geographical unit, such as a state, county, municipality, or ZIP code. While this procedure is widely accepted in the literature, it causes some issues when it comes to generalizing findings that must be addressed and clearly articulated when interpreting the results of the quantitative model.

The following chapter will cover the methodology used in this study. It will identify the underlying theoretical basis for modeling the consumer purchase decision for solar panels, providing a link between the theoretical framework presented in the previous chapter and the operationalized variables described in this one. Moreover, it will describe several important considerations when it comes to interpreting the results of the quantitative model, including limits to the usefulness of such interpretations.

4.2 Modeling Solar PV Adoption

The previous chapter explained how economists often model human behavior as a utility maximization problem. Consumer purchasing behavior is typically viewed as the behavioral result of an individual meeting needs and satisfying wants. What they purchase and how much they spend on that good or service provide an indication of the relative importance of that good or service. However, the purchase decision provides no indication of what characteristics of the purchase contribute to the individual's utility. In the case of a solar power system, Consumer Choice theory would suggest that the utility was derived from monetary savings such as reduced electricity costs. Alternatively, the Theory of Environmentally Significant Behavior indicates that the utility could come from the product's contribution to environmental sustainability or at least the signaling of pro-environmental intent that comes along with the purchase of certain products. The only thing that can be known for certain by examining any individual purchase decision is that the utility derived from that purchase is higher than that of an alternative purchase or remaining with the status quo. However, by aggregating many purchase decisions together and examining the many contextual factors occurring in the areas where purchase decisions are happening, researchers can obtain a broader indication of the social factors that contribute to the purchasing decision. It is important to continue conceptualizing innovation and diffusion as both an individual and a collective act (Jacobsson and Johnson, 1998).

In the case of a solar photovoltaic array, the critical alternative most often cited in empirical research is the decision to continue drawing power from the electrical grid, which has its power supplied primarily by fossil fuels. Certainly, there are other options for power generation available, for instance, small-scale wind power, geothermal heat generation, or even going “off-grid” using gasoline-powered generators. However, the most important part of the decision to purchase solar panels is the decision to engage in distributed power generation over continuing to purchase power from grid-tied utilities, not the decision to adopt solar power over other forms of distributed generation.

The key question left to address is whether choosing to purchase a solar photovoltaic system over remaining a customer of the electric utility is similar enough to other types of consumer purchases to be explained by a standard utility model, as is typical of Consumer Choice Theory? Immediately, several key distinctions become obvious when considering a potential analogous decision, purchasing a new automobile. First, new automobile purchases tend to occur when the previous automobile is on the verge of breaking down. Such is not the case with solar PV arrays. There is rarely ever the threat of utilities breaking down and leaving their customers without power. In fact, unlike automobiles, the electric utilities take all responsibility for maintenance and repairs for the power delivery infrastructure. Thus, customers looking to adopt any distributed power generation would be accepting the responsibility for maintaining their power generation equipment, a responsibility they don’t currently have under the status quo electricity arrangement. However, adopting distributed solar power would be analogous to the decision to purchase an automobile if the alternative was to not own an automobile and instead rely on public transportation.

Second, the decision to adopt distributed power generation technology also involved the opportunity to generate revenue by selling power back to the electric utilities. In this way, the adoption of solar PV technology might involve some considerations that are more similar to producers rather than just consumers. However, because residential solar power systems tend to be very small, their excess generation capacity is also likely to be low, especially compared to larger systems purchased by commercial operations. Therefore, surplus power generation for residential systems is more similar to a fluctuating rebate, going toward reducing the overall purchase price of the system, than a true revenue generating opportunity.

Despite several subtle differences, the purchase of a solar PV array for a residential customer is similar enough to other consumer decisions to purchase large, durable goods such as automobiles, appliances, and housing to be sufficiently explained by a common consumer utility model. This theoretical model has been applied to previous studies of pro-environmental, durable good purchases such as hybrid electric vehicles (Diamond, 2009), solar photovoltaic technology (Shrimali and Kniefel, 2011; Sarzynski et al., 2012; Shrimali and Jenner, 2013) and other types of renewable power generation systems (Shrimali and Kniefel, 2011). In such a model, any customer's individual utility is a function of individual and product factors such that the utility of an individual i for a power system j is given by the equation (1):

$$U_{ij} = f(p_j, x_j, \xi_j, \zeta_i; \theta) \tag{1}$$

In this case, p is the overall price of the good, both long and short term; x accounts for the measurable characteristics (such as size, capacity, weight, etc…); ξ are the unmeasurable product characteristics (such as brand); ζ are individual personal and socioeconomic characteristics; and θ is a vector of parameters to be estimated. In line with Diamond's work, the individual will only purchase a particular solar power system if the utility from that purchase is greater than or equal to the utility from either a competing energy generation system or the status quo, or remaining a customer of the current electric utilities. Such a decision can by demonstrated by the following inequality:

$$U_{ij}\, f(p_j, x_j, \xi_j, \zeta_i; \theta) \geq U_{ir}\, f(p_r, x_r, \xi_r, \zeta_i; \theta) \text{ for } r = 0; 1; 2; \ldots; J; r \neq j$$

Thus, the aggregate of all these individual consumer decisions about solar power generation in a society can be expressed as equation 2, or the total set of decisions to adopt solar photovoltaic technology:

$$A_j = \{ \zeta : U_{ij}\, f(p_j, x_j, \xi_j, \zeta_i; \theta) \geq U_{ir}\, f(p_r, x_r, \xi_r, \zeta_i; \theta)\} \text{ for } r = 0; 1; 2; \ldots; J; r \neq j \qquad (2)$$

Recall that the solar PV adoption as well as other forms of distributed electricity generation, the primary decision a consumer must make is whether to leave the established electricity provider ($r = 0$). Additionally, a researcher must specify a unit of aggregation. Because substantial policy variation related to solar PV occurs at the state level, the state is a reasonable unit of aggregation. When aggregated over time, the sum of consumer decisions within a state (s) during a particular time period (t) for a power system (j) can be understood as the rate of adoption. Therefore, the rate of adoption in a state is:

$$R_{stj} = f(p_{js}, x_{js}, \xi_{js}, \zeta_s; \theta) \qquad (3)$$

In this case, individual utility U is no longer important, but instead the above equation represents the aggregate utility of all solar PV purchasers at the state level as the adoption rate. Likewise, p, x, ξ, and ζ are the individual and product characteristics aggregated to the state level. Given that the United States represents a relatively open market for solar PV technology and that the variation in solar technology is not particularly high (i.e. consumers anywhere typically purchase the most efficient panels available on the market), it can be theorized that state-to-state variation in product characteristics, both measurable and unmeasurable, is very low. Thus, these terms can be dropped from the previous equation to give equation 4:

$$R_{stj} = f(p_j, \zeta_s; \theta) \qquad (4)$$

In order to estimate parameters, a linear regression model was used. Because understanding variation over time is critical to potentially evaluating the causal relationships between the adoption decision and the social, economic, and policy factors used to explain the adoption rate, the model is a cross-sectional time series, or panel model. Panel data analysis involves collecting data for a particular unit in several instances over a particular period of time. While this methodology is typically used for surveys collecting information about individuals, it is increasingly used to analyze data about different types of units including businesses, industries, nations, and various sub-national units (Andress, Golsch, and Schmidt, 2013).

Andress, Golsch, and Schmidt outline the various benefits and challenges of panel design that require special attention, especially because of the design's increasing popularity and use. First, they point out that panel design allows for the analysis of change over time, a benefit over standard cross-sectional analyses. Furthermore, panel data allow researchers to disentangle age and cohort effects, control for omitted variables, and assess causality, all things that cannot be done with cross-sectional data alone. On the other hand, common challenges facing panel data users include selecting proper sampling methodologies, dealing with missing data for particular years, and financing expensive panel surveys. In the case of this dissertation, cost and sampling are not issues. The data used for this study were obtained from free sources. Additionally, there is no sampling involved because this study examines the entire population of U.S. states. Missing data typically comes from panel attrition, which occurs in surveys when a member of the panel elects to prematurely end their participation in the survey. Since this research design is not a survey, that problem will not occur, yet it is possible that some data sources will have omitted data for individual years. Andress et al. suggest the use of imputation techniques using surrounding data points to handle this problem.

While using panel data to evaluate residential solar adoption presents advantages over the bulk of cross-sectional analyses, it is important not to overstate its potential for understanding the role of policy in explaining behavior. For instance, while panel data do generally allow for the assessment of causality, in this particular instance, making that determination from the available data will be difficult, if not impossible for several reasons. First, there may be endogeneity present that produces a feedback effect, though this can be handled using instrumental variables, a technique which will be explained later in this chapter. Second, the time unit of this study is a full year. Most time series analysis that attempts to uncover a causal relationship uses much shorter time frames such as months or weeks. Much unobserved change can occur over the course of an entire year and using yearly average variables could give the impression of causality where none exists.

Previous studies of solar panel adoption have used a wide variety of statistical analysis methodologies with varying degrees of success. In their cross-sectional approaches, Zaharan et al. (2008) and Kwan (2012) made use of zero-inflated, negative binomial regression (ZINB). Their studies share the characteristic of only being interested in spatial variation, and therefore panel data was unnecessary for either study. The ZINB method was chosen specifically to handle the large number of non-adoption cases that produced a zero for the dependent variable. Even without a logarithmic transformation, when more than half of the cases of a dependent variable are zero, a standard OLS regression will not produce unbiased estimators. ZINB solves this problem essentially by running two regressions, a logistical regression plotting the zeros against all positive integer values and a binomial regression with the zero cases dropped. Although ZINB is not a technique commonly used for panel data, the problem of too many zeros is likely to carry over to a panel data set.

In their study of peer effects in solar adoption, Bollinger and Gillingham (2012) utilize a ZIP code level data set. In their model, the primary independent variable of interest is a lag variable for the installed base of solar capacity at the time of a new adoption. However, including this variable in the model resulted in serial auto-correlation between that variable and the errors. Intuitively, it is easy to understand why this choice would cause a problem. The lag independent variable is includes all choices to adopt in a previous time period, including all variables that predict that choice. It is very likely that those variables, omitted in Bollinger and Gillingham's model, actually influence adoption rates in the present as well as the past. To solve this problem of correlated unobservables, the researchers employ a first-difference approach to data analysis in addition to a traditional random or fixed effects specification. They find that the first-difference model produces a better estimation of the role that peer effects play in solar adoption. While it is important to recognize the way that lagged variables will affect a linear model, considering that the model of this study will include lagged variables, it is unlikely that the lagged versions of the policy variables will result in serial autocorrelation due to unobservables in the same way that lagging prior adoptions in an adoption model would.

Sarzynski et al. (2012), Shrimali and Jenner (2013), and Shrimali and Kniefel (2011) also use panel data to explain varying aspects of renewable energy adoption.

Another study, Diamond (2009) uses a similar panel approach to examine the influence of policy incentive and gasoline prices on hybrid automobile adoption.

The Sarzynski et al. study also addresses the problem of a high number of zeros in the dependent variable. Instead of using a zero-inflated analytical methodology, the researchers simply increase the value of every dependent variable by one. This technique keeps the relative value between each dependent variable the same but allows a logarithmic transformation of the data. This method was also used by Diamond (2009) and appears to be readily supported in the econometrics literature. Because the use of logarithmic transformations changes the underlying individual numeric value anyway, preserving relative value is an important characteristic to consider if log transformations are used.

While panel regression models provide a number of advantages over ordinary cross-sectional models including the ability to evaluate the causal relationships between independent and dependent variables, they also come with a number of drawbacks, as discussed above. Another of these drawbacks is that the assumption of independent observations required of standard ordinary least squares estimation no longer holds because cases from the same geographical unit are not independent by definition. As a result, variables omitted from the model, such as the unique characteristics of a particular state, are subsumed by the error term but may also correlate with the observations resulting in omitted variable bias and inefficient coefficients.

Therefore, a decision must be made whether to estimate coefficients under the assumption of fixed or random effects. Under fixed effects assumptions, the error term is assumed to be correlated with the observations. This autocorrelation can be controlled for by a series of dummy variables for each geographic unit. It is important to point out that under fixed effects assumptions, only characteristics that vary over time can be included in the model while all time invariant factors are excluded.

On the other hand, a random effects model assumes that the omitted variables are not correlated with the independent variables; in other words, they are randomly distributed. Because of this assumption, no geographic dummy variables are necessary unless they are used to control for outliers. Moreover, time invariant characteristics can be included in the model. The looming threat of omitted variable bias can be evaluated by using a Hausman Test to compare the difference in variable coefficients between fixed and random effects assumptions.

Previous studies have used a variety of quantitative methods to address this issue. Kwan (2012) and Shrimali and Kniefel (2011) used a pooled model where observations from the same state at different times were examined together. This data analysis technique assumes the standard Gauss-Markov conditions are met, including independence of observations, which leads to biased coefficients. An additional model used in the Shrimali and Kniefel (2011) study as well as those used by Sarzynski et al. (2012), Shrimali and Jenner (2013), and Smith and Urpelainen (2014) employed a fixed effect panel model, thus the use of a fixed effects specification is justified both by logic and by the literature. Still, several of these studies examine renewable energy broadly and do not focus specifically on solar. The two studies that do highlight solar (Sarzynski et al., 2012; Shrimali and Jenner, 2013) do not contain variables for environmental conditions that may be time invariant, such as average solar radiation or average temperature. While these time invariant characteristics are subsumed by the fixed effects term, and thus should not affect the coefficients, their exclusion from the model leaves a logical piece of the solar puzzle missing. Specifically, how much influence do environmental conditions have over residential solar PV adoptions compared to policy, economic, and social variables?

Only by using a random effects specification can the relative influence of both time variant and invariant characteristics be assessed. Therefore, the following study will run two panel models, one using fixed effects and the other using random effects. A Hausman Test will then be used to examine the models for independence to determine which model provides the best estimators. The two models are illustrated below in equations 5 and 6.

Fixed Effects Model :

$$\log R_{st} = \beta_1 \log I_{st} + \beta_2 \log C_{st} + S_s + \varepsilon_{it} \qquad (5)$$

Random Effects Model:

$$\log R_{st} = \beta_1 \log I_{st} + \beta_2 \log C_{st} + \beta_3 \log E_{st} + u_{it} + \varepsilon_{it} \qquad (6)$$

In equation 5, the dependent variable for the adoption rate R is determined by the policy incentives I, a vector of economic and socio-demographic covariates C, and an unestimated term capturing the state fixed effects S. In contrast, the random effects specification (6) includes the same variables for policy incentives and covariates but also has a time invariant term E capturing environmental conditions. This model also has two error terms capturing the between entity error *u* and the within entity error *ε*. All of the measured variables were transformed into log variables for several reasons. First, the transformation provided normality to the dependent variable. Second, this transformation allowed coefficients to be interpreted as elasticities for each of the variables. More about these transformations will be explained in the next chapter.

Lastly, endogeneity is a common problem for public policy models of this type. As Sarzynski et al. (2012) point out, the source of the endogeneity comes from the fact that in states that already had large numbers of solar PV installations, solar installers and manufacturers could form political organizations that lobby lawmakers for particular benefits including policies that lower the cost of solar. In this case, the direction of causality would shift with the installation rate causing the existence of more policy incentives. While equations 5 and 6 can provide valuable information about the relative relationship between the dependent and independent variables, the presence of endogeneity means that causality cannot be inferred from them. One strategy for dealing with the effects of endogeneity and avoiding biased coefficient estimation is to use an instrumental variable in a two-stage, least squares framework (Biernacke-Lievstro, 2014). Furthermore, this model will allow the causal effects of solar PV policy incentives to be assessed.

An ideal instrumental variable is one that is correlated with the endogenous variable of interest, W ($Cov(IV_{st}, W_{st}) \neq 0$), in this case policy incentives, but uncorrelated with the dependent variable ($Cov(IV_{st}, \varepsilon_{it}) = 0$) (Smith and Urpelainen, 2014). Ideally, multiple instruments should be used, as long as they fit the basic conditions. Using multiple instruments can allow for better estimation through increased precision and the ability to develop tests for overidentifying restrictions. The requirement for proper use of instrumental variables, however, is that the number of instruments per endogenous variable in the model be greater than or equal to one.

There are many possible instruments that can be used to solve this problem. The literature on policy diffusion provides a guide to finding such an instrument. A common model from understanding how policies diffuse from state to state is the Regional Policy Diffusion Model (Wiener and Koontz, 2010). This model says that factors like state competition to be regional leaders and regional networks of cooperation influence neighboring states to adopt new policies. Their study results support the existence and strong influence of regional competition over policy diffusion for wind energy incentives. There is reason to believe that solar energy incentives would operate under the same theoretical conditions. Therefore, a potential instrumental variable would be the percentage of surrounding states with solar policy incentives.

While the connection between the endogenous variable and the policy diffusion instrument can be conceptualized relatively easily, the variable's fitness under the exclusion restriction cannot be as easily assumed. Based on the level of analysis of the study, it may seem implausible that the presence of a solar incentive in a neighboring state will directly influence residents within a state to adopt solar panels, but given the speed of both communication and the ease of transportation, it cannot be excluded as impossible, only highly improbable. However, in such studies, the burden of proof lies with the researcher to exclude such possibilities. Therefore, the fitness of policy diffusion as an instrument must be confirmed through empirical means, which will be further explained in Chapter 6.

The diffusion literature is not the only source for potential instrumental variables. Several other potential instruments will be investigated. First, the level of state government debt could indicate a willingness to spend money on social and environmental programs including solar incentives. Moreover, it is not clear that this variable would have any relationship with the decision of citizens to actually adopt solar PV technology, though this assumption must be verified through empirical analysis. Alternatively, the partisan composition of government, particularly whether the executive and legislative branches of state government are controlled by liberals, could influence whether environmental policies like solar incentives become law. Government control by liberals could also be indicative of a population that is sensitive to environmental concerns and therefore correlate with the dependent variable; however, this relationship can also be further investigated. Ultimately, the fitness of each of the proposed instruments in this section will be evaluated in Chapter 6.

An additional model will be estimated using the system of equations below. Systems of equations are commonly used with instrumental variables, though multiple methods of estimation are possible in this framework including two-stage least squares (2SLS) and generalized method of moments (GMM). This study will employ a 2SLS estimation, which has proven effective in similar studies (Smith and Urpelainen, 2014). In equation 8, the instrumental variable IV will be used to estimate the policy incentives along with a vector X of state-level covariates that influence the presence of solar policy incentives, including both state and year fixed effects. Then, using predicted values of the policy incentive variable, the adoption rate will be estimated using the same set of covariates from the first equation. Running both equations simultaneously results in smaller standard errors and ensures that the model does not exclude important exogenous factors at any stage of the process (Biernake-Lievstro, 2014).

$$\log R_{stj} = \beta_1 \log I_{st} + \beta_2 \log C_{st} + \beta_3 \log E_{st} + \varepsilon_{it} \tag{7}$$

$$\log I_{st} = \beta_1 \log IV_{st} + \beta_2 \log X_{st} + \varepsilon_{it} \tag{8}$$

4.3 Data Sources

Utilizing data from multiple sources, a state level data set will be constructed. Each individual data source will be discussed in the variable description sections. Additionally, data will be collected for the six years from 2007 until 2012. This time period was chosen for several reasons. First, it is as contemporary as possible, providing the most up-to-date conclusions about the solar photovoltaic adoption process. Second, it encompasses several major price shifts in solar prices including two major decreases, 2007 to 2008 and 2010 to 2011 as well as a small price increase from 2008 to 2009. Finally, it is also recent enough to coincide with an increase in data availability.

More discussion of the issue of the unit of analysis of this study is required before going any further. This study is ultimately interested in how individuals behave in the presence of financial incentives for residential solar power systems. At first glance, one might think that this study sets out to examine the determinants of individual behavior.

However, all individual variables are aggregated to the state level. This means that particular care must be taken when interpreting the results. For example, if income is a statistically significant predictor of solar adoption, states with higher average levels of income correspond to higher levels of adoption. It does not mean, however, that the wealthy individuals were the ones who purchased solar panels.

Ultimately, a panel study of individuals would be most helpful for understanding individual motivations for purchasing solar panels, yet that data does not exist. However, that is no reason to let the ideal be the enemy of the good. The data that does exist, information on aggregate adoption rates in particular geographic areas, can still be very useful in understanding the solar adoption process. It can help identify areas with the right set of characteristics for increasing the diffusion of solar panels. Additionally, this type of analysis can be used to evaluate variables that are highly spatially dependent, such as policies that vary from jurisdiction to jurisdiction. Therefore, while some of the data may describe the characteristics of individuals while others the characteristics of state government, the unit of analysis for this study is the state and all individual variables in the study will be aggregated to that unit. Moreover, interpretation of the results will be undertaken with extreme caution to make certain that readers do not assume that independent variables are indications of individual behaviors; instead, they can properly be thought of as risk factors for solar adoption in a particular state.

4.4 Dependent Variable

The dependent variable for this study is the residential solar adoption rate for a given state. Previous studies have operationalized this in a variety of different ways. Zaharan et al. (2008) used the percentage of homes using solar power as the primary fuel for home heating, data collected by the U.S. Census Bureau. This dependent variable has several weaknesses including the fact that the Census question does not differentiate between passive and active solar heating and the fact that the variable does not take into account differences in the population of different counties. Most importantly, it is not useful for this study because it asks about solar heating technology and not photovoltaics.

Sarzynski et al. (2012) used total grid-tied solar capacity as their dependent variable. The primary problem with this variable is that not all added capacity is grid-tied. As a result, their dependent variable does not include all new capacity. Shrimali and Jenner (2013) use total capacity and base system cost as their dependent variables. While the cost is not relevant as a dependent variable for this study, capacity could be, though it has some drawbacks that will be discussed below. Finally, many studies have used market share as a dependent variable, including studies of hybrid electric vehicles, solar photovoltaics, and total renewable energy (Diamond, 2008; Diamond, 2009; Shrimali and Kniefel, 2011; Smith and Urpelainen, 2014). For renewable energy, market share would be measured as total renewable capacity divided by total electricity generation from all sources. When all sectors are taken together, this measure is particularly useful. When looking only at the residential sector, however, the small number of households using solar electricity would make the numbers, even for high solar states like California and New Jersey, extremely small and difficult to use in a quantitative model.

I have chosen to follow the approach taken by Kwan (2012) with a slight adjustment. Kwan used the total number of PV installations in a given geographic unit. This measure is particularly interesting and useful to policy makers for two reasons. First, it uses the total number of installations instead of the capacity, giving an indication of exactly how many new solar adopters that policy makers can expect to take action. By using capacity, one cannot distinguish whether the policy is appealing to a broad section of the population or just encouraging people that were already adopting solar to install larger systems. Second, the number or installations is easier for the average person to conceptualize than increases in capacity. As mentioned in Chapter 2, residential installations contribute less to the total solar capacity than commercial or utility scale installations; however, their importance becomes clear when discussed in terms of the number of total installations. Moreover, the average person probably has little idea of what the mean and the range are for the capacity of solar installations. Therefore, the relevance of an increase in capacity of 50 kilowatts may leave even policy makers wondering about whether that amount is significant. However, an increase of 10 installed systems per year is more directly meaningful.

In order to account for the differences between the populations of the states, a second dependent variable was calculated as the installations per capita. While both Kwan and Zaharan et al. included population as a control variable, the large number of potential independent variables in this study necessitates adding as few extra variables as possible. Thus, this technique controls for population differences between states, allowing for low-population states like Mississippi to be compared to high-population states like California.

There exists a possible alternative to normalizing installations across states by population. Because solar panels require a structure to be placed upon and because in the residential sector that structure is a housing unit, it might make more sense to use the number of housing units instead of the population. It is also unlikely that solar panels would be installed on housing units where no one was living. Additionally, the Census Bureau estimates the number of occupied housing units in each state. Therefore, a third dependent variable will be constructed for installations per occupied housing unit.

These dependent variables will be constructed based on the number of solar photovoltaic installations per state recorded as a part of the Open PV Project (https://openpv.nrel.gov/). Because states with higher populations and more housing units have a higher potential base for solar PV adoptions, the raw number of installations will be normalized by dividing it by the state population for that particular year found in data from the U. S. Census Bureau.

The Open PV project is a collection of data on new solar photovoltaic installations identified by state, ZIP code, size, and cost. Data are maintained by the National Renewable Energy Laboratory (NREL) and voluntarily submitted by solar panel installers upon completion of a new installation. Despite being voluntary, Open PV Project data is meticulously maintained by the NREL, which examines it for inconsistencies and duplications. Unfortunately, the Energy Information Administration does not differentiate between the sizes of installations making their data inappropriate for this study. While the exact numbers might be different from the actual installed capacity, the Open PV Project data provide an accurate account of high and low adoption states and will serve as a useful operationalization of solar adoption.

Moreover, the Open PV Project data have proven both reliable and valid in a number of previous studies including Zaharan et al. (2008), Bollinger and Gillingham (2010), and Kwan (2012). Data from the Open PV Project even has some advantages over other sources. For instance, data is tracked on a monthly basis, unlike the data from the Tracking the Sun project, which is only reported yearly. Plus, the Open PV Project tracks every installation by size and cost. While currently there is no plan to use the cost of the installed system, the data on the size of the system is an essential tool for differentiating between residential solar installations and other types such as commercial or utility.

Although the data set does not differentiate between residential, commercial, and utility installations, the size of the installation in kilowatts is given. However, this is a common problem of the previous studies in this area. Zaharan et al. (2008) and Bollinger and Gillingham (2010) set a specific kilowatt level to differentiate between residential and commercial installations. They both use a level of 10 kW, yet an examination of solar policy data from the Database of State Incentives for Renewables and Efficiency (DSIRE) shows that a substantial number of states provide policy incentives to residential installations well above the 10 kW cutoff utilized in previous studies. Some maximums go as high as 35 kW. Unfortunately, at higher levels, it is impossible to distinguish between residential and commercial systems. Therefore, this study will set the maximum value for a residential solar photovoltaic installation at 25 kW with the recognition that some residential systems will almost certainly go uncounted while some commercial systems may end up in the data set.

4.5 Independent Variables

The main independent variables of interest, data about the policy incentives in each state, will come from the Database of State Incentives for Renewables and Efficiency (DSIRE) (http://www.dsireusa.org/). DSIRE is a comprehensive database of state and local policy incentives designed to encourage the development of renewable energy. This research will analyze eleven different policies including:

- Income Tax Incentive
- Property Tax Exemption
- Sales Tax Exemption
- Rebates
- Grants
- Low Interest Loans
- Net Metering
- Solar Renewable Portfolio Standard
- Feed-in Tariff
- Solar Renewable Energy Credits

Policy variables will be treated differently in four different model specifications. In the first model, policy variables will be coded individually based on their availability. This means using a dummy variable coding scheme where 0 indicates the absence of a particular policy and 1 indicates its presence. The second model specification will aggregate the total number of solar policies in order to produce a sense of which states offer their citizens more policy options. It follows logically that states could attract more solar purchasers if they have many different ways to finance the installation of solar panels. Conversely, states with limited policy options may be missing an opportunity to increase solar PV installations simply by diversifying their policy portfolio. This variable will allow that assumption to be tested.

The third model specification treats each policy option as a continuous monetary variable. Based on the legal construction of each state's policy incentives, the value of that incentive for a 5 kW solar photovoltaic system will be calculated. Five kilowatts was chosen as the size because the Solar Energy Industry Association (2014) reports that as the average size for a residential solar installation in the United States. Picking a specific size was important because many of the laws contain cutoff provisions. For instance, the income tax credit in New Mexico allows an individual to claim 10 percent of the purchase and installation costs but caps the total value of the incentive at $9000. By selecting a specific size for the equipment, the calculation of an incentive amount avoids inflating the value of the incentive to an unrealistic level. For indirect policies like net metering and renewable portfolio standards, this type of calculation would not be feasible. Instead, net metering was operationalized as the maximum eligible size limit for the PV system in each state. The rationale behind the selection of this measurement is that fewer solar PV systems will be installed where the maximum size of the system, and thus the amount of electricity that can be generated and sold back to the grid, is highly restricted. Renewable portfolio standards could be operationalized a number of different ways. A potential measurement could be the target reduction in greenhouse gas emissions. Another could be the number of years allowed to achieve the emissions targets. These options will be further explored in the next chapter.

4.6 Environmental Covariates

Previous studies have generally backed up the contention that environmental conditions affect solar adoption rates. In most studies, two important environmental characteristics have been consistently controlled for, namely solar radiation levels and average temperature. As mentioned in previous chapters, solar radiation has consistently been statistically significant while temperature has been insignificant. Thus, solar radiation will be the only environmental factor included in this study. The National Solar Resources Database (NSRD) collects solar radiation, also known as insolation, data for multiple locations in every state and produces an average insolation measurement for each site pooled from 1961 to 1990. The justification for pooling this data is that the yearly fluctuation in solar radiation is very small, as the measure depends more on spatial than temporal variation. These measurements will be averaged for each state based on the number of locations within that state to produce the most accurate statewide average possible.

4.7 Economic Covariates

Considering the goal of economic incentives is to lower the cost of solar PV systems in order to induce adoption, other economic motivators that could influence a consumer's decision to purchase solar panels must be controlled. The most obvious economic control is electricity price. If electricity prices are high or increase substantially over time, using solar energy as a substitute to traditional electricity sources (i.e. purchasing it from the grid) becomes more price competitive. Average retail electricity prices per state are tracked by the Energy Information Administration, a unit of the U.S. Department of Energy, every year measured in dollars per kilowatt-hour.

Wealth is also a critical economic factor. Previous studies have used either state gross domestic product (GDP) per capita or median household income. It is possible that GDP might be an inappropriate measure of residential sector wealth because it includes all economic activity in all sectors of the economy, not just the residential sector. Median household income might be a better measure of household wealth. Moreover, median income should be selected over average income because the distribution of wealth in this country is positively skewed, with a few outliers having very large incomes. Because of the use of GDP per capita in previous studies, this study will investigate the explanatory power of both GDP per capita and median household income as the proxy for wealth in separate specifications. State GDP data will come from the Bureau of Labor Statistics. Meanwhile, the data on average household income is available from the U.S. Census Bureau's American Fact Finder.

Some economic variables have not been included in previous studies. Such economic variables include the average dollar per watt installation costs of solar PV systems. Even without the inclusion of incentives, the retail price of a solar installation has been experiencing an overall decline in recent years. Data tracking this decline are available at the state level from the annual “Tracking the Sun” report published by the Electricity Markets and Policy Group at the Lawrence Berkeley National Laboratory.

4.8 Socio-Demographic Covariates

A number of demographic factors have also been shown to influence solar PV adoption rates in cross-sectional studies. These factors include education, age, the racial make-up of the population, urbanization, and the number of renters compared to homeowners. A set of important demographic variables is available from the U.S. Census Bureau. Education will be measured two ways: as the percentage of the state population with a high school diploma and as the percentage of the population with bachelor’s degree or higher. As discussed in the previous chapter, age should capture the percentage of the population at the peak of the life cycle consumption curve, the period in life where most large, durable goods purchases occur. The relevant age group for these purchases is 35 to 55. The Census Bureau divides age groups into deciles. This study will include variables for the percentage of the population in the 25 to 34, 35 to 44, and 45 to 54 deciles. Race will be measured as two variables capturing the percentage of the state population that is African American and the percentage of the population that is

Hispanic. Also, the percentage of urban population and the percentage of the population that rents in each state will also be controlled.

Political and social variables have also been shown to correspond to solar PV installations. Ideology is also a critical political factor influencing solar adoption. Two ideology variables will be included in these models. The first is a variable for conservatism. Conservatism will be measured as the average rating given to the state's House of Representatives members by the American Conservative Union (ACU), a political group that rates congressmen based on their floor votes for conservative legislation. While some might dispute the validity of ACU ratings, they are theoretically justified by the fact that congressmen are supposed to represent the wishes of their constituents in Washington. Thus, their votes, when aggregated, should closely approximate the views of their constituents. An alternative measure for conservatism was also collected. This variable is an ordinal variable indicating whether the state legislature is controlled be Democrats, divided between the parties, or controlled by Republicans.

Environmentalism, on the other hand, will be similarly measured using the League of Conservation Voters (LCV) legislative scorecard. The rationale behind its selection is similar to the ACU scores. However, an alternative measure was also selected. Jon Krosnick of Stanford University used multiple public opinion surveys capturing American opinions about climate change and global warming to estimate climate change opinion within the states (Krosnick, 2013). These direct expressions of opinion on an environmental issue were used as an alternative proxy for environmentalism.

4.9 Market Covariates

There are several market characteristics that have been theorized to influence solar PV installation, but for which there is little empirical evidence. One such market factor is the effective marketing of solar incentives by the government. As mentioned before, citizens cannot seek out an incentive that they do not know exists. While the amount of money allocated by states to marketing their incentive programs would serve as the ideal measurement of this construct, calls to several state energy agencies failed to yield results. Thus, a proxy variable was constructed using a content analysis of state energy department websites. The content analysis coded the websites based on how prominently information about the state's solar incentives was displayed. The results of the content analysis are explained in the next chapter.

Several additional market characteristics were also measured. The number of solar installers per state was obtained from the Solar Energy Industry Association. A variable was created to identify the number of utilities within a state that are supportive of renewable energy. Using the DSIRE data, the number of utilities offering their own solar energy incentives was recorded. DSIRE also identified which states have a mandatory green power option to provide competition to solar installation. This variable was recorded as a dummy variable. The amount of coal mined in the state was also recorded using data from the Energy Information Administration. Finally, a lone dummy variable was created for the state of California. As described in Chapter 2, California has historically supported solar development even when other states have not. As a result, a dummy variable will control for California in the random effects model. This condition is naturally controlled for in a fixed effects model.

4.10 Lagged Variables

It is entirely possible that the influence of policy on the adoption process does not occur immediately. Even if consumers are immediately aware of the incentive, the shopping and installation process may take a substantial amount of time. Therefore, lagged variables will be created for several policy and economic variables. Additionally, a lagged variable for residential capacity will attempt to control for the peer effect identified by Bollinger and Gillingham (2010, 2012).

4.11 Summary

Previous studies of the adoption of solar technology, other renewable energy technologies, and environmentally friendly products provide a guide to selecting a viable methodology to investigate the hypotheses and answer the research questions posed in the previous chapter. Most importantly, these extant studies illustrate that the use of panel data in this field is a reliable and valid way to explain the effects of various factors, including public policy, on the adoption process of pro-environmental durable goods over time. Building off of the lessons learned from these previous attempts, this study will expand upon the work by including several omitted economic variables and a full slate of social predictors and market characteristics into a linear model utilizing panel data. This study will also make several improvements suggested by Sarzynski et al. (2012) including adjusting economic variables for the effects of inflation.

The next two chapters will present the results of the quantitative analysis. Chapter 5 will provide descriptive statistics for the data and explain any transformations that were necessary. It will also present the results of the content analysis used to construct the marketing effectiveness variable. Chapter 6 will present the results of the quantitative model along with each of the sub-specifications.

5. Data Descriptions

Because the data used in this research was derived from multiple sources, a substantial amount of data cleaning was required. Additionally, many transformations were used to bring the data from its raw form to a form that was useful for quantitative analysis. This chapter will examine the distribution of each variable and explain the rationale for any transformations that were made. First, the dependent variable, solar installation rate, will be examined.

5.1 Dependent Variable

Initially, the dependent variable of interest was the number of solar PV installations occurring within a particular state in a particular year. The use of this variable presented a number of problems immediately. The most critical issue was the fact that the raw number of installations in a particular year is inherently difficult to compare between states. In the United States, the individual states differ substantially in a number of characteristics, not the least of which are size and population. One would expect that the population of the state would explain a substantial portion of the variation in the number of solar PV installations. States with many more people, such as California or Texas, may have more raw installations than less populated states such as

Rhode Island or Wyoming. As a result, an additional dependent variable, installations per capita (*install_percap)* was generated to account for differences in population by dividing the number of residential solar installations by the number of adult residents 18 and over.

In addition to accounting for differences in population between the states, the number of installations in a given year might also be constrained by the available housing stock. While it is very likely that the number of occupied housing units track fairly closely with the population, it is not the case that they are always perfectly correlated. For example, a housing crisis like the one that occurred in the United States may result in a temporary consolidation of housing units within familial units when extended family who lose their homes are forced to move in with relatives temporarily. In this case, the occupied housing stock has declined while the population has remained the same. Additionally, the rates of increase in housing stock may not be able to keep up with rapid population expansion in any particular year. This limited housing stock might slow the installation rate of solar PV systems despite increasing overall population numbers. Thus, one additional dependent variable was created to account for the installations per occupied housing unit (*install_homes*).

With these three dependent variables in mind, initial descriptive statistics were run for each. Based on the analysis of the descriptive statistics in Table 5.1, several important characteristics of the data become apparent. First, in the case of each dependent variable, the median is less than the mean, sometimes substantially less, indicating that the data are not normally distributed. An examination of the frequency distributions (Figure 5.1) and the normal quartile plots (Figure 5.2) indicate strong evidence that each of these variables is highly non-normal and exhibits substantial positive skew.

Table 5.1: Descriptive Statistics of Dependent Variables

Variable Name	Observations (n)	Mean	Median	Mode	Standard Deviation	Minimum	Maximum
Installations	306	650.6373	22	0	3039.08	0	33980
Installations per Capita	306	7.25×10^{-5}	6.04×10^{-6}	0	1.769×10^{-4}	0	0.0015873
Installations per Occupied Housing Units	306	1.958×10^{-4}	1.59×10^{-5}	0	4.806×10^{-4}	0	0.0043484

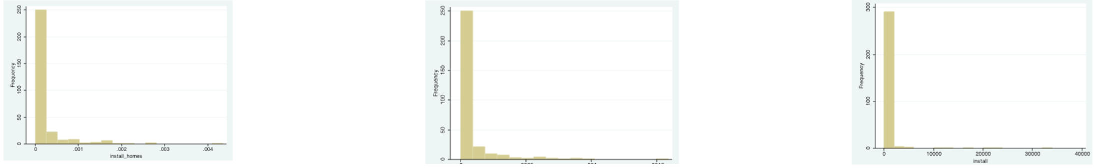
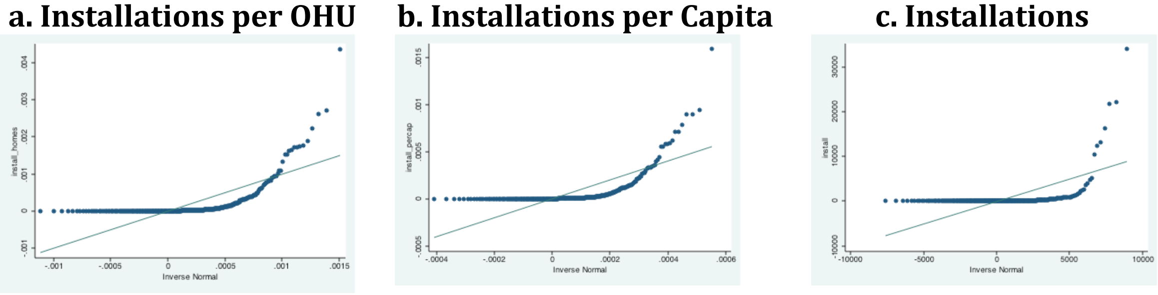

a. Installations per OHU
b. Installations per Capita
c. Installations

Figure 5.1: Frequency Distributions of Three Dependent Variables Based on Solar PV Installations per State



a. Installations per OHU **b. Installations per Capita** **c. Installations**

Figure 5.2: Normal Quartile Plots of Three Dependent Variables Based on Solar PV Installations per State

Normality is a key assumption of many model estimation techniques, and therefore, utilizing a highly non-normal variable as the dependent variable in such a model could cause substantial bias in the estimated coefficients. Commonly, transforming a variable by taking its natural logarithm is often used to correct for non-normality. A natural logarithmic transformation provides the added bonus of making estimated coefficients interpretable as elasticities.

As noted in Table 5.1 above, the modal value for each variable is zero. This fact complicates a natural logarithmic transformation because the natural log of zero is undefined. This problem can be easily remedied by adding the number 1 to the measurement of installations. As a result, the interval between each data point remains constant. Meanwhile, all zeros will become ones, and thus they will not be dropped during the logarithmic transformation.

The result of the natural logarithmic transformation for each dependent variable measure seems to have made each variable substantially more normally distributed. Figures 5.3 and 5.4 show histograms and normal quartile plots for each log dependent variable. Though they are not perfectly normally distributed, they are clear improvements over the untransformed dependent variables.

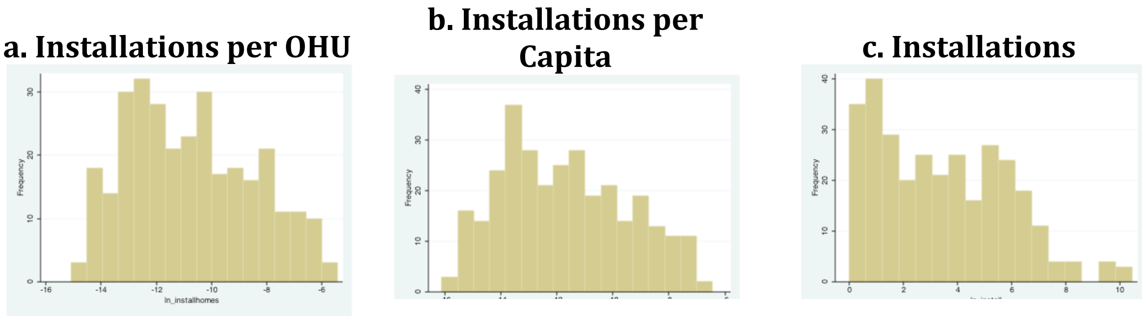


Figure 5.3: Frequency Distributions of Natural Logarithm Transformed Dependent Variables

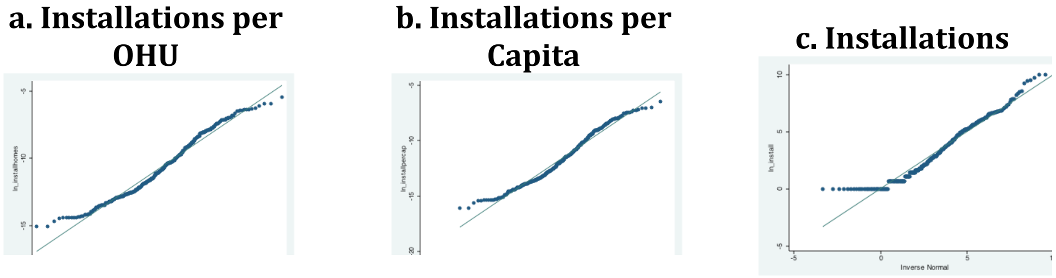


Figure 5.4: Normal Quartile Plots of Natural Logarithm Transformed Dependent Variables

5.2 Independent Variables

This study will include a number of important independent variables of interest. The most important of these involve the policy characteristics of each state; however, these will be evaluated in the following section. Table 5.2 lists the descriptive statistics for each of the remaining economic and socio-demographic independent variables in the dataset. Each of these will be evaluated in more detail below.

Table 5.2: Descriptive Statistics for Key Independent Variables

Variable	Mean	Median	Standard Deviation	Minimum	Maximum
elec_price	11.73735	10.6	3.973485	6.4	37.29
install_price	7.53007	7.65	1.628292	3.9	11.7
income	51,256.52	49,423.5	8423.541	36,646	71,122
gdp_pc	45,858.5	43,192.9	17,511.1	28,923.4	160,519.4
age25	0.1322	0.131	0.0137	0.109	0.22
age35	0.1322	0.132	0.00923	0.11	0.156
age45	0.1451	0.145	0.010001	0.108	0.171
ed_college	0.2788	0.268	0.05682	0.171	0.53
race_black	0.1106	0.0725	0.1106	0.003	0.547
race_hisp	0.1029	0.076	0.0981	0.01	0.47
urban	0.7411	0.7420	0.14763	0.387	1.00
rent	0.3303	0.319	0.055	0.248	0.588
environmentalism	51.506	51	27.367	0	100
conservative	43.641	45.0	26.196	0	100
insolation	4234.622	4133.5	533.1389	2372.4	5477

Electricity Price

As previously explained, the average electricity price within a state should be an important influencer of an individual's decision to purchase a solar electric power system. As energy prices rise, solar PV systems become a more attractive alternative to conventional grid power, even in the absence of government incentives. Yet it is also important to realize that substantial political incentives exist to keep retail electricity prices relatively constant over time. Spikes in electricity prices, like many other important commodities, could be blamed on the politicians in power.

An examination of the frequency distribution in Figure 5.5 reveals that, like the data for installations, the variable is positively skewed with the median value lower than the mean. It is also important to note that the average is dragged up by a small number of very large outliers. Additionally, this distribution holds even when the electricity prices are examined within each individual year. Again, transforming the variable using the natural logarithm method should serve to make the distribution more normal and less influenced by the large outliers.

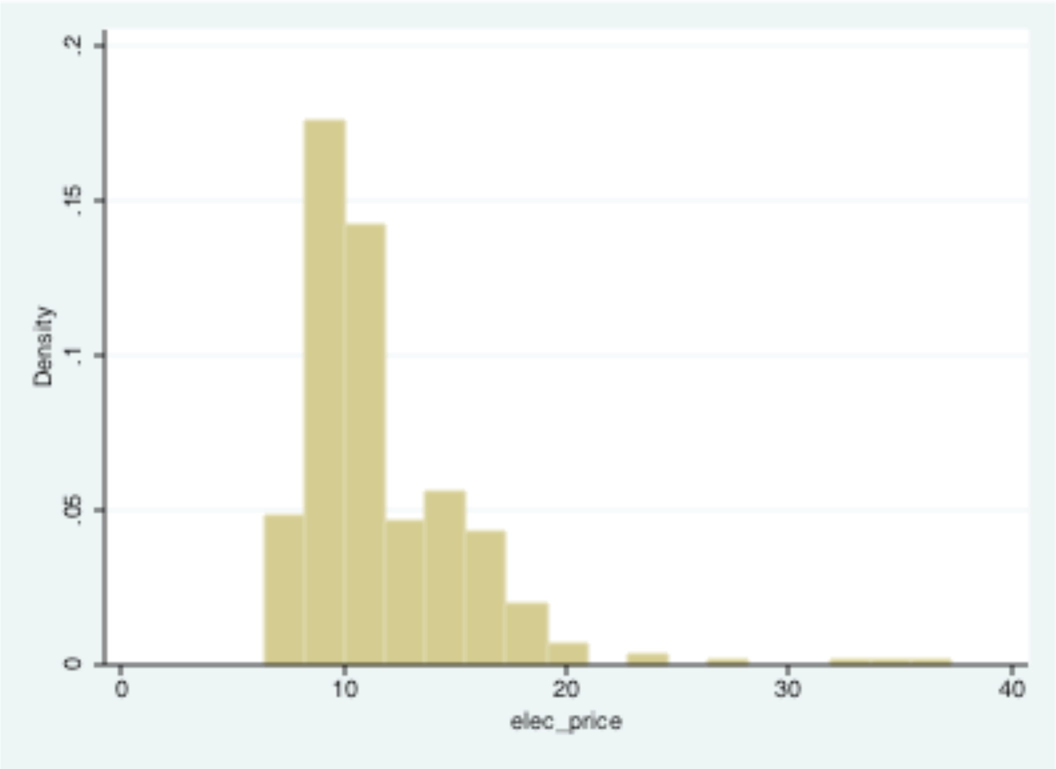


Figure 5.5: Frequency Distribution of Average Electricity Prices by State

A closer examination of electricity prices in individual years reveals a small, positive trend. Table 5.3 reveals that, on average, electricity prices appear to be rising over the entire time period, though by only a small amount. This trend continued even when electricity prices were transformed from nominal to real dollars using the 2012 CPI-U. Thus, the concern about electric price stability over time appears quite founded, though it may still prove to be significant in the quantitative model, even with limited variability. Also, it is important to remember that just because the mean value rises steadily over time does not mean that the individual values in each state exhibit the same trend.

Table 5.3: Summary Statistics of Real Electricity Prices by Year

Year	Mean Price (cents/kWh)	Standard Deviation	Minimum	Maximum
2007	10.73	3.543035	6.40	24.09
2008	11.57	4.362233	7.05	32.48
2009	11.66	3.579487	7.70	24.15
2010	11.88	3.702895	8.01	28.09
2011	12.19	4.182787	7.89	34.70
2012	12.38	4.356886	8.37	37.29

Solar Installation Price

A number of sources have pointed out that the price to install solar panels varies substantially over both time and geography. Accounting for the different price in different areas of the country is essential to understanding the adoption decision. Although some data was available for installation costs in every year of the study, the *Tracking the Sun VI* report did not have cost data for all states in any single year.

As a result, the cost data for some states had to be imputed using existing data. The number of available state data points in any given year ranged from 21 to 17. Using an average-value imputation method, the missing data points were replaced by the average cost of a solar installation in the given year. This technique preserves the average in any given year while also preserving the most likely trend in change of price over time.

After imputation, the average costs in dollars per watt of direct current were adjusted for inflation using the 2012 CPI-U as was done with the price of electricity. The new variable, *inprice_real*, was also examined for normality. In this case, the variable appeared more normally distributed than electricity price, though the large amount of imputation in some years ensured that the mean of the measured data was the mean in any given year.

Examining the descriptive statistics in each year of the study, Table 5.4 shows a steady year-over-year decline in the cost of solar installations (panels + modules + labor). This conforms to the generally accepted trends over the time period.

Table 5.4: Average Solar PV Installation Costs per Year, 2007 – 2012

Year	Mean Price ($/$W_{dc}$)	Standard Deviation	Minimum	Maximum
2007	10.39935	0.601013	8.415634	11.95906
2008	9.553851	0.4732205	7.891184	10.98368
2009	8.991737	0.5271087	7.063212	10.59482
2010	7.431842	0.4978103	5.791021	8.844469
2011	6.451206	0.8583499	5.205542	11.94213
2012	5.048973	0.3421243	3.9	5.9

Additionally, this trend matches what is known about the decline in the cost of solar equipment as a whole. Figure 5.6 plots the overall decline in installation costs from 2007 to 2011 against the decline in solar panel and solar module costs. Though they all follow the same general trajectory, the installation price decline does not reflect only the decline in the price of equipment. It is likely that at least some of the decline in cost is attributable to declining labor and soft costs that are possibly the result of increasing returns to scale as individual operations increase in size or a decline in price due to competition as more solar installers enter the growing market. Whatever the reason for the decline in price, the most important factor to keep in mind is that declining equipment cost is not the only contributing factor.

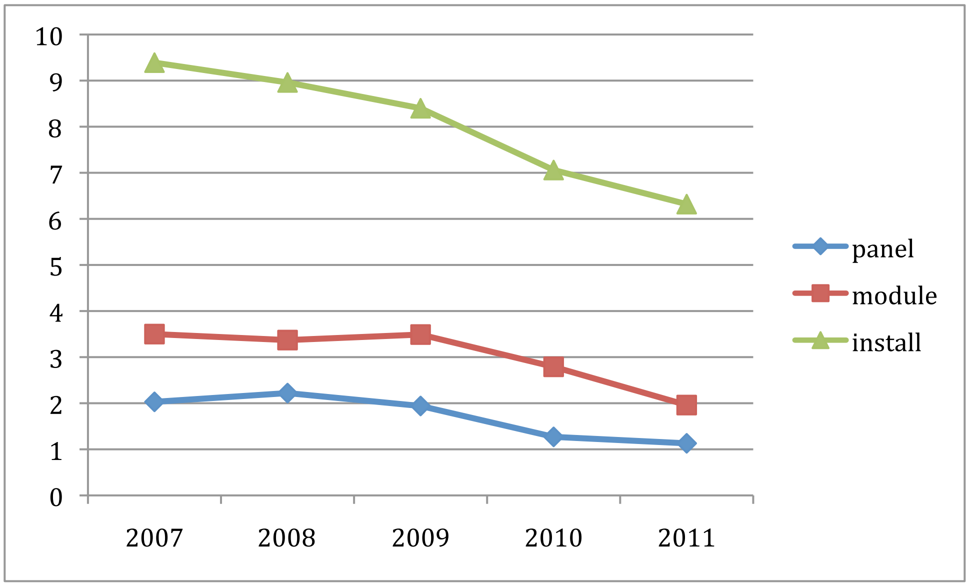


Figure 5.6: Average Price Trends for Solar Installations, Solar Panels, and Solar Modules

Income and Gross Domestic Property per Capita

State median income and gross domestic product per capita were both used as proxies for wealth. Both variables had values approaching a normal distribution with the median only slightly lower than the mean. According to Table 5.2, the two variables have substantially different distributions with GDP per capita having a substantially larger variance and a much wider range of values. This difference could be explained by the fact that GDP includes all economic output from all sectors while income might make a better explanation of economic conditions in the residential sector. Still, the reliance of previous studies on GDP as a critical significant explanatory variable justifies its inclusion in the model.

Both income and GDP per capita values were transformed into real 2012 dollars. They were also transformed using the natural logarithm in order to make them interpretable as elasticities. These transformations did not substantially change their distributions, which remained normal though it did decrease the power of outliers for GDP like the District of Columbia.

Demographics: Age, Education, Race, Urbanization, and Renting

All of the demographic variables used in this study were obtained from estimates calculated in the U.S. Census Bureau American Community Survey except the values for 2010 that were population parameters measured by the decennial census. All of the variables are measured as percentages of the adult population of each state.

Because this study is most interested in capturing the age groups that are at or near the peak of the life cycle consumption curve, age variables were created for three deciles: 25 to 34, 35 to 44, and 45 to 54. Table 5.2 shows that aside from difference in the range of values, each variable exhibits similar values for mean and standard deviation.

Race measurements were captured for the percentages of African-American (*race_black*) and Hispanic (*race_hisp)* adult residents in each state. Because these values were taken at the state level, the mean percentages differ substantially from the actual percentages of the population for Hispanics. Because many states have little or no Hispanic population, the mean of 10 percent overinflates the value of small-population, low-Hispanic states while the actual Hispanic population of the United States is around 30 percent. The same thing is true of the African-American population even though it is not reflected in the mean state value, likely because African-American populations are more widely dispersed across the states.

Education was measured as the proportion of the population of a state with at least a college degree (bachelor's). Urbanization was defined as the proportion of the state population that lives in urban areas, as defined by the Census Bureau. A variable was also created to capture the proportion of the state population that rents as opposed to owns their living quarters. It is likely that renters will have a more difficult time obtaining solar panels since they cannot make significant structural changes to the property and because the time they spend in the average domicile is typically shorter than home owners.

It is important to point out that the District of Columbia is an outlier and a maximum value for many of these demographic variables including education, African-

Americans, urbanization, and rental properties, and in some cases by a substantial proportion. The degree of influence of the District of Columbia should be diminished when the values are transformed into logarithmic values, but it should be considered that DC is an outlier beyond the characteristics of its government.

Environmentalism and Conservatism

As mentioned in the previous chapter, environmentalism and political conservatism were both measured using congressional member scorecards from the League of Conservation Voters and the American Conservatives Union. Therefore the measure for each state is an average of the scores of the state's delegation to the House of Representatives. Because the District of Columbia has no voting member in the House of Representatives, no score exists for this political unit. Therefore, a value was imputed using the average value of all Democratic Party members in each year. Both variables range from 0 to 100 with means around 50. The mean for conservatism was around 43. This lower mean value indicates that the ACU might be more stingy in awarding high marks for conservatism or it could indicate a natural lean towards liberalism in the years measured. During the time period of the study, Democrats controlled the House of Representatives from 2007 through 2010 while Republicans held control for 2011 and 2012. As with the other variables, these were transformed into logarithmic values.

Insolation

Insolation, or average daily solar radiation, data were obtained from the National Solar Radiation Database. The values are measured for flat pane, concentrating collectors. For each state, average values were calculated from all locations within the state. Some of these locations include actual measurements of insolation while others are estimates constructed from historical data. The unit of measurement is in watt-hours per meter squared (Wh/m^2). The distribution of the average values was relatively normal though logarithmic transformations were still conducted to provide elasticities.

5.3 Market Characteristics

The market for solar photovoltaic installers in each state has also been theorized to have an effect on the number of installations and the installed capacity in each state. This study examines several variables that attempt to take these market factors into account despite the fact that they are absent in most other studies in this area. The descriptive statistics for each variable are included below in Table 5.5 including measures for marketing effort, the number of installers located in the state, and the presence of a competitive green power option. The first and most complicated of these variables is marketing effort.

Table 5.5: Descriptive Statistics for Solar PV Market Characteristics

Variable	**Mean**	**Median**	**Standard Deviation**	**Minimum**	**Maximum**
marketing	3.2	3.0	1.55	1	6
installers	40	21	70.12696	1	481
utility_support	2.879	1	5.064349	0	23
gpo	0.1405229	0	.348098	0	1

Marketing Effort

In the context of this study, marketing effort is conceptualized as the effort taken by governments to communicate the details of their solar PV incentive programs to the public. However, finding a valid and reliable operational measurement of this construct proved exceedingly difficult. Originally, budget filings of state energy departments were examined to determine spending on marketing and advertising, but these numbers were often subsumed into larger categories of additional spending or completely unavailable. Additionally, the Solar Energy Industry Association was contacted and asked if they tracked any information on the marketing of solar incentive programs in states, but they did not have any publicly available data on the subject.

Ultimately, the decision was made to use the content of state department of energy websites as a proxy for marketing effort. The use of this variable requires the underlying assumption that marketing efforts that occur online are indicative of off-line marketing efforts. In the current environment, marketing best-practices include multi-channel marketing efforts where messages are disseminated on multiple platforms. Thus, the presence and prominence of information about solar incentives on the website of the agency responsible for administering the program should provide an indication that the agency put a higher level of effort into communicating the details of the programs to the public than an agency that either did not include the information on its website or did not display that information prominently. It is fully recognized that this measure is not a perfect proxy for marketing communication effort and may suffer from issues of both reliability and construct validity. However, it was the best available measure of the underlying construct for this research study and provides some new information where none previously existed.

The variable for marketing effort required a separate data collection. Fifty government agency websites were analyzed and coded on the basis of how prominent information about solar incentives was featured on the webpage. The number of nested pages required to pass through to obtain information about at least one incentive program was coded for every state. The beginning of the marketing effort was assumed to begin upon the effective start date of the first incentive program enacted in the state. It is important to point out that it is impossible to glean from this data the exact start date of marketing efforts.

The scale of the marketing effort variable ran from 1 to 6. In this case, a coding of 1 indicates that the solar incentive program was specifically mentioned or described on the agency's homepage. This placement is theorized to correspond to the high level of importance placed by the agency on marketing and communicating the existence of the incentive program. The maximum number of webpages on any state agency website necessary to navigate through to find some sort of information about solar incentive programs was 5. State agencies' websites that contained no information about solar programs were coded as 6. Additionally, states where no incentive programs exist were also coded as 6.

Thus, the scale of the variable runs toward lower marketing effort as the number coded increases in value, a critical fact to remember when interpreting coefficients in regression models. Moreover, despite being a count variable, the variable ought to be interpreted as ordinal meaning that every additional nested page should not be interpreted as signifying a standard interval of marketing effort, only somewhat less than the previous number. Figure 5._ shows the frequency distribution of the marketing effort variable. While the mode is 2, the mean falls between 3 and 4 (3.2). Generally, this indicates that marketing efforts across the board were strong. In states with solar incentive programs, information could typically be found on the agency's homepage or within 1 click.

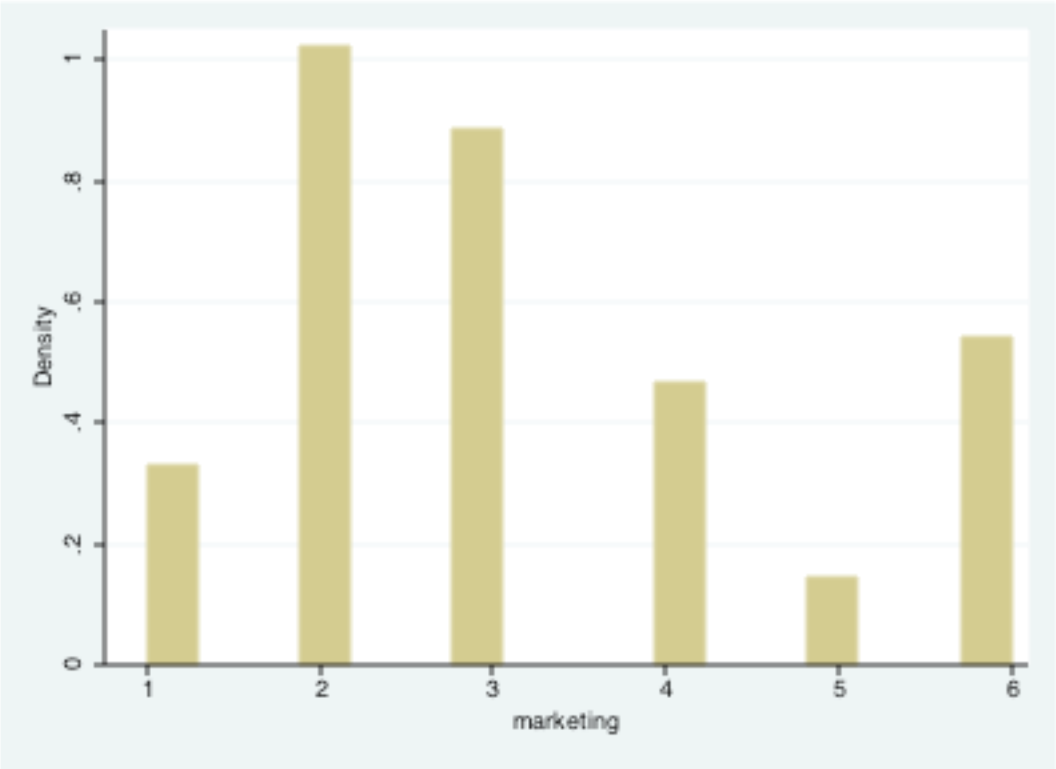
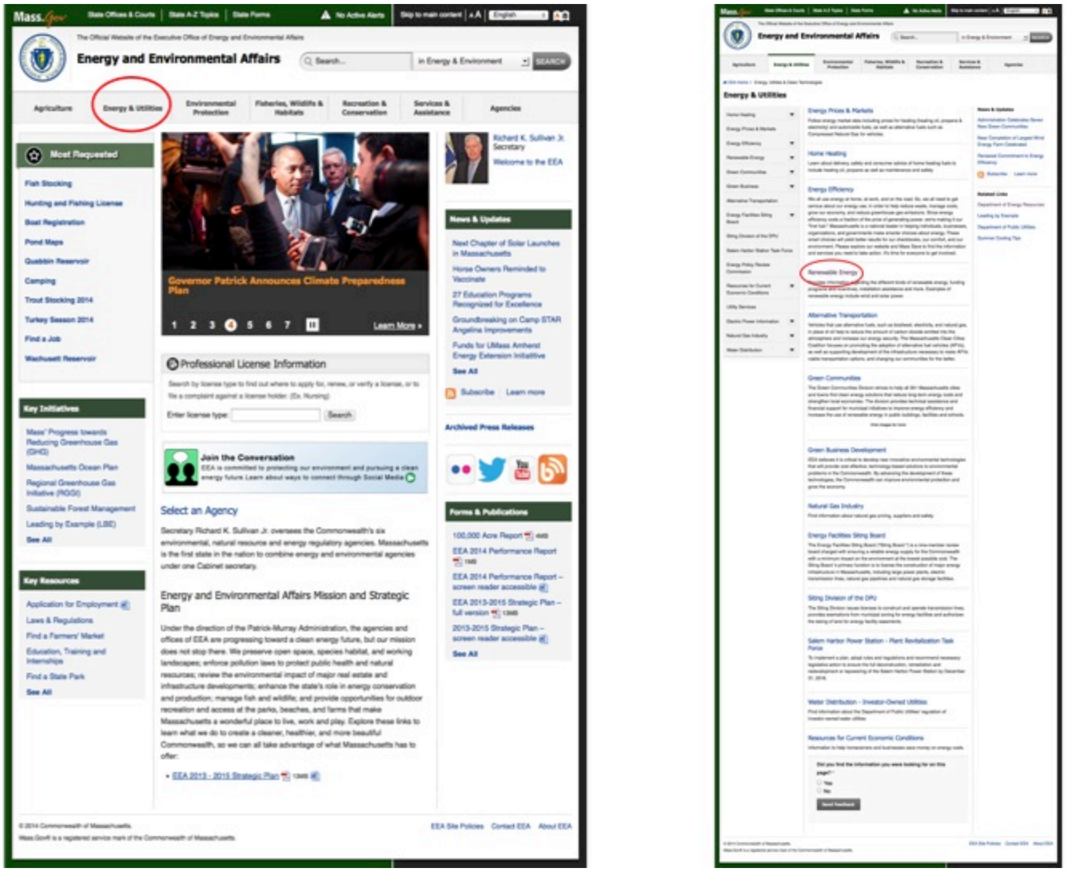


Figure 5.7: Frequency Distribution of Marketing Effort in All Years, 2007 - 2012

Still, there were clearly some laggards that required more that three clicks to find any information on their solar incentive programs. In some cases, such as that of Massachusetts, this might not necessarily be an indication that the state agency responsible for the administration of the incentive program is not favorable to renewable energy. Figures 5._ and 5._ show pages 1 through 4 of the website for the Massachusetts Department of Energy and Environmental Affairs. In this case, there are many mentions of climate change and renewable energy throughout all the pages of the website, but the first mention of a specific solar incentive does not occur until page 4. This measure still implies that Massachusetts does not place more marketing effort toward their solar incentives than other environmental and climate change mitigation programs but should not be construed to imply that they made no effort to publicize solar PV incentives.



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Search by license type to find out where to apply for, renew, or verify a license, or to file a complaint against a license holder. (Ex. Nursing)

Enter license type: Search

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EEA is committed to protecting our environment and pursuing a clean energy future. Learn about ways to connect through Social Media

Select an Agency

Secretary Richard K. Sullivan Jr. oversees the Commonwealth's six environmental, natural resource and energy regulatory agencies. Massachusetts is the first state in the nation to combine energy and environmental agencies under one Cabinet secretary.

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Under the direction of the Patrick-Murray Administration, the agencies and offices of EEA are progressing toward a clean energy future, but our mission does not stop there. We preserve open space, species habitat, and working landscapes; enforce pollution laws to protect public health and natural resources; review the environmental impact of major real estate and infrastructure developments; enhance the state's role in energy conservation and production; manage fish and wildlife; and provide opportunities for outdoor recreation and access at the parks, beaches, and farms that make Massachusetts a wonderful place to live, work and play. Explore these links to learn what we do to create a cleaner, healthier, and more beautiful Commonwealth, so we can all take advantage of what Massachusetts has to offer:

- EEA 2013 - 2015 Strategic Plan

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Figure 5.8: Pages 1 and 2 of the Massachusetts Department of Energy and Environmental Affairs Website

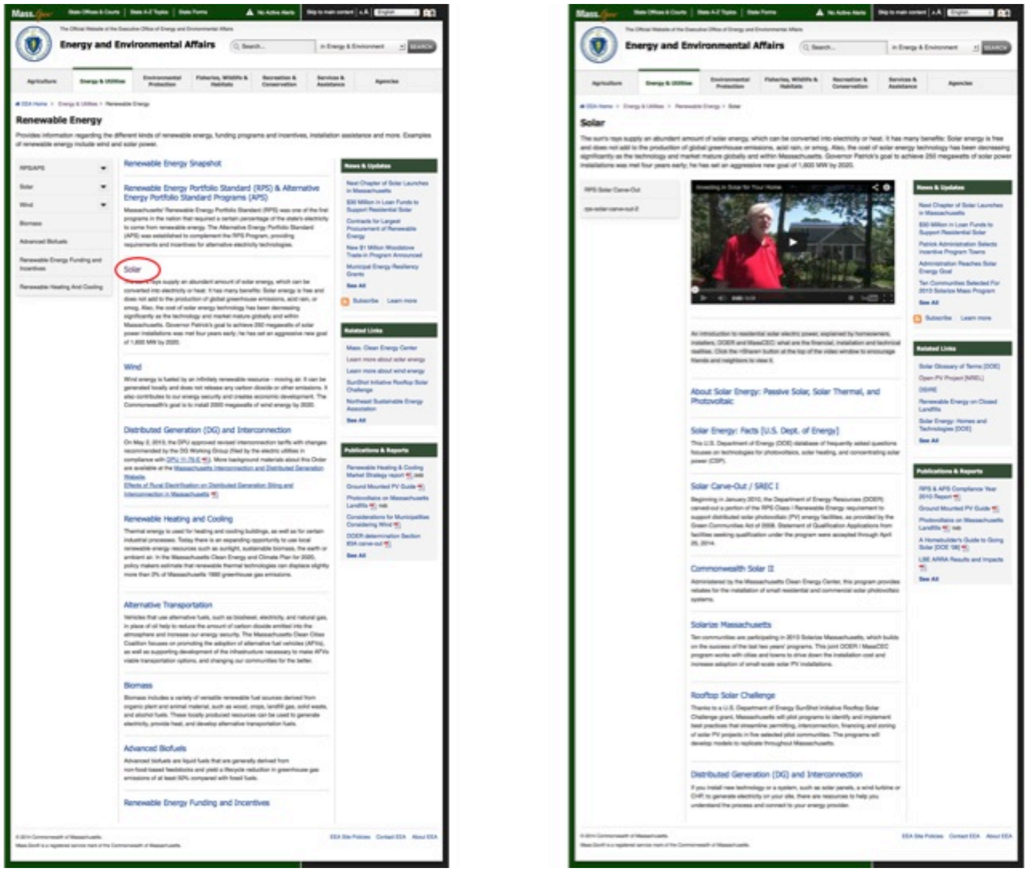

Figure 5.9: Pages 3 and 4 of the Massachusetts Department of Energy and Environmental Affairs Website

Lastly, because the variable assumes marketing effort to be constant over time once a program has begun, the only variation over time will be due to the creation of the state's first program. Therefore the presence of time effects will specifically capture the effect of going from zero programs to the current level of marketing efforts. While this data might invite some interesting speculation, it should not be used to draw any definitive conclusions about either the power of marketing efforts or the introduction of incentive programs. Instead the value of this variable lies primarily in cross-state comparison.

Number of Installers

The next important market characteristic is the number of solar installers located within a state. While this number varied substantially by state running from 1 in states like Nebraska to 481 in California, many states have very few installers. Still, it is important to standardize this measure on the basis of a state's population. Because of the large difference between the number of installers and the number of residents in a state, the variable for solar installers per capita was calculated per 100,000 residents.

The variable for solar installers per capita, as with the variable for installers, was highly positively skewed and likely non-normally distributed. As with most of the other variables in this study, this variable was transformed using the natural logarithm. Figure 5.10 reveals that this transformation corrected for both the skew and the normality.

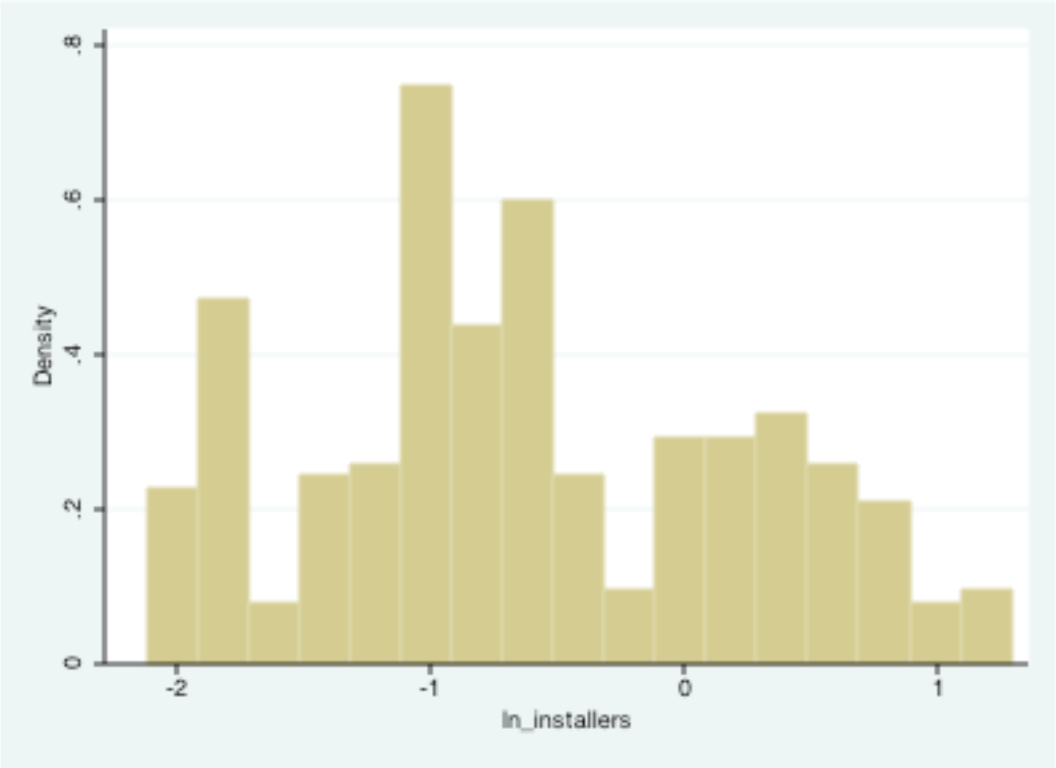

Figure 5.10: Frequency Distribution of the Natural Logarithm of Solar Installers per 100,000 Residents

Utility Support

A variable measuring utility support for solar programs was generated by counting the number of utilities within a state that sponsored their own solar incentive program. In 142 of the 306 cases, no utilities had solar programs of their own. Of the states were utilities were supportive of solar electricity, the number of utilities offering programs varied widely. For instance, Illinois has only one utility that offered a solar incentive while California has 23. Because of the large number of zero values in a continuous variable could skew coefficients in a regression model, the variable was recoded as a dummy variable indicating the presence or absence of supportive utilities within the state.

Mandatory Green Power Option

Finally, many states have mandated that utilities offer customers an option to purchase their electricity from green power sources at a premium rate. This study treats the presence of a green power option as a prominent source of competition for solar power, particularly for those whose motivation is ideological instead of economic. Instead of baring the upfront cost and effort of placing solar panels on their roofs, utility customers can add a small premium to their bill and force the utility to bare the cost of finding or generating electricity from a renewable source.

This variable is a dummy variable noting the presence of a statute requiring all utilities within a state to offer a green power option. Only one state, Maine, passed a mandatory green power option law during the time frame of the study. The remaining states remained constant. In fact, seven states, excluding Maine, have mandatory GPOs. Those include Colorado, Iowa, Montana, New Mexico, Oregon, Virginia, and Washington.

5.4 Policy Variables

The solar photovoltaic incentive policies varied substantially from state to state and over time. The presence of each policy was coded as a dummy variable, and then additional details about each policy, such as the amount of incentive available for a 5 kW solar system, were also coded. Table 5.6 shows the total number of states that instituted each type of program at some point between 2000 and 2012.

Table 5.6: List of Solar Incentives by States 2007 to 2012

Incentive Type	**Total States with Incentive Program**
Performance Based Incentives (pbi)	16
Feed-in Tariff (fit)	8
Renewable Energy Credit (srec)	8
Rebate (rebate)	14
Income Tax Deduction (income_tax)	17
Property Tax Exemption (property_tax)	26
Sales Tax Exemption (sales_tax)	16
Loan Program (loan)	13
Grants (grant)	3
Net Metering (net)	46
Renewable Portfolio Standards (solar_ rps)	19*

*These are the 19 states with a specific solar carve out. 8 additional states have an RPS program that doesn't contain a specific solar carve out.

The single most popular incentive program to induce individuals to adopt solar power is net metering. This finding makes sense because it costs the states very little to implement and maintain. Often, utilities are required to absorb the cost of upgrading net metering customers to two-way meters, and they also bare the responsibility of paying customers for excess generation. Many of these net-metering policies have been in place since the energy crisis of the 1970s. Even when utilities oppose them, the legislative fix involves adjusting the payment rate or imposing fees for participation (See Arizona and Oklahoma for recent examples) rather than repealing the programs all together.

At the opposite end of the spectrum, grants are the least popular incentive mechanism with only three states having active grant programs. In a way, grants represent to opposite of net metering with the state baring the entire cost of the program. Grants differ only slightly from rebates in that the amount granted is usually predetermined and often upfront while a rebate is typically based on the size of the system or its expected energy production and payments are often spread out over multiple years once the solar panels are installed and operational.

While 27 states have some sort of performance-based incentive, this variable represents a wide range of programs. Thus, two additional variables were coded to identify the two most popular types of performance-based incentive programs. The first identifies states with state-sponsored feed-in tariff programs. Feed-in tariffs allow customers with solar PV systems to sign long-term contracts (10 to 20 years) to supply power at a rate usually above market rate. The second common performance-based incentive is the Solar Renewable Energy Credit. Several states allow residents with solar PV systems to obtain renewable energy credits, which can be sold on the open market to power producers in order to meet their requirements under renewable portfolio standards or other pollution control measures within the state. The price of the credit fluctuates like in any other market, so their main difference from feed-in tariffs is the presence of a high degree of uncertainty about their long-term payback potential.

Once the presence of each policy was accounted for and its potential value calculated, two additional variables were created to measure the total number of incentives in each state (*total_policy*) and the total yearly aggregate value of the incentives available in each state (*total_incentive*). The *total_policy* variable accounts for the nine direct incentives examined in this study (net metering, feed-in tariffs, solar renewable energy credits, rebates, income tax, property tax, sales tax, loans, and grants). The presence of renewable portfolio standards was not included because they are an indirect incentive not directly applicable to the individual consumer. Instead, they often apply to utilities, governments, and markets for renewable energy as a whole.

The average number of policies in each state for each year was 2.4. The *total_policy* variable ranged from 0 to 7, with fours states having no policy incentives for solar photovoltaics and one state having 7 of the 9 possible policy incentives. The distribution of the variable can be seen below in Figure 5.11.

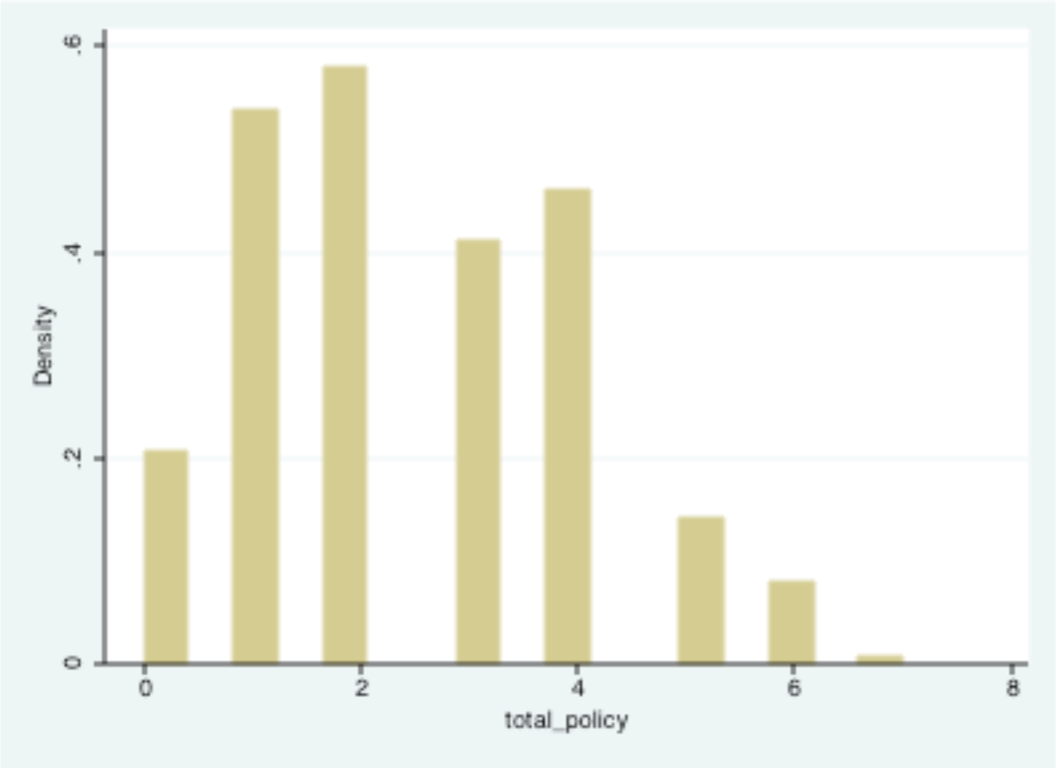

Figure 5.11: Distribution of All Solar PV Incentive Policies Across All States

The total value of incentives ranged from $0 to slightly over $22,000 with a mean value of $3043.99. The total value of each state's incentive programs should be interpreted with caution for a number of reasons. First, they are estimations using an average value for system size and tax rate. For instance, the value of the income tax incentive is estimated using the median income tax rate for states with a progressively tiered system. The actual amount available will vary based on the circumstances of the individual as well as the size of solar PV system they choose.

Second, some incentive values were impossible to calculate because of the nature of the incentive statute. For example, Illinois's property tax incentive provides a special assessment for qualifying solar systems including water heaters and photovoltaics worded as follows:

> "Illinois offers a special assessment of solar energy systems for property-tax purposes. For property owners who register with a chief county assessment officer, solar energy equipment is valued at no more than a conventional energy system. Eligible equipment includes both active and passive solar-energy systems. The exemption is not valid for equipment that is equally usable in a conventional energy system or for components that serve non-solar energy generating (e.g., structural, aesthetic, insulating, etc.) purposes."
>
> (DSIRE, 2013)

The assessment based on the value of "conventional" equipment makes sense in the case of a solar water heater because the price of a conventional analog is easy to find. However, it is unclear what the conventional version of an electricity-generating piece of equipment would be. Would it be the equivalent of a backyard, gas-powered generator? Is a natural gas generator conventional or alternative? In the cases where the vague wording of the statute prevents an incentive estimate, the value of the incentive is set at zero in order to underestimate the total incentive value. This conservative approach seems like the most prudent course of action, though may unduly limit the explanatory power of the *total_incentive* variable.

5.5 Summary

With all of the variables cleaned and properly transformed, multiple variable models can now be generated to determine the relative effect of each individual variable and test hypotheses proposed in Chapter 3. The next chapter will explain the results of a number of different models while the following chapter will explain whether these results support the hypotheses presented earlier and how they fit into the overall context of the problem of solar PV adoption.

6. Research Results

6.1 Introduction and description of approach

After examining each individual variable and transforming when necessary, they were grouped into 51 panels (50 states and the District of Columbia) over 6 years (2007 – 2012). Then, panel regressions were run to determine the relationship between different groups of independent variables and the primary dependent variable, installations per capita. Two additional dependent variables were considered as robustness checks, installed capacity per capita and installations per occupied housing units.

Table 6.1 shows that each of these variables is highly positively correlated. In fact, installations per capita and installations per occupied housing units are almost perfectly correlated. Their similarity makes it unlikely that results of regression models will differ substantially; thus, installations per occupied housing unit was not used in further models. Capacity per capita, on the other hand, was strongly positively correlated with installations per capita ($r = 0.6603$), though not perfectly correlated. While both measures might rise as more individuals adopt solar PV technology, the capacity measure captures not only the adoption choice but also the size of system choice. As mentioned in the Chapter 4, many previous studies have used capacity or market share as dependent variables; therefore, comparing results between installations per capita and capacity per capita will add extra weight to these results and provide an important link to previous research.

Table 6.1: Correlation between Dependent Variables of Interest

	Installations per Capita	**Capacity per Capita**	**Installations per Occupied Housing Unit**
Installations per Capita	1.0000		
Capacity per Capita	0.6603	1.0000	
Installations per Occupied Housing Unit	0.9997	0.6568	1.0000

Spatial Distribution of Installation and Insolation

Installations of solar photovoltaic systems vary widely across the United States. Figures 6.1 and 6.2 show the state-by-state distributions of residential solar PV systems for the entire study period from 2007 to 2012. When the raw numbers of installations are examined, it seems that states with many residential PV systems are spread throughout the country, particularly in the Sun Belt stretching from the desert of southern California to the Gulf Coast. However, controlling for the state population by mapping installations per capita paints a slightly different picture.

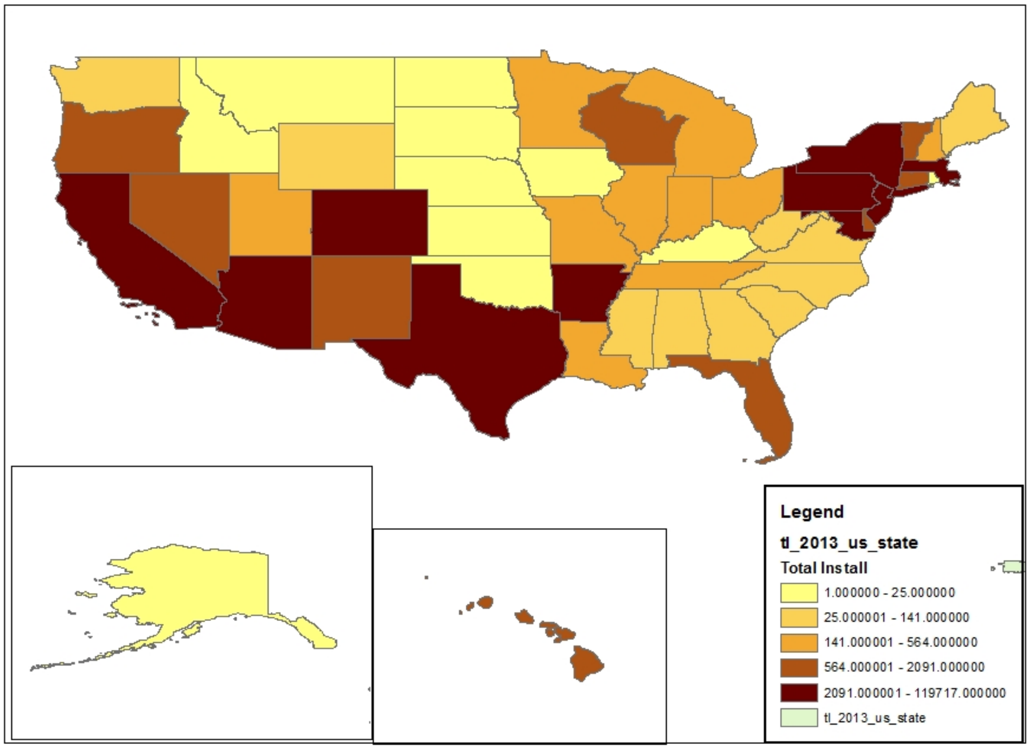

Figure 6.1: Solar Photovoltaic Installations per State

Once population is taken into account, two regions become the obvious epicenters for solar PV installation activity. The first is the desert southwest including California, Arizona, and New Mexico. With abundant solar resources and little precipitation, this area has ideal environmental characteristics to support solar PV deployment. The second main installation area encompasses New England and the Mid-Atlantic regions. In contrast to the Southwest, this area is not considered ideal for solar deployment. There are frequent rainy days with substantial cloud cover, limiting the average solar radiation especially during the fall and winter. Winter months are have even less sunshine because the sun sets at an earlier time in the high latitudes. Figure 6.3 maps the average solar radiation by state according to the National Renewable Energy Lab's National Solar Radiation Database.

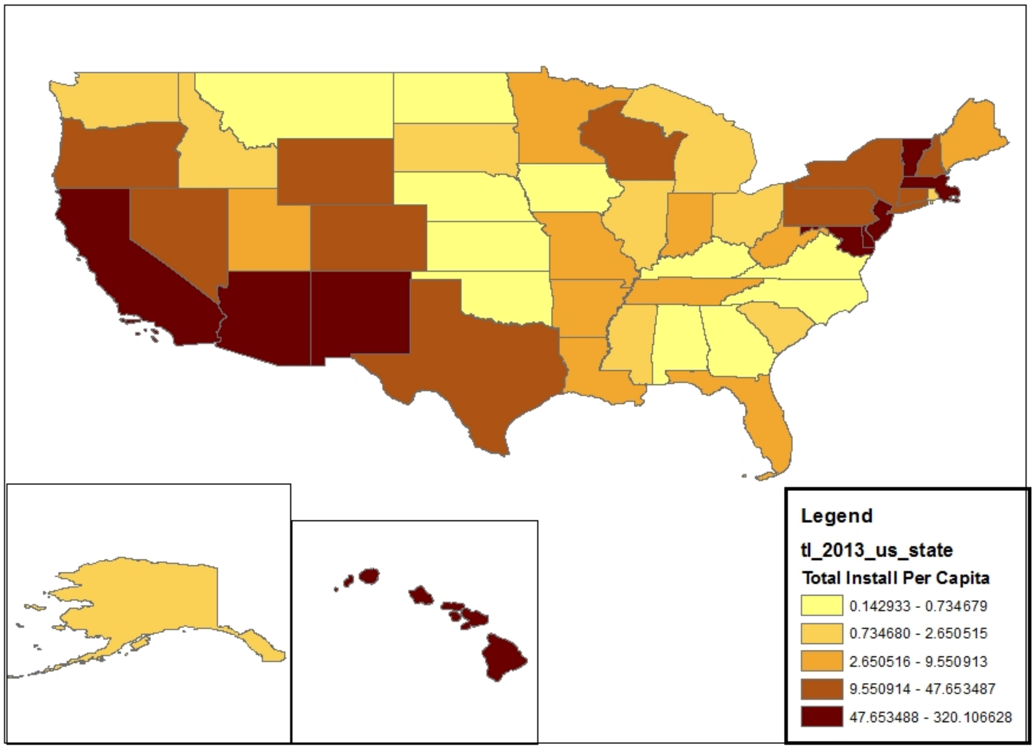

Figure 6.2: Per capita Solar Photovoltaic Installations per State

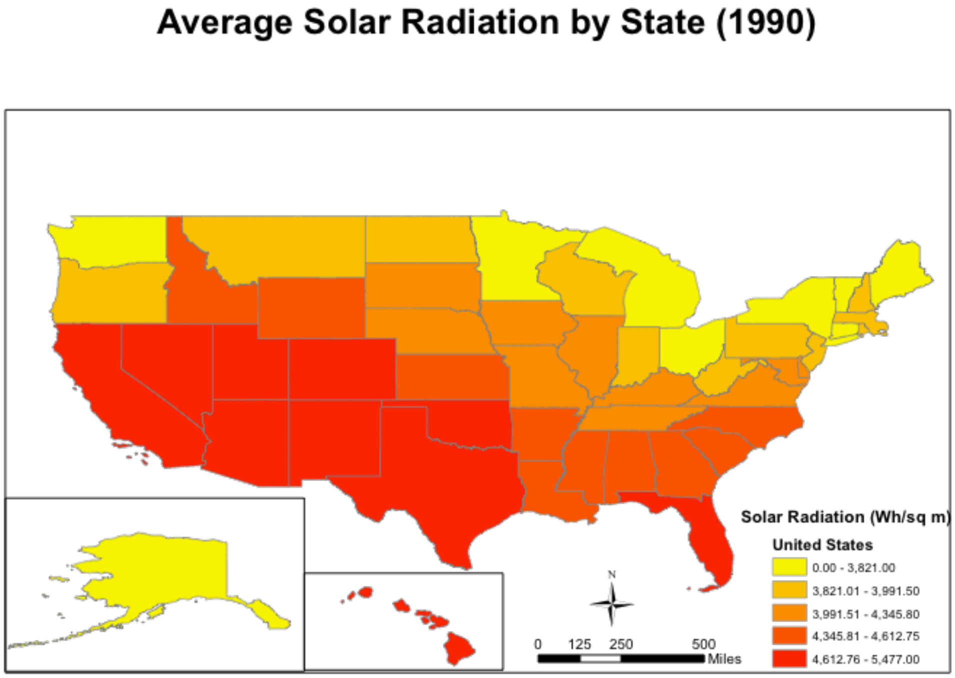

Figure 6.3: Average Solar Insolation (Wh/m^2) per State (1961 – 1990)

Two things immediately pop out when comparing the solar radiation map to the installations per capita map. The northeastern United States has low solar radiation but high solar PV installations per capita, and the southeastern United States has high solar radiation but low installation rates. More importantly, a cursory look at the solar radiation map reveals that insolation itself does not explain the spatial distribution of solar photovoltaic arrays. One potential reason that the Northeast has high installation rates while the Southeast has low installation rates is that many of the New England and Mid-Atlantic states belong to the Regional Greenhouse Gas Initiative (RGGI), an organization of states with a tradable permit system allowing renewable energy producers to obtain and sell credits for the electricity they generate from renewable sources. However, this is only one possible reason. These states might also offer valuable financial incentives that lower the cost a solar PV system to the extent that the consumer can make a financial profit despite the limited solar radiation. The only way to definitively investigate these speculative conclusions is to analyze data about solar installations in a multiple variable model. The following sections contain the results of several quantitative models testing many of the previously stated propositions.

6.2 Model 1: Policy Variables

Model 1 considers only the effect of policy variables on the solar adoption both in terms of the installations per capita and the capacity per capita present in each state for each year. The purpose is to establish a baseline explanatory power that each policy variable has over installations and how much additional explanatory power is added to the subsequent models by including economic, socio-demographic, and market characteristics. Because the previous work in this area clearly shows that solar PV installations are influenced by factors beyond financial incentives, some of which vary over time and others that are time invariant, this initial model was constructed as a fixed effects model to avoid omitted variable bias.

Table 6.2 compares the results for several different specifications of Model 1. The first two specifications use installations per capita as the dependent variable while the last two use installed capacity per capita. The models also differ in that two examine the presence or absence of each policy individually while the other two examine the effect of the total number of policy incentives offered by each state. The fixed effects in the model control for differences between states that do not vary over time. This fixed effect includes, among other things, differences in solar radiation (insolation) between the states, though it is impossible to evaluate the explanatory power of insolation through this type of panel model.

Table 6.2: Model 1 - Effect of Policy Presence

	ln_installpercap	***ln_installpercap***	***ln_capacitypercap***	***ln_capacitypercap***
net_meter	1.046 (0.448)*		0.285 (0.166)^t	
rebate	1.934 (0.904)*		0.650 (0.142)***	
income_tax	0.140 (0.483)		-0.029 (0.089)	
property_tax	1.162 (0.301)***		0.511 (0.184)**	
sales_tax	-0.923 (0.687)		0.365 (0.295)	
loan	-0.958 (0.418)*		-0.414 (0.106)***	
grant	2.845 (0.884)**		1.214 (0.226)***	
rps2	0.357 (0.484)		-0.035 (0.145)	
solar_rps	-0.225 (0.834)		0.242 (0.202)	
fit	-0.310 (0.597)		-0.033 (0.159)	
srec	0.431 (0.810)		0.362 (.123)**	
total_policy		0.675 (0.239)**		0.290 (0.075)***
R^2 *(within)*	0.2410	0.1209	0.3132	0.1892

[1] t = $p<0.05$, one-tailed; * = $p<0.05$, two-tailed; ** = $p<0.01$; *** = $p<0.001$

Initially, Model 1 reveals four individual policies that explain the variation in installations and capacity at the state level: net metering, rebates, property tax exemptions, and grants. Because the independent variables are dummy variables while the dependent variable is log transformed, the interpretation of the coefficients requires the application of a formula. Giles (2011) indicates that the interpretation of a dummy variable in a semi-logarithmic model can be given by the formula 100[exp(β) – 1]. Therefore, as x goes from 0 to 1 for net metering, the dependent variable increases by 177 percent. In other words, the average increase in installations per capita of solar photovoltaic systems that can be brought by introducing a net metering policy is 177 percent. This positive effect can also be seen at different levels from rebates (602 percent), property tax exemptions (206 percent), and grants (1664 percent). Overall, the policy variables explained 23.72 percent of the variance in installations per capita. As theory would suggest, there appear to be many additional variables that explain the installation of solar photovoltaics in the residential sector.

A comparison to the capacity per capita specification reveals two additional policies that might be effective at influencing changes in capacity: loans and solar RPS carve outs. Loan programs have a negative effect on capacity levels while solar RPS carve outs have a weak positive effect. Still, the most important comparison between the two models is that all of the variables from the installation model remained significant in the capacity model.

Additionally, for both installations and capacity the total number of policy incentives offered by a state appears to be significant. In the case of installations per capita, every additional policy incentive program corresponds to a 67.5 percent increase. The total number of policy incentives also explains 12.09 percent of the variance in installations per capita.

Instead of relying solely on dummy variables as the only way to explain the effect of policy on solar PV installations, Model 1 specifications were also created using continuous variables. Most of these variables account for the expected value of each incentive for a 5 kW solar PV system. These include a dollar-value amount for rebates, income tax credit, property tax exemption, sales tax exemption, grant amount, feed-in tariff amount, and the value of the sale of solar renewable energy credits. Non-monetary continuous variables that account for indirect policies including net metering and renewable portfolio standards were also included. For net metering, these continuous variables included any cap on size of a system that can be eligible for net metering (*nm_size*) and any aggregate capacity limits (*acl*), essentially a cap on the amount of electricity that can be net metered in a given time period. Distinctions in renewable portfolio standards were accounted for by three variables including the duration of the standards (how long the state has to reach its goal) and the yearly and total targets for added capacity.

Accounting for the value of a loan program presented a number of difficulties. First of all, while loans provide up-front financing for solar equipment, they by nature require the installer to pay more than market price for the installation once interest payments are factored in. At best, these loan programs provide a subsidized interest rate that offers savings over loans obtained on the open market. Additionally, interest rates vary not only by time and state but also lending institution. It was virtually impossible to determine what rate most individuals are receiving at any given time. Therefore, no continuous variable could be computed for loan programs.

As with the dummy variable specifications, rebates, property tax incentives, and grants were statistically significant. A one percent increase in the amount of rebate offered corresponded to a 0.25 percent increase in installations per capita. The increase in installations from a property tax exemption was slightly less at 0.19 percent while grants were slightly higher at 0.33 percent.

Although the maximum size limit of the net metering system was not significant, the aggregate capacity limits were significant. An increase in capacity limit of one percentage point corresponds to a 246 percent increase in installations per capita. The duration of the renewable portfolio standards policy was the only additional variable that was statistically significant in the capacity specification. Each of these specifications explained between seven and 18 percent of the variance in their respective dependent variables, again indicating the necessity of adding additional explanatory independent variables.

Table 6.3: Model 1 – Effect of Policy Incentive Level on Installations and Capacity

	ln_installpercap	***ln_installpercap***	***ln_capacitypercap***	***ln_capacitypercap***
ln_rebate	0.240 (0.115)*		0.067 (0.020)**	
ln_incometax	0.023 (0.084)		-0.032 (0.018)^{t}	
ln_propertytax	0.174 (0.067)*		0.077 (0.034)*	
ln_salestax	-0.144 (0.098)		0.025 (0.039)	
ln_grant	0.257 (0.086)**		0.085 (0.016)***	
ln_fit	0.023 (0.095)		0.019 (0.028)	
ln_srec	0.023 (0.107)		0.039 (0.023)^{t}	
nm_size	0.004 (0.009)		0.010 (0.006)	
acl	1.247 (0.518)*		0.585 (0.122)***	
rps_duration	0.016 (0.057)		0.012 (0.016)	
rps_target	5.325 (11.962)		-6.923 (7.167)	
rps_yearlytarget	-11.884 (19.082)		15.084 (12.747)	
ln_incentive		0.059 (0.053)		0.015 (0.018)
R^2 *(within)*	0.2068	0.0048	0.3615	0.0026

[1] t = p<0.05, one-tailed; * = p<0.05, two-tailed; ** = p<0.01; *** = p<0.001

Taking the entire model into account, it is also important to point out that this assortment of policy variables explained more of the variance in capacity per capita than in installations per capita in three of the four model specifications. For example, in the specification where policy programs are measured as dummy variables, the same set of policy variables explained 31.32 percent of the variance in capacity per capita compared to only 24.10 percent of the variance in installations per capita. This result was repeated in the total policy and the individual policy amount model specifications. While it is not detrimental to the purpose of this study, these results provide an indication that policy-related factors might better explain variation in capacity than variation in individual adoptions. However, making that determination is beyond the scope of this study.

Although Model 1 was created with the knowledge that its explanatory power would be limited and that significant policy covariates may change as additional independent variables are included in subsequent models, it was still a valuable exercise to examine just the effect of the policy incentives to establish a baseline by which to judge the additional models and their specifications. If one looked exclusively at the differences in public policy, the results they would find would be those that are above, but will these results hold once economic, demographic, and market factors are included?

6.3 Model 2: Policy Variables with Economic and Socio Demographic Data

The previous model provides an initial indication of the individual types of policies that might be significant in the residential sector and that these policies likely explain some portion of installations and capacity per capita. However, the explanatory power of the model is weakened by the fact that it does not control for exogenous factors which are theoretically and empirically known to influence solar adoption behavior. After accounting for the explanatory power of policy variables alone, I subsequently added sets of covariates in two stages according to the model theoretically laid out in Chapter 4. These additional covariates fit into three broad categories including economic, socio-demographic, and market variables. By adding different categories of variable in waves, I hope to evaluate the sensitivity of the policy variables to different influencing factors.

The first additional data included in the policy model correspond to critical economic factors theorized to drive solar PV adoption. For this model, four specifications were run (a – d), differing solely on the dimension of how policy is accounted for in the model. Specification 2a accounts for policy incentives using the individual policy dummy variables while specification 2b uses only the total number of policy incentives. Specifications 2c and 2d instead use continuous variables for the policy measures with 2c accounting for each policy individually and 2d using only the aggregate amount of incentive available in a given state. Each subsequent model follows the same structure. Initially, each specification included all variables in the category (economic, demographic, and market), but the model was refined in subsequent iterations to provide the highest possible level of explanatory power. Therefore, not all variables are in every specification; however, all coefficients are included in the tables below if the variable contributed explanatory power to the model but was not itself statistically significant.

From Model 1 to Model 2, the significance of the policy variables was generally consistent. In specification 2a, the same five policy dummy variables from Model 1 remained statistically significant but dropped somewhat in their overall effect on the dependent variable. Net metering, rebates, property tax exemptions, and grants all showed positive, statistically significant relationships with installations of residential solar PV systems. Additionally, the presence of a state-sponsored loan program was also significant but in the negative direction. Moreover, the total policy variable remained significant controlling for economic and socio-demographic factors. As shown in table 6.4, increasing the total number of incentives and time by one unit corresponds to an increase in solar PV installations per capita of 52 percent.

Model specifications 2c and 2d treat the policy independent variables as continuous. In this case, net metering, rebates, property taxes, and grants all have a positive, statistically significant relationship with installations per capita of solar PV systems. Due to the complex and highly variable nature of loan programs, there was no continuous variable equivalent for loan programs so a direct comparison between specifications 2a and 2c is not possible. Because coefficients are likely to change as more data is input into the model, interpreting the policy coefficients will wait until Model 3. It is also important to note that despite the fact that individual incentive amounts appear to be significant, that the total value of all financial incentives is not statistically significant.

The findings for the economic control variables were also highly consistent regardless of how policies were accounted for between each model specification. Across all four specifications, the electricity price was statistically significant in the positive direction. An increase in the real retail price of electricity (cents/kWh) of one percent corresponded to between a 1.858 and 2.541 percent increase in solar PV installations per capita. Neither GDP per capita nor real median income was statistically significant. Income was insignificant in all models and decreased the total explanatory power of the model. Thus, it was excluded from this and further model specifications. GDP per capita approached statistical significance in the discrete total policy model with a p-value less than 0.1.

The other critical economic variable was also significant in the expected direction in all model specifications. The retail price of a solar PV installation was negatively correlated with installation rates as expected. According to the model, a one percent increase in the installation cost (dollars/Watt_{dc}) corresponded to a decrease in solar PV installations per capita of between 1.263 and 1.924 percent. This effect is substantial, though it is less than the effect of higher electricity prices on a percentage basis. The actual values of percentage changes in the independent variables will be discussed and compared in the final chapter.

Model 2 also added an array of socio-demographic variables to the previous specifications. Despite the theoretical expectations, the empirical results from these variables were unexpectedly weak. Education, environmentalism, and conservatism were all insignificant across all four model specifications. However, both age and race showed statistically significant results. For the former, having large populations of young adults between 25 and 34 corresponded to more solar installations per capita in three of the four models and approached significance in the other. Moreover, having large populations of middle-aged adults in prime consumption years from 45 to 54 was positively statistically significant in one model and approached significance in the one other.

Again, in line with theoretical expectations, states with large numbers of African Americans had statistically significantly fewer solar PV installations, though this effect was very small. An increase in the African American population of one percent corresponded to between 0.325 and 0.423 percent fewer solar PV installations. States with large Hispanic populations were insignificant in all models; thus, the variable was excluded from the final specifications.

As discussed in Chapter 4, each model specification was run twice, once under fixed effects assumptions and again under random effects assumptions. The primary difference between these two types of panel models is that the fixed effects model controls for unobserved characteristics of the individual states that do not change over time. These time invariant characteristics are controlled for essentially by generating dummy variables for each state, the equivalent of fifty-one extra dummy variables in the model. Given the fact that at this stage the model specifications contain many additional covariates, particularly the models using individual policy variables rather than aggregate policy variables, the fixed effects specification runs the risk of introducing too much variance into the model, resulting in an increased risk of Type II error, or the identification of a false negative resulting in the failure to reject a null hypothesis that should be rejected.

Still, both fixed and random effects models were employed, and a Hausman Test was used to determine whether fixed or random effects assumptions were more appropriate for the data. The test accomplishes this by comparing the coefficients and error terms for each model to one another to determine whether the coefficients are systematically different in the fixed effects specification compared to the random effects specification. Table 6.4 reports the results of the four Hausman tests that were run for each model specification. The null hypothesis of the Hausman test, which states that the coefficients are not systematically different and therefore random effects assumptions should be used, was rejected in the two aggregate policy models (2b and 2d) but failed to be rejected in the individual policy models (2a and 2c). Thus, Table 6.5 reports the results of two random effects models and two fixed effects models.

Table 6.4: Hausman Test Results for Fixed or Random Effects in All Policy Models

	P-value
Policy Dummy Variables (2a)	0.1868
Total Policy (2b)	0.0094
Individual Incentives (2c)	0.2053
Total Incentives (2d)	0.0246

[1] When $p<0.05$, the null hypothesis that errors are not correlated with regressors is rejected. This means that fixed effects must be used.

The random effects model specifications (2a and 2c) also added the time invariant characteristic of insolation due to its previously recognized importance as a predictor of solar PV installations. This variable was positively statistically significant in all model specifications. A one percent increase in the available solar radiation resources in an area corresponded to between 4.559 and 4.664 percent increase in installations per capita, more than the electricity price, installation price, or amount of any individual policy incentive.

Adding the economic and socio-demographic variables substantially enhanced the explanatory power of the model as a whole. By adding the time invariant insolation variable, the model specifications incorporating random effects examining change both between panels and within panels over time, explained a more than half of the variance in installations per capita with Adjusted R-squared values of 0.5610 (2a) and 0.5656 (2c). The inclusion of these additional variables also more than tripled the explanatory power of the fixed effects models from policy alone, with Adjusted R-squared values ranging from 0.2042 (2d) to 0.3400 (2b), without substantially changing the statistical significance of the policy variables.

Table 6.5: Panel Model Explaining Installations with Policy, Economic Conditions, and Socio-Demographics

	Model 2a (re)	**Model 2b (fe)**	**Model 2c (re)**	**Model 2d (fe)**
net_meter	0.835 (0.380)*			
rebate	1.594 (0.586)**			
property_tax	0.548 (0.244)*			
income_tax	0.006 (0.351)			
sales_tax	0.254 (0.490)			
fit	0.002 (0.540)			
srec	0.533 (0.566)			
loan	-0.841 (0.287)**			
grant	2.405 (0.567)***			
rps2	0.202 (0.417)			
solar_rps	-0.292 (0.528)			
total_policy		0.520 (0.172)**		
nm_max			0.024(0.005)***	0.023(0.006)***
ln_rebate			0.216 (0.067)**	
ln_property			0.098 (0.045)*	
ln_income			-0.023 (0.053)	
ln_sales			0.020 (0.064)	
ln_fit			0.022 (0.082)	
ln_srec			0.026 (0.075)	
ln_grant			0.258(0.069)***	
ln_incentive				0.047 (0.064)
ln_epricereal	1.858 (0.564)**	1.953 (0.908)*	2.399(0.658)***	2.541 (0.909)**
ln_inpricereal	-1.263 (0.548)*	-1.347 (0.589)*	-1.282 (0.549)*	-1.924(0.500)***
ln_gdppc	1.133 (1.006)	3.103 (1.684)^{t}	1.263 (1.104)	1.322 (1.483)
ln_age25	6.144 (3.195)^{t}	7.369 (3.680)*	6.789 (3.046)*	8.863 (4.100)*
ln_age45	8.138 (4.377)^{t}	8.045 (5.404)	7.524 (4.632)	11.306 (4.965)*
ln_college	-1.326 (1.432)	10.835 (5.231)*	-0.838 (1.655)	12.351 (5.371)*
ln_black	-0.423 (0.181)*	1.382 (0.515)**	-0.342 (0.160)*	-0.325 (0.185)^{t}
ln_conservative	0.067 (0.121)		0.025 (0.126)	0.022 (0.134)
ln_environment	0.335 (0.268)	0.222 (0.274)	0.220 (0.274)	0.311 (0.286)
ln_insolation	4.559 (1.425)**		4.664 (1.401)**	
R^2	0.5610	0.3400	0.5656	0.2042

[1] t = p<0.05, one-tailed; * = p<0.05, two-tailed; ** = p<0.01; *** = p<0.001

6.4 Model 3: Policy and Market Characteristics

The final model included all economic, socio-demographic, and market covariates in a single model along with the policy variables. The table reporting the results of all variables in all specifications of the model can be found in Appendix A. The influence of the policy variables remained relatively steady, with only a few of the previously significant variables failing to remain statistically significant. In Model 3a, the dummy variable for net metering became insignificant at the 95 percent level, though it did approach significant. Likewise, the property tax incentive in Model 3c became insignificant despite approaching significance. As demonstrated previously, the interpretation of the dummy variable coefficients takes the most work. The presence of cash incentives (rebates and grants) appears to have the strongest effect on per capita solar PV installations. Having a rebate program corresponds to an average of 357 percent more residential solar PV installations. Moreover having a grant program corresponds to 1122 percent more residential solar PV installations. Having a property tax exemption for solar PV equipment corresponds to a more meager 63 percent increase in solar PV installations per capita, according to Model 3a. Finally, states with a low-interest loan program have on average 123 percent fewer solar PV installations. Despite being a statistically significant predictor of solar PV capacity, the presence of a solar renewable energy credit-trading scheme does not achieve statistical significance in predicting residential PV installations. The other common performance based incentive, the feed in tariff, also failed to achieve statistical significance in any model. RPS programs, solar carve-outs, income tax credits, and sales tax credits failed to achieve statistical significance whether the programs were accounted for by dummy variables or by continuous variables.

Examining the results of Model 3c using continuous policy variables, results were generally consistent with the dummy variable model. The coefficients for grant and rebate programs indicate that a one percent increase in the available incentive corresponds to an increase in solar PV installations of 0.293 and 0.190 percent, respectively. The continuous variable used for net metering was the maximum size limit for net-metered systems. As the size limit for systems increases by one megawatt, solar PV installations increased by 2.5 percent. Lastly, in all models, the aggregate incentive failed to achieve statistical significance. The implications of these policy results will be discussed further in the following chapter.

The covariates in the final model also showed results consistent with the previous models. Electricity price was statistically significant in all four models at the 95 percent confidence level for a one-tailed hypothesis. A one percent increase in the electricity price corresponded to an increase in solar PV installations that ranged from 1.61 percent to 1.95 percent. Installation price was also statistically significant in all four models for a two-tailed hypothesis but in the negative direction. A one percent increase in the installation price for a solar PV system corresponded to between 1.30 and 2.00 percent fewer solar PV installations. GDP per capita did not achieve statistical significance in the final model.

Race and age remained the most significant socio-demographic variables while environmentalism, conservatism, and education were insignificant in all model specifications. Race was statistically significant at the 95 percent confidence level for a two-tailed test in three of the four models. In the *total_policy* model, the inclusion of a variable for race decreased the overall explanatory power of the model so the variable was excluded. States with large populations of African Americans had between 0.40 and 0.44 percent fewer solar PV installations on average. Again for a two-tailed test, the 25 to 34 year-old age group was statistically significant at a 95 percent confidence level in two of the four models while the 45 to 55 year-old age group was only statistically significant in a single model. Still, it is important to note that both of these age groups at least approached statistical significance in every model. A one percent increase in the population aged 25 to 34 corresponded to an increase in solar PV installations of between 7.05 and 8.55 percent while a one percent increase in the age 45 to 54 demographic corresponded to an increase of 11.32 percent.

Solar radiation remained one of the most important variables in the random effects models. The effect of insolation was statistically significant and positive at the 95 percent confidence level in both models. It is important to remember that, unlike most of the other variables, insolation is time invariant; therefore, all of the variation occurs between the panels and not within the panels. A one percent increase in solar radiation corresponds to between a 4.38 and 5.20 percent increase in solar PV installations.

The last group of covariates evaluate the role that market conditions play in solar PV installation rates. Overall, these variables added little overall explanatory power to the model compared to the economic and socio-demographic covariates, but several of the results are still important to note. The variable indicating marketing effort was statistically significant at the 95 percent confidence level for a one-tailed test in two of the four models. The influence was in the negative direction, but for this variable, a lower number indicates a higher marketing effort. Thus, the effect was in the expected direction. An increase in the marketing effort, or a decrease in the number of pages an individual has to click through in order to obtain information about state solar incentive programs, corresponds to an increase of between 21.4 and 23.2 percent in the adoption of solar PV systems.

Utility support for solar installations, measured as the number of utilities operating in the state that offer their own incentives for solar PV equipment, was statistically significant in a one-tailed test for two of the four models also. An increase of one in the number of solar supportive electric utilities in the state corresponded to an increase of between 4.80 and 6.70 percent in solar PV installations. The presence of a mandatory green power option for utilities, a prime competitor for residential solar PV, was also statistically significant in the negative direction for a one-tailed test. The presence of a mandatory GPO corresponded to a decline in residential solar PV installations of between 73.6 and 84.6 percent. The number of installers in the state was only statistically significant for a one-tailed test in one of the models, and more often than not, the inclusion of this variable decreased the overall explanatory power of the model. In the one model where it was significant, an increase in the number of installers in the state corresponded to a 0.3 percent increase in solar PV installations.

On the whole, the four specifications of Model 3 are a good fit for the data. The final random effects models explain between 57.4 and 60.3 percent of the variance in per capita solar PV installations. The model specification with the highest explanatory power included the policy-specific, continuous variables. Meanwhile, the fixed effects models had within R-squared values of between 0.3031 and 0.2478, indicating that the model specifications explained between 24.8 and 30.3 percent of the within case variance over time. Because of the inclusion of the fixed effects terms, it was expected that the variables in the fixed effect models would explain less variance than the variables in the random effects models.

The general insignificance of several theoretically important socio-demographic covariates including environmentalism, political conservatism, education, and income leaves important questions about the role of these factors yet to be answered. One final panel regression was run to test whether it was possible that some of these socio-demographic factors were indirectly influencing installations through a greater policy response in certain states. Therefore, an additional panel regression was run to model the total number of solar incentive policies in a state by a vector of socio-demographic factors including environmentalism, conservatism, the percentage of college graduates, the percentage of renters in the state, and the median income in the state. Because of the lack of time invariant factors in this model, the regression includes a control for state fixed effects. Table 6.6 contains the results.

Table 6.6: Fixed Effects Model of Total Policy Incentives and Socio-Demographic Factors

	Coefficients
environmentalism	0.005 (0.004)
conservatism	0.004 (0.003)
renters	-1.25e-06 (8.36e-07)
college_100	0.2840 (0.069)***
income_real	-0.0001 (0.00002)***
R^2	0.4088

[1] *** = $p<0.001$

Two of the insignificant socio-demographic variables from the previous models appear to significantly influence the total number of solar incentives available in a state. States with a higher percentage of the population obtaining a college degree tend to have more solar incentives. For every 100 resident with a college degree, the number of solar PV incentive policies increases by 0.2840. Conversely, income appears to have a negative relationship with the total number of solar policies. An increase in real median income of 10,000 corresponded to a decrease in the number of solar incentive policies by 1. The role of environmentalism, conservatism, and the percentage of renters in a state remains a mystery as these covariates were statistically insignificant.

6.5 Panel Model Diagnostics

Several model diagnostics were run to test the robustness and goodness-of-fit for the primary random effects panel model, Model 3. First, each specification was tested for time fixed effects. In all four cases, no year controls achieved statistical significance in the presence of the other covariates. Therefore, it is unlikely that panel invariant, time variant factors explain much of the unexplained variance.

Additionally, heteroskedasticity is a common problem for linear panel regression models. This issue arises from the fact that error terms might not be uniform across cases. In fact, there tends to be trends present in error terms for both cases within the same panel and between panels in the same year. The presence of heteroskedasticity can result in coefficients that, while unbiased, are inefficient and do not represent the minimum mean squared error. To correct for this, all panel models in this study were calculated using heteroskedasticity-corrected robust standard errors to produce coefficients that are both unbiased and efficient.

6.6 Instrumental Variable Analysis

Despite the significance of policy variables in the previous two models, these results are not enough to establish causality because of the endogenous relationship that likely exists between the existence of policy incentives for solar PV diffusion and installation rates. All the previous model explains is that a correlation exists over time between the presence of solar PV policy incentives and solar installation rates, and it does not provide any indication of whether solar policy incentives cause adoption rates to increase. Moreover, the endogeneity could cause either upward or downward bias in the coefficients depending on the nature of the endogenous relationship, brining into question their ability to properly characterize the extent of the correlation. As explained in Chapter 4, one way to deal with this endogenous relationship is to use a set of equations along with an instrumental variable to estimate the potentially endogenous independent variable.

The selection of proper instruments is critical to the success of this type of analysis. Proper instruments must be correlated with the endogenous variable but not correlated with the dependent variable. Hutcheson and Sofroniou (1999) indicate that a correlation of 0.3 or higher provides a good empirical standard for correlation. Because of the mounting empirical evidence of the role of cash incentives (rebates and grants) and the total number of total policy incentives, as indicated by Hypotheses 1 and 2, an attempt was made to find instruments for these two variables. Similar methods could potentially be used to assess the effect of property tax incentives, net metering, and loan programs, but these models were not run because more evidence of their correlation needs to be collected in future studies. Theoretically, several instruments provide good candidates for cash incentives and total policy. The following instruments were tested:

1) The percentage of neighboring states with cash incentives,
2) The average number of solar incentives in neighboring states,
3) Liberal control of state government,
4) And the amount of state government debt.

The most theoretical and empirical support exists for using neighboring state policy as an instrument. Substantial theoretical work has shown that policy diffusion occurs between neighboring states, and this variable has been used as an instrument in previous studies of the effect of renewable energy policies (Smith and Urpelainen, 2014). In that study, the researchers found that though this variable was correlated with the endogenous policy variable, it was also correlated with the dependent variable, the renewable energy share of electricity generation. However, they were still able to use the instrument because they controlled for the primary source of the correlation between the dependent variable and the instrument by including a variable for the neighboring state's level of renewable energy generation. The ability of this control variable to take out the effect of the correlation between the instrument and the dependent variable was confirmed by the direction of the coefficient for that control (negative) in the final model.

The other two potential instrumental variables have a theoretical justification rooted in the fact that liberal governments and governments with high debt levels generally spend more money on social and environmental programs than more conservative states or states that don't take loans to meet spending priorities. However, no previous study of renewable energy policy provides a justification of their validity; thus, their appropriateness for this study will depend largely on their level of correlation with the policy and dependent variables.

Table 6.6 shows the correlations between each of these potential instrumental variables, the endogenous variable of interest, and the dependent variable. All variables are moderately correlated with the endogenous variables of interest (rebate or total policy). Liberal control of government was the weakest instrument, just barely achieving a correlation above the cut-off level of 0.03. Meanwhile, its correlation with the dependent variable was just below the cut-off point. As a result, it is questionable as to whether this variable would be a proper instrument; therefore, it was not used as an instrument in this study.

The neighboring state policy variables were correlated with both the endogenous and the dependent variables. This relationship was expected, as it was identified in the Smith and Urpelainen study. To deal with this issue and continue using the variable as an instrument, the system of equations must include a control for the amount of solar electricity within neighboring states, as this is likely the source of the correlation between these two variables. Average neighboring state solar capacity will be included in the instrumental variable models to provide this control. Finally, the amount of state debt appears to be a strong candidate for use as an instrument for cash incentives, being correlated with the policy variable but uncorrelated with the dependent variable. An additional instrumental variable model will be run using state debt as an instrument for cash incentives.

Table 6.7: Correlations Between Endogenous Variables and Instrumental Variables

	Dependent Variable	**Endogenous Variable**
Rebate Incentive and Number of Neighboring States with Rebates	0.5162	0.4322
Total Policy and Policy in Neighboring States	0.3342	0.4541
Liberal Control of Government	0.2903	0.3086
Amount of State Debt	0.2299	0.3640

The instrumental variable models were estimated using a 2-stage equation described in Chapter 4. The specification for the model was based on the significant variables found in Model 2 and include electricity price, solar installation price, race, and age variables. Because of the expected endogeneity of the other types of solar incentives, these variables were left out of the instrumental variable model. Instead, the variable for total policy incentives was used in the cash incentives model to act as a control for the presence of other solar incentives in the state. Additionally, state and year fixed effects were included in each model. In models where the instrumental variables were measures of the diffusion from neighboring states, a control for the average solar capacity in the neighboring state was included. Tables 6.7, 6.8, and 6.9 report the results of the IV model specifications.

Table 6.8: Instrumental Variable Panel Regression for Cash Incentives (Rebate) Using Neighboring State Policy

	Cefficient (SE)
Rebate (IV – *cash_diff*)	1.928 (0.322)***
ln_epricereal	2.464 (0.865)**
ln_inpricereal	-0.822 (0.398)*
total_policy	0.177 (0.079)*
ln_age25	4.650 (1.436)**
ln_age45	-1.779 (4.540)
ln_black	-0.331 (0.079)***
ln_capacity	-0.218 (0.340)
utility_support	0.075 (0.019)***
cons	-55.177 (25.358)*
R^2	0.4790

[1] t = p<0.05, one-tailed; * = p<0.05, two-tailed; ** = p<0.01; *** = p<0.001

Table 6.9: Instrumental Variable Panel Regression for Cash Incentives (Rebate) Using State Debt

	Cefficient (SE)
Rebate (IV – *statedebt*)	2.054 (0.262)***
ln_epricereal	2.875 (0.366)***
ln_inpricereal	-5.408 (1.304)***
total_policy	0.177 (0.079)*
ln_age25	4.082 (1.390)**
ln_age45	-1.779 (4.540)
ln_black	-0.101 (0.229)
utility_support	0.065 (0.017)*
cons	-6.687 (7.056)
R^2	0.5167

[1] t = p<0.05, one-tailed; * = p<0.05, two-tailed; ** = p<0.01; *** = p<0.001

Table 6.10: Instrumental Variable Panel Regression for Total Policy

	Coefficient (SE)
Total Policy (IV – *tp_percent*)	0.310 (0.076)***
ln_epricereal	4.165 (.547)***
ln_inpricereal	-6.378 (1.345)***
ln_gdppc	0.501 (0.645)
ln_age25	5.045 (2.342)***
ln_age45	1.013 (2.461)
ln_capacity	-1.616 (2.327)
ln_black	-0.342 (0.083)***
utility_support	0.055 (0.021)*
R^2	0.4961

[1] t = p<0.05, one-tailed; * = p<0.05, two-tailed; ** = p<0.01; *** = p<0.001

In the cash incentive IV model, the instrumental variable achieved statistical significance at the 99.9 percent level in both instrumental variable models. The estimated coefficients differ somewhat from the original panel model, which appears to underestimate the effect of cash incentives like rebates. In the case of both instrumental variables, the presence of cash incentives corresponds to more than 400 percent more solar PV installations, over the six years of the study. Most variables remained significant including the electricity price and the installation price; however, it is difficult to compare the relative effects of these variables to the binary estimate of rebate.

Meanwhile, the aggregate policy instrumental variable also achieved statistical significance at the 99.9 percent level. Each additional policy suffices to increase the per capita solar PV installation rate by 31 percent over the six years of the study, with all other factors held constant. In contrast to the cash incentive variable, this estimate is lower than the estimate in the original panel model. Ultimately, both of these models suggest positive causal effects of both the presence of cash incentives and the total number of policy incentives.

Instrumental Variable Diagnostics

The use of instrumental variables can be fraught with uncertainty. Because the method requires predicting values of one variable with another and using those predictions in the model, there is no guarantee that the selected instrument will provide better estimates than the original variable that is being instrumented. Additionally, the selection of instruments inherently holds a high degree of uncertainty. Simply meeting the conditions of correlation with the endogenous variable and non-correlation with the dependent variable does not mean that the specific instrument selected is the best instrument for the variable. Ideally, the use of multiple instruments can produce better estimates, but not necessarily. The previous models for cash incentives use two different instruments for the endogenous variable, state debt and the presence of cash incentives in neighboring states.

Additionally, several diagnostic tests exist to determine the appropriateness of the instruments used. One of the central issues is whether the instruments either over- or under-identify to instrumented variable. If over-identification occurs, the instrument could over-estimate the significance of the real variable, resulting in an indication of causality where none exists. A common test used for over-identification is the Hansen's J-Test. The null hypothesis of that test is that the instruments together over-identify the instrumental variable, and therefore are invalid. For both variables for cash incentives, the null hypothesis of the Hansen's J-Test can be rejected with p-values below 0.000. This means that the instruments do not over-identify the cash incentives variable. Likewise, the null hypothesis of the Hansen's J-Test for the total policy variable can also be rejected with a p-value of 0.000. As a whole, the instruments selected for these models do not over-identify the endogenous variable.

On the other hand, indications of under-identification are not nearly as clear. The Kleinbergen-Paap Test for weak identification determines whether excluded instruments might be correlated with the endogenous regressors. Stock and Yogo (2005) provide a set of critical values for this test. When the test statistic exceeds the critical values, researchers can be confident that omitted instrumental variables do not correlate with first stage regressors. Often, a base value of 10 provides confidence that the variable is not under-identified, even if it is still weakly identified. The percentage of neighboring states with cash incentives falls just under this threshold with a K-P statistic of 9.884.

Meanwhile, the state debt model has a K-P statistic just above the threshold value of 10 with a value of 13.109. They both fall short of the highest Stock-Yogo critical value of 16.38. These statistics indicate that even if the variables are not under-identified, they are likely weak instruments. It is possible that including both instruments in the same model might solve this problem in future research. On the other hand, the average number of policies in neighboring states does not appear to be weakly identified, with a K-P statistic value of 20.241 exceeding the maximum Stock-Yogo critical value.

The model diagnostics above indicate potential weaknesses in the instrumental variable choices, particularly for the cash incentives model; however, it is clear that these models are an improvement over the original panel model specifications in that they handle the endogeneity that clearly exists between the policy variables and solar PV installation rates. Though refining the instrumental specifications can certainly help produce more accurate estimates of effect sizes, these models provide an initial indication of the possibility of a causal relationship between solar PV policy incentives and solar PV installation rates at the state level.

7. Individual State Profiles

7.1 Introduction

The previous chapter reports the results of a national model of state solar incentives; however, these big-picture results run the risk of misstating the importance of factors in every state. There are unique characteristics present in every state that can enhance, confound, or mediate the role that solar incentives play in influencing solar adoption. Moreover, many of these characteristics do not easily lend themselves to quantification in the same way that others like electricity price or solar installation prices do.

Therefore, the following chapter will more closely examine the political and social contexts surrounding solar policy in several individual states within the United States, specifically Arizona, Louisiana, Illinois, and New Jersey. This sample of individual cases was selected based on a number of criteria.

Selection of Cases

Individual state cases for this chapter were selected purposively using a systematic set of criteria, particularly the level of insolation and the number of per capita installations. Figure 7.1 shows a four-quadrant matrix that was developed with insolation on one axis and installations per capita on the other. Using this matrix, four states were selected that met the particular criteria to be placed in each quadrant: high insolation and high installations, high insolation and low installations, low insolation and low installations, and low insolation and high installations. High and low measures of these two characteristics were determined relative to the mean of the distribution for all states of each variable. After describing the mix of electricity generation sources within the state, the state's solar policy is examined and compared to the results of the quantitative model, particularly the presence of policies or factors indicated as significant predictors of high or low residential solar PV installations.

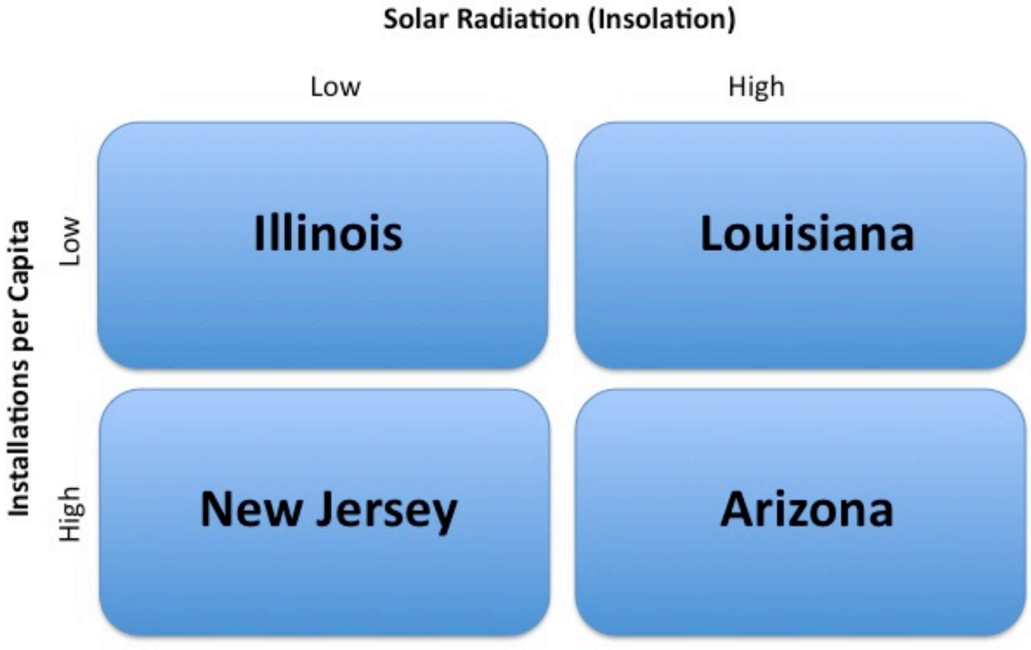

Figure 7.1: Four-Quadrant Selection Matrix for Individual State Cases

7.2 Arizona

As mentioned in the first chapter of this dissertation, Arizona serves as an interesting case particularly because of the political fight going on over solar incentives in the state. Arizona is just one of 19 states where public policy is being considered to change either the amount of solar incentives or the indirect regulations related to solar PV (Farrell, 2014). Additionally, Arizona was selected for this case examination because it has installations per capita and solar radiation resources above the mean for the entire United States. As Figure 7.1 shows, the number of solar installations per capita rose sharply against the national average over the course of the entire study.

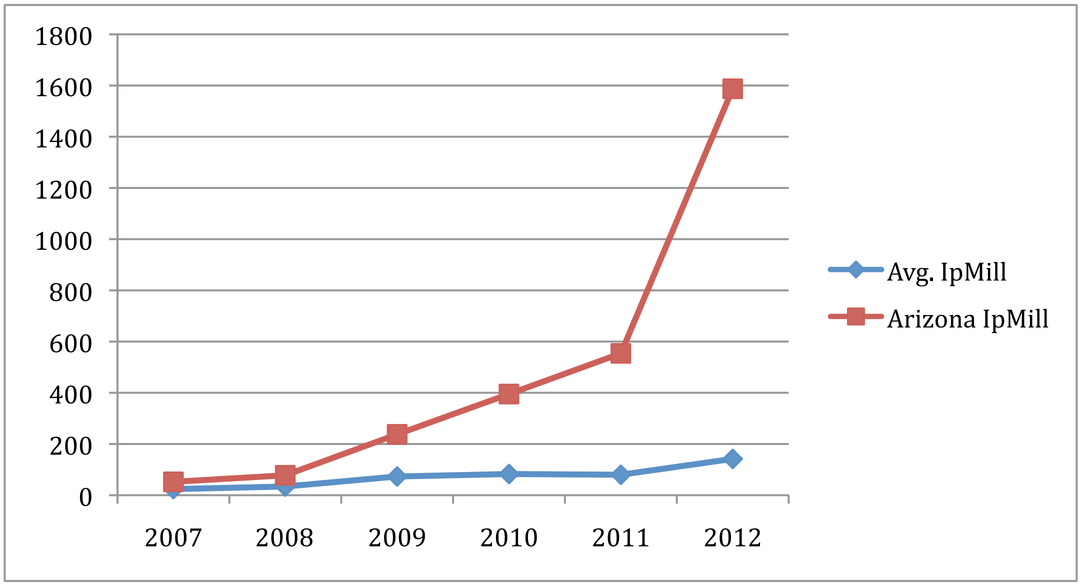

Figure 7.2: Residential Solar Photovoltaic Installations per Million Residents in Arizona, 2007 – 2012

Energy Policy Profile

Arizona's electricity comes from a mix of coal, natural gas, nuclear, and renewable energy sources, in descending order of production as of July 2014 (EIA, 2014). Most of the fossil fuels used for electricity production are imported. Arizona has one currently operating coal mine that primarily supplies fuel for the Navajo and Hopi Indian reservations. The largest nuclear power plant in the nation is located near Palo Verde in unincorporated Maricopa County near the state capital Phoenix.

Renewable energy sources account for a relatively substantial portion of Arizona's electricity generation (EIA, 2014). Overall, renewable sources produced 12 percent of the state's electric capacity in 2010. Hydroelectricity made up the largest portion of that amount accounting for 10 percent of the total capacity. The Glen Canyon and Hoover Dams, two of the most well known hydroelectric dams, are both located in the northern part of the state and provide much of that region's renewable electricity. Other renewable sources accounted for 340 GWh of electricity production in July 2014, including both solar (PV and concentrated) and wind. Though wind currently generates more capacity, the Energy Information Administration (2014) reports that solar has substantially higher potential to generate electricity compared to wind. Since the state's first commercial solar PV array went online in 1997, the state has been steadily adding capacity. Yuma, Arizona, a city in the southwest corner of the state, hosts the largest photovoltaic facility in the world, which went online in 2014. Given these abundant solar resources, the state has ranked second in installed capacity since 2013, trailing only California.

The cornerstone of Arizona's renewable energy development is their renewable portfolio standard. The state has experimented with various renewable energy standards since 1996; however, that law, with its modest goal of one percent renewable electricity generation for utilities by 2003, was repealed and replaced with a slightly weaker standard requiring 0.4 percent renewable electricity generation by 2002, to increase to 1.1 percent by 2012. The one benefit to this new bill was that it heavily favored solar power, requiring 60 percent of the renewable generation to come from solar. In 2007, a new rule was enacted to raise the standard to 15 percent renewable generation by 2025. The new law also required that thirty percent of that renewable generation derive from distributed generation, at least half from the residential sector. By requiring that utilities purchase a minimum amount of their electricity from the residential sector, it comes as little surprise that residential installations would begin increasing after the implementation of this new standard.

This increase in solar PV installations in the residential sector was supported by additional policy incentives. While Arizona does not have a state-based rebate plan, 12 utilities including two of the state's largest, offer their own solar PV rebates. Given the requirements to purchase residential, distributed generation power, the utilities have a strong incentive to support its development, at least to a point. The state offers income, property, and sales tax incentives. Additionally, Arizona implemented their net metering requirements for utilities in 2009, a policy responsible for the political conflict currently going on in the state.

With the surge in residential solar PV adoption that occurred in the wake of Arizona's net metering law, the Arizona Corporation Commission (ACC), which operates the state's largest utility, considered a change to the law in 2013 that would impose an additional fee on net metering customers. Ostensibly, the fee was intended to compensate utilities for increased costs derived from installing reversible meters and maintenance to the electric grid, which they claim had increased since the number of net metering customers surged in 2009. Solar industry groups and PV system owners countered that distributed generation saved the utilities in the long run by providing additional power during peak demand periods and allowing them to put off construction of utility scale solar facilities they would have to construct to meet the state RPS, at least until solar production efficiencies allowed the technology to reach parity with fossil fuels.

The original proposal by Arizona Public Service (APS), the utility regulated by the ACC, called on net metering customers to pay a monthly fee of $50 to $75, a 50 percent reduction in the average customer savings from the program. A study by the Residential Utility Consumer Office (RUCO), the state's consumer watchdog organization for the electricity industry, found that the average cost shift related to infrastructure improvements for the average solar customer to the average non-solar customer was about $20 per month. As a result, they proposed a graduated fee scale that would begin at $7 per month and increase to $20 per month over several years (Wyloge, 2013).

Following this proposal, the solar industry was able to mobilize substantial political support for the reduced fee structure. A public hearing conducted by the ACC became a “nearly unanimous, anti-APS public comment marathon,” (Wyloge, 2013; 2). In the end, the ACC approved a compromise plan that imposed a per-kilowatt fee on grid-tied solar PV systems of $0.70 per kW. The monthly fee for the average customer would be about $5 per month, one-tenth of the original fee proposed by APS. While this was a victory for the solar industry, it establishes a precedent for reducing financial incentives at the request of the electric utilities. Future reductions of solar financial incentives in Arizona are now more likely.

Ultimately, Arizona’s success in solar PV diffusion appears to be due to the perfect storm of abundant resources, strong regulation, and valuable financial incentives, particularly from net metering. Opponents of solar incentives argue that growth in distributed generation in Arizona might be too rapid and places increasingly expensive burdens on the state’s electric utilities. The pace of growth evident in Figure 7.2, particularly the rapid increase that occurred after the implementation of the net metering policy in 2009, provides at least partial support for their claim. Solar PV growth might be sustainable, even if financial incentives are lowered, because of the specific structure of the RPS regulations and the abundance of solar resources.

7.3 Louisiana

Louisiana is another state with high solar resources, but solar PV technology has yet to be widely adopted in the residential sector. Average insolation is 4561.75, less than one standard deviation above the mean; however, total installations per capita have remained below the national average for the entire period of this study. According to Figure 7._, the gap between installations in Louisiana and the national average began to widen, two years after the state implemented an aggressive system of tax breaks in 2007. A closer examination of the policy, economic, and social conditions within this state could help explain Louisiana's poor performance.

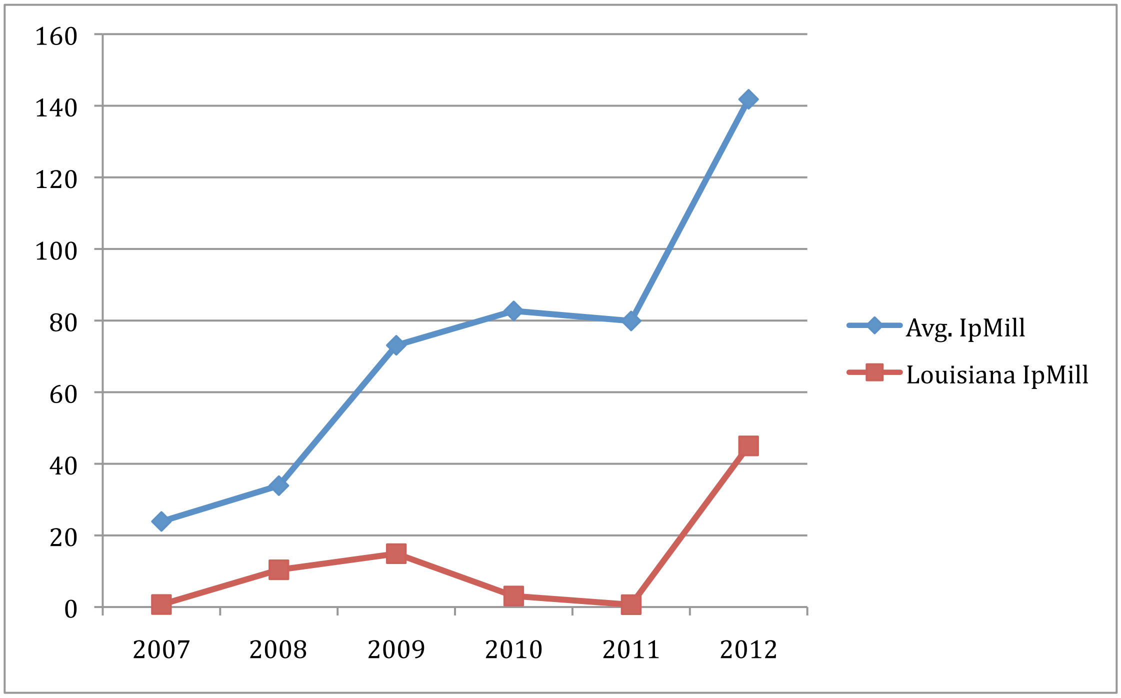

Figure 7.3: Residential Solar Photovoltaic Installations per Million Residents in Louisiana, 2007 – 2012

Energy Policy Profile

The roots of the fossil fuel industry run deep in Louisiana. Louisiana is second to only Texas in total petroleum refining capacity, and Louisiana is the hub for one of the nation's largest natural gas pipelines (Henry Hub) and the location of the only deep-water port (the Louisiana Offshore Oil Port) capable of offloading deep draft tankers (EIA, 2014). Moreover, the oil and gas industry accounted for nearly 300,000 jobs throughout the state and $73.4 billion in economic impacts (direct and indirect) in 2011 (Scott, 2014). As a result, the renewable energy industry in the state is of negligible size and strength, accounting for almost no measurable portion of electricity generation within the state.

Despite the strength of the oil and gas industry, Louisiana implemented one of the most generous tax breaks in the country for solar PV technology in 2007. Unlike the cash incentives offered by Arizona, Louisiana's tax incentive allowed the purchaser of solar equipment to receive an income tax deduction equal to 50 percent of the first $25,000 of installed costs for qualifying solar PV equipment. This incentive was paired with a net metering law that required state-regulated utilities to purchase excess power generated by solar PV systems. Still, despite the existence of these incentives, Louisiana failed to keep up with the national average of solar installations per capita. With the available federal tax credit, up to 80 percent of the cost of a solar PV system could be funded by government incentives.

Louisiana's lagging status was not because individuals and businesses were not claiming the tax credits. Reports indicated that the state paid out almost 20 times more tax credits than they expected when the program was passed (Larino, 2012). Between 2007 and 2012, the state spent \$37 million on solar tax credits compared to an expected value of \$500,000. After the Great Recession, programs such as tax expenditures came under significant government scrutiny, as Louisiana officials looks for ways to limit government financial shortfalls in the wake of declining revenues (McGaughy, 2013). Ultimately, the 2013 state budget imposed a sunset provision to end the solar incentive by 2018, though this happened well after the end date of this study.

There are a number of plausible explanations as to why solar PV technology adoption failed to take off despite generous financial incentives. For example, Louisiana doesn't have a renewable portfolio standard (Larino, 2012). With no state regulations requiring that utilities pursue renewable energy or meet certain targets, the incentive to develop solar in both large and small-scale projects was lacking. Furthermore, the specific details of the net metering policy allowed some state utilities to stop taking new net metering customers (Hammer, 2014). For those utilities regulated by the state Public Service Commission (PSC), the original net metering law allowed these utilities to opt out of providing net metering once they purchased "more than 0.5 percent of their peak load power from customers' rooftop solar systems" (1). This loophole would likely limit the effectiveness of any financial incentive, regardless of the type of incentive (cash, tax, or loan) or the incentive's monetary value.

Most importantly, Louisiana has incredibly low residential electricity prices. Electricity prices in the state are 23 percent below the national average, meaning that individuals have little motivation to look for alternative forms of electricity generation.

Referring back to the quantitative model in the previous chapter, it is important to remember the strong, positive influence of electricity prices on per capita installation rates.

Louisiana represents a case of policy failure. Whether through an absence of RPS regulation, loopholes written into the net metering laws, the selection of tax incentives over cash incentives, or a political unwillingness to raise electricity prices to make distributed electricity generation more attractive to consumers, the solar policy regime pursued by Louisiana was unsuccessful in making the state a leader in the deployment of solar PV technology, despite the presence of abundant solar resources. While other barriers to solar diffusion exist in the state, such as conservative politics and a politically powerful fossil fuel industry, Louisiana clearly missed an opportunity to become a leader in solar-generated electricity due at least in part to poor policy planning and execution.

7.4 Illinois

By all accounts, Illinois should have a booming solar market. Their solar resources are slightly below average at 4001.2 Wh/m^2 compared to a national average of 4234.6 Wh/m^2 but well within one standard deviation of the mean (s = 537.6 Wh/m^2). Meanwhile, it boasts an array of solar incentives including net metering, rebates, and property tax exemptions, all of which were demonstrated by the model in Chapter 6 to correspond to higher numbers of residential solar installations. However, Figure 7.4 shows that solar installations per capita (millions) lag substantially behind the national average and seem to be holding steady even as national trends favor growth. What factors could be behind this trend?

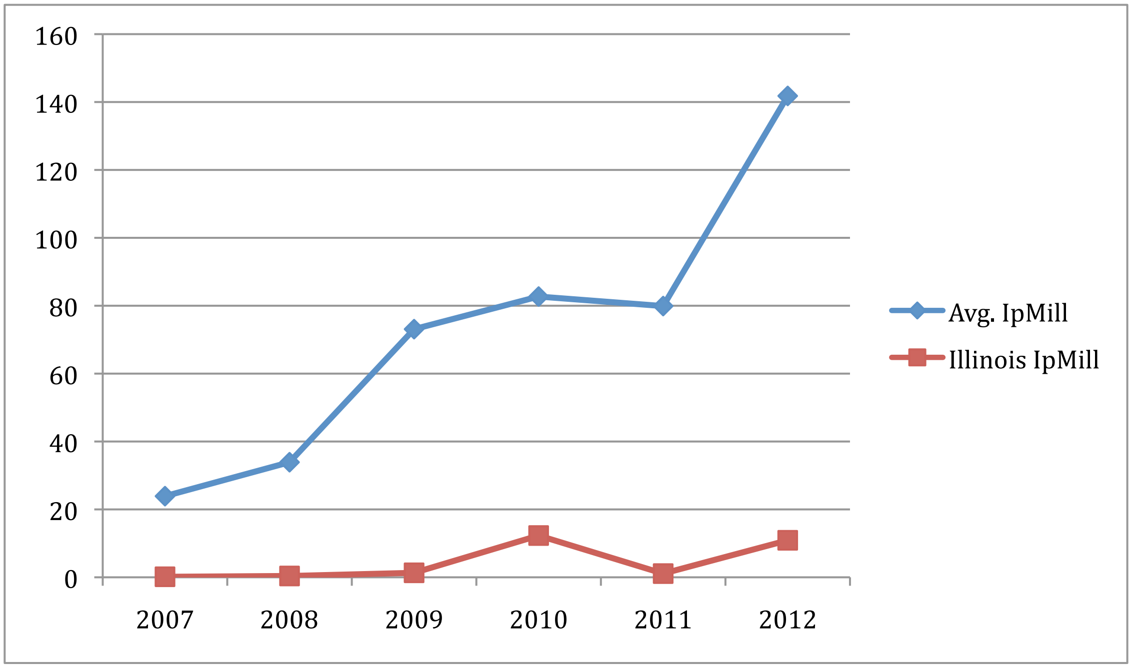

Figure 7.4: Residential Solar Photovoltaic Installations per Million Residents in Illinois, 2007 – 2012.

Energy Policy Profile

Despite the fact that Illinois possesses a powerful array of solar incentives during the limited period of time of this study, it is worth pointing out that most of these solar incentives are relatively new. Rebates, net metering, and property tax incentives either became law or were implemented between 2003 and 2008. The state also passed a renewable portfolio standard in 2007, but the solar portion of that program did not initiate until 2013.

The details of the policy incentives are also critical to understand in order to judge their potential effectiveness. The rebate program, as currently funded, may not be able to keep up with the rising interest in solar photovoltaics (Morris, 2012). The current rebate program is built to serve both solar and wind projects. In the first year of the rebate program, the total requests for funding were $500,000. By 2011, the budget of the program had risen to $2,000,000, yet the program fielded more than $4,000,000 in requests during the first week of the program, 60 percent of which were for residential projects. Although municipalities such as the state capital Springfield have started offering their own rebates, it is unclear whether these programs will be able to fill the likely substantial gap in demand.

Another negative consequence of having relatively new policies for solar is the lack of public awareness both of solar PV technology as well as the policies themselves. Despite the existence of solar incentive programs, the state's newspaper of record, the *State Journal-Register* hardly mentions the programs until between 2007 and 2012. In fact, most mentions of solar PV in the State Journal-Register are of high profile, low impact solar installations at the Governor's Mansion (Finke, 2010), on the University of Illinois at Urbana-Champaign's campus (Staff, 2011), and at the Taylorville airport (Nevel, 2011).

Lack of time, funding, and a strong public profile are not the only reasons for residential solar's slow pace. Despite being a net importer of energy fuels (Learner, 2012), the electricity generation industry is highly competitive in Illinois. The state has large stakes in the petroleum, natural gas, coal, and nuclear power industries (Energy

Information Agency, 2014). Its position in the middle of the country makes Illinois a key transportation hub for crude oil and natural gas with the state crisscrossed by pipelines containing both fossil fuels. Illinois also has the largest crude oil refining capacity in the Midwest. Moreover, the state ranks in the top three in recoverable coal reserves, ethanol production, and electricity generation from nuclear power. In fact, Illinois generates more electricity from nuclear power than any other state, 12 percent of all nuclear generation in the country. With all of this competition in the market for electricity generation, it is difficult to envisage a role for solar PV in the utility sector, though the residential sector might be a possibility.

Electricity prices in Illinois also present a barrier to solar diffusion. Despite the growth in the solar market, the national average cost of electricity generated from solar power remains 57.5 percent higher than conventional coal generated electricity. In a state with below average solar radiation, the discrepancy could be higher. Additionally, Illinois residents enjoy relatively low electricity rates. Electricity prices in the state are approximately 12 percent below the national average. The quantitative model indicates that low electricity prices significantly correspond to low solar PV installation rates. Plus, these low prices lead the residents of Illinois to consume 44 percent more electricity than the national average. As a result of the low prices and high consumption, residents' total electricity bills are 2 percent higher than the national average. The introduction of large amounts of solar capacity would likely increase electricity prices in the short term. While residents could clearly compensate for higher prices with reduced consumption, it is unlikely that such a situation would be viewed positively and produces the risk of a negative political backlash against solar power.

When it does come to generating renewable electricity, Illinois is first and foremost a wind state. According to the Energy Information Administration (2012), wind power made up 4.4 percent of the total electricity generating capacity in Illinois during 2010 as well as 92 percent of the total renewable electricity capacity. Solar only accounted for 0.43 percent of the renewable capacity during the same year. Additionally, the wind energy business is well entrenched within the state. Thirteen major wind power companies are headquartered in Chicago (Learner, 2012). Moreover, the state was number 2 in the nation in new wind energy generation in 2011.

The low market price for electricity coupled with the entrenchment of wind as the preferred renewable source of energy in Illinois present substantial barriers to solar development in the state, even with a demonstrably effective array of incentives. For policy makers looking to increase solar PV diffusion in the state, expanding the size of the combined rebate program could satisfy the increasing demand for residential renewable energy that appears to exist in the state. Moreover, this policy action would allow consumers, rather than the state government, dictate which form of distributed generation they prefer. It is also possible that the implementation of the solar carve out portion of the Illinois RPS could lead commercial and utility sectors to adopt more solar PV power, leading to a higher public profile and more generation within the state. However, addressing the interests in coal, natural gas, and nuclear power industries will be the more difficult task. It is unclear whether Illinois residents who enjoy such low electricity prices would accept the government-forced diffusion of large-scale solar power that would likely increase their electricity bills in the short term.

7.5 New Jersey

New Jersey poses an additional puzzle that is the opposite of Illinois. With solar radiation of 3964.5 Wh/m^2, well below the national average, New Jersey has grown into the second largest market for solar PV after California. Even more amazingly, it has achieved this milestone while phasing out its solar rebate program. While the rebate program was active, installation rates were above the national average but still tracked along with the national average, as evident in Table 7.5. However, rebates began to be phased out in 2007, and by 2011, they were completely gone. Still, this has not slowed down the growth of residential solar PV installations. In fact, 2011 saw a surge in growth. So, why does New Jersey continue to see growth despite a decline in incentives.

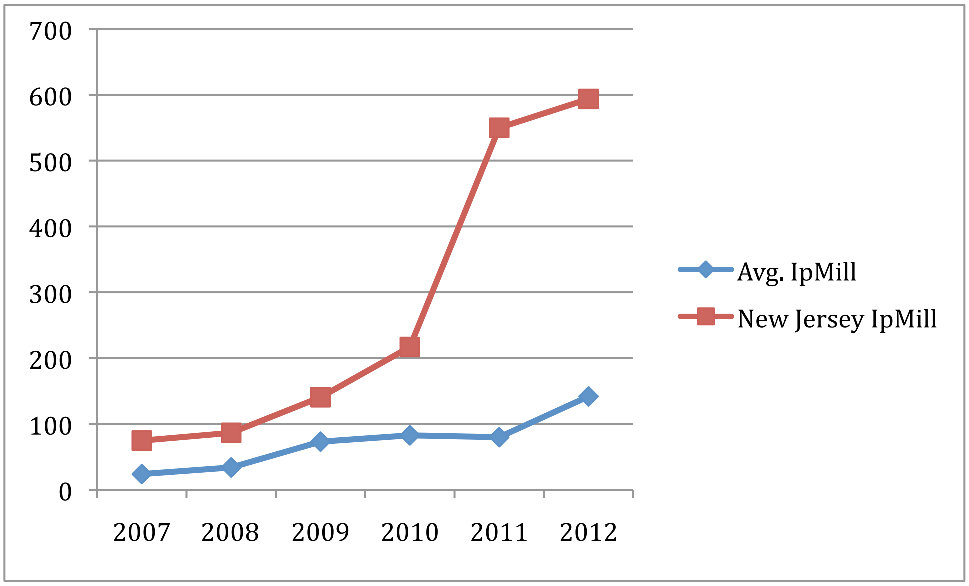

Figure 7.5: Residential Solar Photovoltaic Installations per Million Residents in New Jersey, 2007 – 2012.

Energy Policy Profile

The reason behind New Jersey's lead and growth in photovoltaic installations is multifaceted. Certainly, a critical factor is that New Jersey was an early implementer of solar incentives, both direct and indirect. New Jersey passed renewable portfolio standards in 1999, considered to be one of the most aggressive in the country (DSIRE, 2013). The program called for all utilities to supply 22.5 percent of their retail electricity from renewable sources by 2021 with a 4.1 percent carve-out for specifically for solar.

Additionally, the rebate program that was enacted to support this goal in 2001 was well funded. In nine years, the program paid out $130 million in rebates (DeMarrais, 2010). Moreover, rebates in New Jersey would cover up to 50 percent of the up-front cost, making it one of the most generous programs in the country. Much of this spending came in the early years of the program, as the state began to phase out the rebates in 2007 in favor of a market-based approach to solar financing.

This market-based approach was accomplished through the sale of Solar Renewable Energy Credits (SREC). Every time a solar PV system generated 1,000 kilowatt hours of electricity, the owner received an SREC. These could then be sold for a certain price to electric utilities to meet their requirements under the RPS. The spike in installations between 2010 and 2011 can be explained almost exclusively by this program. In 2007 when the rebates were being phased out, the SREC price was around $200. By the middle of 2011, the price had more than tripled to $685 (Gallucci, 2012). This high price led to an influx of solar entrepreneurs who flooded the market with SRECs, thereby reducing the market price. By June of 2012, the price had crashed to around $140 (DeMarrais, 2012).

While the SREC price spike explains the temporary installation increase from 2010 to 2011, these remaining policy-related factors do not paint a clear picture of why solar PV has been consistently popular in New Jersey. It would be convenient to believe that solar's popularity was due entirely to astute policymaking, but this would overstate the efficacy of such methods. SRECs aside, solar policy was continuously diminished or eliminated during the time period of this study, yet New Jersey's solar industry continued to grow. For example, Governor Chris Christie's administration used $158 million from the clean energy budget to balance the state's budget in 2010 (DeMarrais, 2010). This cut back included reducing funding for solar projects by half. Still, solar continued to grow.

The reason for this growth lies in the high electricity prices in the state. Electricity prices in the residential sector are 27 percent higher than the national average. As a result, solar PV appears more competitive than in other states even with in an absence of incentives. The quantitative model supports this conclusion with high retail electricity prices being statistically significantly related to higher rates of solar installations. While growth in New Jersey's residential solar sector may never reach the heights for the SREC boom in 2011, growth should be expected to continue as long as electricity prices remain high and photovoltaic technology costs continue to decline, reducing installation costs. While it is almost a certainty that early and aggressive solar incentive policies played a role in New Jersey's solar growth, market factors appear to be the undeniable drivers of expansion.

7.6 Summary

The four cases discussed in this chapter allow several important conclusions to be drawn from the quantitative model presented in the previous chapter. The differences in how these states implemented their renewable energy policies along with differences in energy prices provide plausible explanations for the differing levels of residential solar diffusion. Solar resources alone do not provide a complete explanation for solar diffusion.

In three of the four states, electricity prices explain the diffusion of solar PV technology in the residential sector. Despite valuable incentives for solar in Louisiana and Illinois, low electricity prices stifle any incentive to invest in solar panels. Comparatively, the expensive electricity prices in New Jersey make solar panels competitive even though market-based incentives provide a high degree of uncertainty regarding the length of the payback period.

In the case of the two states with high numbers of solar PV installations per capita, Arizona and New Jersey, both states possess strong, ambitious RPS policies. Moreover, both of these policies provide a large carve-out for solar power, making it a popular source for meeting requirements under the RPS. On the other hand, Louisiana has no RPS while Illinois has an RPS that substantially favors electricity generated from wind over solar-generated electricity.

Unfortunately, comparing these cases reveals little about the effectiveness of cash incentives like rebates, the strongest incentives according to the quantitative model. At the time of the study, no state policy for incentives existed in Arizona, New Jersey, or Louisiana. Only Illinois has a rebate policy, and that state had a below-average level of installations. However, it is important to point out that New Jersey had previously had an active and generous rebate program that was phased out at the beginning of this study. Moreover, Arizona utilities offered their own rebate programs, even though the state had no cash incentive policy. It is possible that the existence of these programs could have increased solar PV adoption rates within their respective states, despite not being reflected in the quantitative model. Despite having only tax incentives, it is also difficult to draw any conclusions about the effectiveness of those programs in Louisiana since the state did not pair these incentives with an RPS mandate for utilities to purchase specific amounts of solar-generated electricity.

Lastly, while many researchers have made it a point to identify states that are large fossil fuel producers and refiners, it is also important to account for competition between renewable energy sources, particularly when policies favor one source over others. For example, even though Illinois is the only state examined in this chapter with a rebate program for solar, the RPS in the state strongly favors wind power, requiring independently-owned utilities to purchase between 60 and 75 percent of their renewable electricity from wind-generated power compared to 6 percent from solar (DSIRE.org, 2014). This finding raises important questions about whether policies that favor one type of renewable energy over another can result in the cannibalization of otherwise competitive and complementary renewable energy sources.

While these results cannot be generalized to every state, they provide important insights into the effectiveness of the quantitative model found in the previous chapter. For electricity prices, these case examinations provide support for the model's prediction that high electricity prices result in higher levels of solar PV diffusion, as higher cost solar electricity becomes more competitive with electricity offered by utilities. On the other hand, these cases cast doubts on the power of cash incentives and the ineffectiveness of RPS policies and solar carve-outs. In the limited cases of these four states, it appears that strong RPS policies, particularly those that provide a favorable position for solar power, can encourage higher rates of solar PV diffusion, regardless of the mix of financial incentives provided in the state.

8. Discussion and Policy Implications

The previous chapters presented the results of three, increasingly complex quantitative models examining the factors that influence the rate of residential solar photovoltaic adoptions at the state level over the time period from 2007 to 2012 along with in-depth case examinations of solar policy incentives in four states with varying degrees of solar resources and installation levels. These results apply to a variety of hypotheses and research questions, each of which will be explored below. The primary variables of interest are those that account for differences in public policy incentives offered between the states. This chapter will conclude with a selection of implications for policy makers based on the conclusions of the quantitative analyses.

8.1 Influence of Policy Incentives

This study began with a model (Model 1) that examined only the influence of public policy incentives over residential solar photovoltaic adoption. In each successive model, an array of control variables was added to the model in order to test the robustness of the policy incentives. When it comes to evaluating the explanatory power of the policy incentives, the results of all of the models are remarkably consistent. The states with rebates, grants, and property tax exemptions had higher rates of residential solar photovoltaic adoption during the six-year study period than states without such programs. Together, grants and rebates are cash incentive programs that offer a set amount of money regardless of system performance, typically early in the system lifecycle. Previous research examining all solar photovoltaic market segments has consistently found that cash incentives significantly influence solar adoption, and this research is consistent with those findings. Furthermore, instrumental variable regression confirmed the causal relationship that exists between the presence of cash incentives and higher levels of solar PV installations per capita. Moreover, states offering more incentive programs also had consistently higher levels of adoption than states with fewer incentives, even when controlling for environmental, economic, social, and market factors. However, instrumental variable regression failed to confirm a causal relationship between the number of solar incentives and installations rates. Theoretical and empirical evidence for the effectiveness of property tax incentives is sparser, but this study provides an indication that these programs should continue to be studied closely. The presence of net metering, an indirect policy incentive, was also positively statistically significant in most of the models.

Each model also accounts for public policy in four different ways: as dummy variables indicating the presence of a particular policy, as a total number of policy incentives present, as an estimated dollar amount for each policy, and as an estimated total amount for all policy incentives together. Aside from providing another level of robustness to the findings, the inclusion of estimated dollar values for the policy incentives will allow a comparison between the marginal influence of a dollar of incentives compared to an equivalent dollar of increase in electricity price and installation cost of solar panels (though this will be explored in more detail in the following section). Ultimately, the policies that were significant in the dummy variable model (rebates, grants, and property tax exemptions) were also significant when the policy value was calculated as a dollar amount.

A continuous variable measure of net metering that accounted for the maximum allowable size of solar photovoltaic system eligible for net metering was also consistently significant across all models. The implication of this finding is that the ability to have a larger system, and thereby the potential to produce more excess electricity to sell back to the grid, is itself a powerful incentive for solar adoption. The consistency of the quantitative results across models and specifications adds to the confidence and robustness of the findings.

Hypotheses 1a and 1b pertain to the influence of cash incentives. While previous studies lumped cash incentives into one group, this study disaggregated rebates and grants in order to see if their subtle differences had an impact on their ability to predict per capita solar installations. Extant research has consistently found that cash incentives do correspond to higher solar photovoltaic installations rates when examining all market sectors together. For the residential sector examined in this study, it appears that the power of cash incentives remains strong. Hypothesis 1a predicts that the presence of cash incentives like rebates and grants will correspond to more per capita solar installations. This directional hypothesis was supported for both rebates and grants as the null hypothesis of no positive effect was rejected at a 95 percent confidence level.

Furthermore, Hypothesis 1b stated that a higher value of cash incentives would correspond to higher per capita solar installations. Again, this hypothesis was supported by the regression model for both rebates and grants and the null hypothesis of no positive effect was rejected at a 95 percent confidence level.

The remainder of the incentives were evaluated under Research Question 1 because of the lack of clear and consistent empirical evidence about their effects. As mentioned earlier, the only other policy to consistently achieve statistical significance was the property tax exemption. Other tax incentives, namely an income tax rebate and a sales tax exemption, were consistently insignificant. The reason for this remains unexplained. Property tax exemptions are more widely available than income tax and sales tax incentives with more than half of the states offering a property tax exemption. Although a sales tax exemption is the most like cash in that it is obtained at purchase and the savings can easily be calculated, it is also likely to be overlooked by prospective buyers because they never see the savings reflected in the price. The savings from property and income tax incentives, on the other hand, are more complicated to calculate because the assessment of value and tax liability is more difficult and varies substantially on a state-by-state basis. However, property tax exemptions have the advantage of being applied to the entire life of the photovoltaic system while the income tax rebate typically only applies to the year of the purchase. Sales tax exemptions also have this disadvantage. The long-term nature of the property tax exemption coupled with its widespread availability present plausible explanations for the effectiveness of the incentive. Ultimately, interviews with solar adopters that used the property tax incentive when purchasing their photovoltaic equipment would be the best research tool to achieve a better understanding of the role this particular incentive plays in influencing residential solar installations.

The presence of loan programs, included in the first specification of each model, was statistically significant in the negative direction for every model. This result is not well explained by the theoretical research in this area because low interest loan programs have not been included in previous studies of solar incentives. As a matter of speculation, two explanations are possible. First, the nature of a loan, even with a subsidized interest rate, is that it increases the long-term costs associated with purchasing solar panels. Rather than receiving a cash payment or a tax refund, loan programs add interest costs to the purchase cost. As such, loan programs, though providing the possibility for liquidity, actually disincentivize purchasing solar photovoltaic technology. The second possibility is that because of the freeze in credit precipitated by the Great Recession that began in 2007, lower income individuals most in need of the immediate liquidity provided by loan programs were not eligible for such programs. While the effectiveness of loan programs and their contingency on external events remains an interesting question for future research, the current data make it impossible to distinguish between these two plausible explanations.

In many cases, the incentives that were consistently insignificant proved as interesting as those that were significant. Because most states implemented performance-based incentive such as feed-in tariffs and solar renewable energy credits only recently, this study is the first to account for them in a quantitative model. In the case of both types of PBIs, they were consistently insignificant in predicting per capita solar installations. When the variable for SRECs was computed as a continuous variable using the actual market value of the credit, the variable approached significance in the robustness check specification of Model 1 with capacity as the dependent variable. This may indicate that SRECs influence the size of the systems installed in the residential sector but not the number of installations. Still, further evaluation of PBIs is necessary before any definitive conclusions about their effectiveness can be drawn. Future studies will be aided by the inclusion of more data as the programs increase their lifespan. For now, it seems that they are not good predictors of per capita solar photovoltaic installations.

Indirect policy incentives also showed mixed results. The presence of a net metering policy proved consistently statistically significant as did the policy regulating the maximum size of a solar photovoltaic system eligible for net metering. Meanwhile, Renewable Portfolio Standards, both general standards and specific solar carve-outs, proved consistently insignificant in the quantitative model, which was a departure from the results of previous studies. By contrast, a closer examination of the situation of the four states in Chapter 7 suggests that the quantitative model might have underestimated the influence of RPS policies and solar carve-outs, as the two states with higher RPS requirements that were also favorable to solar power had higher installation rates despite differences in insolation levels and financial incentives. It is also possible that an RPS is more targeted at commercial and utility sector solar installations while net metering applies more to residential and commercial sectors where distributed generation is more common. Because most direct financial incentives require that solar PV systems be grid-tied in order to receive the rebate or tax incentive, it could be true that net metering acts as a sort of prerequisite program for having other financial incentives.

The final policy hypotheses, 2a and 2b, dealt with whether states presented an advantage to consumers by offering a wider variety of solar incentives. Hypothesis 2a suggests that a higher total number of incentives will correspond to more solar PV installations. This hypothesis was consistently supported. However, Hypothesis 2b states that states with a higher total value of incentives would also have more solar PV installations. In this case, the null hypothesis failed to be rejected in any model. This dual finding presents an interesting conundrum. Under what circumstances could having more policy incentives positively correlate with installations while a higher projected value for the incentives would not correlate with incentives. One possibility is that the amount calculated for the performance-based incentives was too high because the value calculated was the maximum possible output for a 5kW PV system, an amount certain to overestimate reality. Thus, the total incentive amount would be most highly influenced by PBIs, policies that alone were insignificant. Alternatively, it could also be possible that just because a state offered an incentive, it did not necessarily mean that the value of the incentive was high. Many states capped the total budget for incentives at low levels despite the amounts of individual incentives being relatively high. When budgets were depleted, often early in the program years, no further incentives were given out even though they were technically available. Meanwhile, states with low diffusion rates could have been tempted to boost the value of its incentives to spur adoption. Further investigation is necessary to fully explain this conundrum; however, one conclusion remains evident for either explanation. Pouring more money into solar incentives does not necessarily guarantee higher adoption rates, at least in the short term.

8.2 Influence of Solar Radiation

The map of average solar radiation from the previous chapter (Figure 6.3) demonstrated that insolation alone could not explain solar adoption rates at the state level. Despite large amounts of solar radiation present in the southeast, installations per capita in this region remain low. Meanwhile, states in New England and the Mid-Atlantic regions have some of the largest adoption rates in the residential sector even though they possess moderate to low solar resources. Still, the quantitative models show that solar radiation must be taken into account when attempting to understand solar photovoltaic diffusion. Insolation was statistically significant in every model. In the final model incorporating all economic, social, and market control variables, a one percent increase in the amount of solar radiation between states corresponded to between 4.3 and 5.2 percent more solar installations per capita, controlling for the availability of policies related to solar development.

Ultimately, incentives have a limit to how attractive they can make solar photovoltaics appear. For PV technology, the more available solar radiation a state has, the more energy solar panel owners can produce. Especially in states that embrace performance-based incentives, the amount of available solar radiation is probably a more critical factor for anticipating the success of the program compared to states that offer cash incentives that pay a particular amount regardless of actual electricity production.

Still, it is important to remember that a low level of solar adoption does not imply that renewable energy is unpopular. In the central plains states and the Midwest, for example, other forms of renewable energy may be more viable substitutes for solar power including wind and biofuels, respectively. The ubiquity of sunlight, unlike wind or biomass, could mean that the drop-off between resource rich and resource poor areas is more gradual than for other renewable energy resources; however, that is a question for another study. For the purposes of this study, solar radiation is a key time invariant factor that clearly must be controlled for, though these results support the contention that insolation does not, by itself, provide sufficient explanation for residential solar photovoltaic installations.

8.3 Influence of Economic and Socio-Demographic Factors

The fact that some policy incentives appear to have an influence over the decision of residential consumers to adopt solar PV technology only tells part of the story. Only by controlling for other factors that could also influence the solar adoption decision can we fully understand the magnitude of the influence that policy incentives have.

Extant empirical research suggests two large groups of factors influence the decision to adopt solar panels in the residential sector. The first group is economic factors. Chief among these are the price of electricity and the price of a solar installation. Even though some of the solar policy incentives are statistically significant, it is possible that individuals' adoption decisions are more responsive to an additional dollar of electricity cost than an additional dollar of incentive. If this is the case, it would provide a strong argument that state governments should focus their policy efforts on increasing electricity prices, for instance through a higher tax on electricity usage and production, and place less focus on providing financial incentives. By this comparison, solar photovoltaic arrays represent a direct competitor for the incumbent system where electricity is purchased directly from utilities.

Hypothesis 3 suggests that higher electricity costs will lead to more residential solar PV installations in a particular state. Models 2 and 3 show a positive, statistically significant relationship between retail electricity price and per capita residential solar PV installations, providing support for this hypothesis. Model 3c measures both policy variables and the electricity price as continuous variables allowing for a direct comparison between the relative marginal impacts of the two variables on installations per capita.

Because of the structure of the regression model, which provided elesticities for each log-transformed variable, an increase or decrease in the independent variable by one percent would correspond to an increase of decrease in the solar PV installations per capita of the coefficient percentage. Many of the independent variables are measured on different scales, so to make sense of the comparison between them, it would be helpful to identify how much of an increase one percent actually is.

For rebates, the average amount available in all states during the study period was $1080. A one percent increase from the mean, or an increase of $10.80, over the course of a year would correspond to an increase in solar installations per capita of 0.190 percent, or 0.00000013775 installations per capita, which is less than one installation per million residents. Likewise, the mean final value of a property tax exemption for a 5kW solar PV system was $157.11. A one percent increase of $1.57 would correspond to an even smaller 0.083 percent increase in solar installations per capita, less than one installation per million residents, even when the dollar amount is increased to the same amount as the rebate increase.

Meanwhile, an increase of one percent in the mean residential retail electricity price of $0.1174 per kWh, a change of approximately one-tenth of a cent, would correspond to an increase of 1.931 percent in installations per capita corresponding to 1.4 more installations per million residents. Comparatively, the average solar PV system in the study costs 7.53 dollars per Watt (DC). A decrease in the cost of an average solar system of one percent, or $0.075 per Watt, would correspond to a 1.358 percent increase in solar installations per capita. That increase is the equivalent of approximately one solar PV installation per million residents.

These monetary value comparisons demonstrate that dollar-for-dollar, the strongest factor influencing solar adoption is electricity price, followed closely by the retail installation price of a solar PV system. Financial incentives still have a positive influence, but to a lesser degree. It is important to point out that no states completely eliminated their financial incentives during the course of this study. Therefore, it is unclear what the effect on solar PV installations would be of such a policy decision, which is currently under debate in many states. This result echoes the findings of

Diamond (2008, 2009) who found that policy had a relatively weak effect on the adoption of Hybrid Electric Vehicles compared to fluctuations in the retail price of gasoline.

Of course, consumer responsiveness is only one factor to consider when setting policy. Cash incentives require the state to pay out money to private citizens while the imposition of an energy consumption tax to raise the price of electricity, which already exists in most states, would actually generate revenue for the state. Additionally, it is important to consider that a $0.001 increase in the energy consumption tax would be a substantial relative increase that might be met with political opposition even though the net average increase in electrical bills would be small on a monthly basis. For example, the current state energy consumption tax in the Commonwealth of Virginia is $0.00155 per kWh (Commonwealth of Virginia, 2001). An additional tax of $0.001157 would be an increase of 75 percent.

The relationship of installation cost with financial incentives is more theoretically complex. After all, the purpose of financial incentives is to lower the cost of installation. However, this variable accounts for costs before incentives are applied. Factors influencing this cost include technological efficiencies, increasing scale of production, and lower costs due to increasing competition in the industry, among others. It is possible that government attempts to stimulate demand by offering end consumers financial incentives might not be as effective as offering producers supply-side incentives, even though both policies are intended to lower the final cost of the solar photovoltaic system. Hypothesis 4 predicts that states with lower installation cost will have a higher number of per capita solar PV installations. Consistently, the data from the models support this hypothesis.

The influence of socio-demographic factors is also important to understand in order to apply the proper context to the policy and economic results. Although theory suggests that a variety of socio-demographic factors including political conservatism, environmentalism, education, and income should be significant factors in aggregate consumption decisions, the empirical models find that these factors do not matter when economic and policy variables are taken into account. The only demographic variables that were consistently statistically significant were age and race.

Two age groups were consistently statistically significant or approached significance. The first group was between the ages of 25 and 34. States with large percentages of the population in this age demographic had larger numbers of residential solar PV installations than states with smaller percentages of young adults. Generally, the current theory does not have a good explanation for this finding, though it mirrors the finding of the ZIP Code-level study conducted by Kwan (2012). It is possible that states with more renewable energy development or financial incentives are more attractive to a younger demographic, but the potentially endogenous nature of the relationship between age and installation rates should make any researcher take caution when proffering speculative explanations. The other statistically significant age group was 45 to 54 year-olds. This group is in the middle of the lifecycle consumption curve, meaning they are at an age where income and long-term investment behavior are at their peak resulting in the more frequent purchase of large, durable goods such as a solar PV array.

While previous studies have shown that African Americans hold substantially different views on environmental issues than whites, it is unclear whether the negative statistical relationship between solar PV installations and the percentage of African American population in a state is due to these differing environmental viewpoints or due to the fact that the southern United States has a disproportionately high black population and consistently low solar PV installation rate. Because African Americans express seemingly conflicting viewpoints on renewable energy, favoring government incentives funded by increasing taxation but opposing renewable energy policies that would increase retail electricity costs, the relationship between African Americans and solar energy policy is one that scholars should continue to investigate.

The implication of the significance of race and age in explaining solar PV adoption is different than those of the economic variables. For instance, governments can't manipulate these factors through policy intervention in the same way as they can economic factors. However, government agencies responsible for the implementation of solar incentive programs can target the demographic groups that appear most likely to adopt the technology. Additionally, they can ask whether African Americans are inherently less likely to consume distributed renewable energy technology or whether insufficient effort has been made by government agencies and solar installers to inform this minority community of the benefits of solar energy and make them aware of the incentives available for the purchase of such equipment.

Finally, Research Question 2 pertains to the influence of environmentalism over the solar PV adoption decision. This study contributes to the mounting body of evidence that environmentalism is not a deciding factor in consumers' purchase decisions for solar PV technology. The consistent insignificance of this variable suggests that even those without a strong environmentalist ideology can still be enticed to engage in pro-environmental behavior if the economic incentives are properly aligned with the state's goals and communicated to the public. Still, the uncertain effect of environmentalism leaves open a question of whether it plays any role in the diffusion process, not just a direct one. One possible scenario is that instead of directly influencing individuals to purchase solar panels, states with populations possessing a high degree of environmentalism have more policy options, which in turn leads to more installations. In the final regression model created to capture this indirect effect of environmentalism, the variable proved to again be an insignificant predictor of the number of policy incentives available in the state. However, an interesting finding occurred when a number of other socio-demographic variables that were insignificant in the main models were significant predictors of total policy. These included the percentage of the population with a college degree or higher education and the state median income. According to the model, states with a more educated population are likely to have more solar incentives than states with lower education levels. This finding could indicate that solar panels are a product desired primarily by the educated elite. Alternatively, states with a higher median income had fewer residential solar PV installations than states with a lower median income. This finding could be due to the fact that higher income states find policy incentives unnecessary to induce solar PV diffusion.

Though the role of environmentalism remains obscure, the answer to Research Question 2 is that there appears to be neither a direct nor an indirect effect of environmentalism on solar diffusion. More interestingly, there appears to be no propensity for states to sort themselves into pro-solar and anti-solar states on the basis of environmentalist ideology. Instead, evidence continues to mount supporting the contention that adopting solar PV is an economic decision that will occur in any jurisdiction where it makes good economic sense. While pro-environmental behavior can be part of an individual’s utility function, it is not a strong and ubiquitous enough of a factor to be demonstrated in aggregate consumer behavior.

8.4 Influence of Market-Related Factors

One substantial addition to the literature on solar diffusion offered by this dissertation is the examination of several market-related factors not explored in previous work. The first of these factors is the effort undertaken by states to market and generate public attention for their programs. Theory suggests that marketing incentive programs, especially generating public awareness of the program existence and how to qualify for the incentive, is a key component to the success of such policy programs, yet there exists no quantitative empirical evidence documenting the effect of marketing effort on any solar incentive program in the residential market segment.

The variable for marketing effort was measured as the total number of clicks required on the website of the state governmental department charged with managing the solar incentive programs to obtain information about those incentives. Certainly there could be other, more complex measures of marketing effort, but this measure provides an initial entry into this line of research, which has heretofore been unexplored.

Hypothesis 5 proposed that higher marketing effort would correspond to a higher number of per capita installations. Because fewer clicks on the website corresponds to a higher marketing effort, the relationship between the independent and dependent variable should be negative. In two of the four model specifications, marketing effort was statistically significant with a p-value below 0.05 for a one-tailed hypothesis test. Additionally, the direction of the statistical relationship was negative, meaning that fewer clicks (i.e. higher marketing effort) corresponded to higher per capita installation rates. This relationship existed in both models where policy was accounted for by a continuous variable. Conversely, the marketing effort variable was insignificant when policy was simply a dummy variable.

Though this result provides support for the idea that marketing matters, it is far from conclusive proof. Future research must find a better variable for measuring marketing effort. Some possible substitutes include creating an index that accounts for online marketing efforts as well as traditional marketing channels such as television and outdoor advertising reach. Additionally, state spending on marketing could be determined by interviewing or surveying individuals from state departments of energy. If nothing else, these statistical model results open up the possibility for a future strand of research focused on the power of marketing renewable energy incentive programs.

However, marketing was not the only key market variable identified. Another was utility support. When presented with a government program that offers an alternative to utility-supplied power, namely distributed generation in the form of solar photovoltaics, the utilities in a state could attempt to thwart efforts to aid in the expansion of solar themselves. Thus, a variable was included in the study indicating the percentage of electric utilities in a state that offered their own solar incentives.

As with marketing effort, utility support was statistically significant in two of the four model specifications with a p-value of below 0.05 for a one-tailed hypothesis test. Also, the variable was statistically significant in the specifications where policy was a continuous variable. Increasing the number of supportive utilities by one percent increased the per capita solar photovoltaic installations by between 6.3 and 5.7 percent. Because policy is controlled in both models, this increase is in addition to the increase accounted for by the policy variables. Unfortunately, it is unclear from this data whether utility programs complement state policy efforts or compete with them, but the basic relationship seems to be that having more channels to obtain incentives increases the adoption of solar technology.

This relationship will also have to be further explored in future research. Based on the data collected in this study, it is impossible to conclude whether utility incentive programs might harm the utilities in the long run, initiating the rate payer death spiral feared by utilities that tend to oppose state incentives for distributed electricity generation. Moreover, better measures of utility support could provide clarity for this relationship. Such a variable could be generated by interviews and content analysis of news stories covering state renewable energy incentive programs, yet this data provides at least an initial indication that it is important to assess how utilities react to these incentive programs and that obtaining their support might be advantageous for policy makers in achieving their ultimate goal of expanding the diffusion of renewable energy technology.

Hypothesis 7 suggests that the more solar equipment installers there are in a state, the more installations will occur. This hypothesis does not appear to be well supported by the evidence. The variable for the number of installers in a state was only statistically significant in one model specification and actually detracted from the total explanatory power of two specifications. Additionally, the addition of one solar installer only corresponded to a 0.3 percent increase in per capita solar installations. Although theoretically it makes sense that a large number of installers would increase the visibility and availability of solar technology while decreasing the retail price of a solar photovoltaic installation because of increased competition, this relationship is unsupported by the evidence in this study. An explanation for this lack of a relationship could be the fact that all states had at least one solar installer and that individual installers are successful at growing to keep up with demand, resulting in few new market entrants. In the end, further investigation is needed, but this result does conform to evidence from other studies (Zahran et al., 2008; Kwan, 2012) that found either no relationship or a weak relationship between solar installations and proximity to a solar installer.

Lastly, this study controlled for the presence of a mandatory green power option. While the GPO is technically a policy, its purpose is to compete with distributed electricity generation by offering an alternative option for consuming sustainable electricity without the capital and labor intensive process of placing renewable energy generation equipment on an individual's property. Hypothesis 8 proposes that, as a chief competitor to solar panels, the presence of a mandatory GPO will correspond to fewer residential solar photovoltaic installations. The variable was statistically significant in two of the four model specifications with a p-value below 0.05 for a one-tailed hypothesis test. The presence of a mandatory GPO corresponded to between a 108 and 130 percent decrease in the per capita solar photovoltaic installations.

Therefore, GPOs represent a viable alternative to distributed renewable energy generation. On one hand, this result could be interpreted as a case of there being more than one way to skin a cat. GPOs provide electricity consumers with a cheaper and possibly easier way to go green and reduce carbon emissions. However, policy makers should probably consider whether the presence of a mandatory GPO might be decreasing the effectiveness of solar incentives in the residential sector and consider pursuing one policy or the other, but not both.

Taken together, the market condition variables provided some initial evidence that supports theoretical relationships between key factors that any policy maker should consider when implementing solar policy incentives. However, these variables added little explanatory power to the overall model, and despite their inclusion, a substantial portion of the variance remains unexplained. The inclusion of these variables to the previous model increased the r-squared value between 0.01 and 0.07, explaining at most 7 percent of the total unexplained variance from the previous model.

8.5 Contribution to Theory

The quantitative model and hypotheses that make up the foundation of this study were firmly rooted several theories of technology adoption. Most studies of this kind are built upon Consumer Choice Theory that predicts that an individual will adopt a new piece of technology over the status quo technology when the technology provides them a higher level of utility. That utility is theorized to be a function of the price of the technology, the individual's characteristics, and the technology characteristics. In contrast, the Theory of Environmentally Significant Behavior suggests that contextual factors that are exogenous to the individual and the product, including public policies that incentivize adoption, communication, and market characteristics, increase the likelihood of adoption. The results of this study provide some support for both theories. Clearly, the marginal contribution of solar PV policies, even those that are effective, are small compared to the marginal effect of electricity prices and the prices of solar installations. However, the significance of contextual factors such as policy incentives, marketing effort, utility support, solar installers, and green power options provide an indication that these factors matter, particularly for high cost environmentally-friendly behaviors like purchasing expensive solar PV equipment. Given the imperfect nature of the measurements chosen for these non-policy contextual factors, future studies should continue to assess the importance of these factors for predicting or causing environmentally significant behavior.

Moreover, the Theory of Environmentally Significant Behavior makes the additional prediction that as the cost of a specific behavior increases, environmentalism becomes less important to predicting the likelihood of engaging in the behavior while contextual factors become more important. Again, the evidence from this study supports this prediction. Environmentalism appears to have neither a direct nor an indirect effect on solar PV installation rates. The absence of a direct effect supports previous empirical studies that have shown no significant effect of environmentalism on renewable energy adoption. Meanwhile, this study shows that environmentalism does not indirectly influence adoption rates by influencing the adoption of multiple solar PV policies to be adopted within a particular state. The diminished role of environmentalism in the adoption of environmentally significant behaviors is important beyond policy making. It implies that the adoption of environmental behaviors do not require people to also adopt environmental beliefs or values. In fact, as Stern (2000) suggests might be the case, individuals can adopt pro-environmental behaviors without environmental intent, making these behaviors much more likely to be widely adopted. However, contextual factors must support the adoption of these behaviors.

8.6 Implications for Policy Makers

The results discussed above can provide guidance for policy makers considering changes to existing solar PV incentives or contemplating instituting some sort of solar policy for the residential sector for the first time. These recommendations are especially important in states that are considering repealing or severely limiting incentives. They are each outlined below in detail.

Cash incentives including rebates and grants are effective at encouraging consumer demand for solar photovoltaics.

The most effective policies for encouraging solar PV diffusion in the residential sector are cash incentives. They are powerful influencers of consumption decisions when compared to other possible financial and policy incentives that could be implemented but also when compared to other factors that influence consumption decisions. The findings of this study support the findings of Shrimali and Kniefel (2011), Sarzynski et al. (2012), and Shrimali and Jenner (2013), each of whom found similar results using slightly different models. This makes sense because cash incentives combine the advantages of immediacy with certainty. The rebate amounts are often known before the purchase is made, or at least the value of the incentive is easier to compute than incentives based on labyrinthine and cumbersome tax codes. In the case of grants, the money arrives prior to the purchase of the system, though these programs are rare and only exist in three states.

It is also important to recognize the importance of net metering for the residential sector. Net metering serves as a prerequisite for qualifying for many of the incentive programs including the cash incentives. It is unlikely that cash incentives would be as appealing or effective if utility companies in several states are successful at repealing this indirect incentive.

Tax expenditures are generally not as effective as cash incentives, though property tax exemptions were shown to be an effective tool for encouraging solar development.

The evidence in support of using tax incentives for solar deployment in the residential sector remains mixed. Income tax credits, which had previously been shown to be effective when all sectors are taken together, failed to be significant in the residential sector alone. Sales tax exemptions continue to appear ineffective, which is a puzzle because they seem to be both immediate and relatively easy to calculate. It is possible that sales tax exemptions become quickly taken for granted because they are automatically taken off of the price of the installation, but this explanation remains unclear and cannot be gleaned from aggregate consumer data.

Property tax exemptions, on the other hand, do appear to me minimally effective at influencing solar PV adoption. Though computing the actual savings from this policy is complex, it does promise financial savings for the life of the solar array, unlike income and sales tax incentives, which are typically offer only one-time savings. Further studies of income tax credits should examine whether policies that offer deductions in more than one year are effective.

Ultimately, tax expenditures as incentives for residential solar diffusion ought to be evaluated not by whether they exist, but by how much they are used. Certainly, state tax agencies keep records of how many exemptions are claimed and how much the total actual value of the credits is. Just because the presence of an incentive program correlates with a higher number of installations doesn't necessarily mean that the program is being used. Moreover, the complex nature of tax credits and itemized deductions in general makes it likely that these programs are underutilized. Perhaps the reason that income tax credits become statistically significant when commercial and utility sectors are included in the data is that commercial enterprises and utilities have accounting departments that are paid to maximize their eligible deductions? This area could certainly prove fruitful for further investigation.

Not all incentive programs are created equal. PBIs have yet to be shown to be as effective as cash incentives and loan programs might be counterproductive.

This study goes beyond any other on the same subject by including a number of solar incentives that have yet to be examined. One such type of program is performance-based incentives. Despite their popularity and perceived effectiveness in Europe, these programs have yet to move the needle on residential solar PV installations in the United States. Two types of performance-based incentives were examined together and separately, and neither made a statistically significant impact on per capita solar PV installations. Still, it is important to recognize that these programs are relatively new compared to other types of incentives and may require time before their effect is fully evident in aggregate data. Despite little help with upfront costs, these programs are designed to increase the return on investing in a solar PV system over the long-term. Additionally, these programs become more lucrative as the size of a photovoltaic system increases, so they may be more effective in the commercial sector than in the residential sector.

This study also examines loan programs; however, the presence of a loan program appears to correspond to fewer solar PV installations per capita. It is possible that the time period selected for this study is the cause of this effect. States that relied on loans as their primary form of incentive would likely be affected by the Great Recession and the concomitant credit freeze that occurred during the study period. Moreover, consumers could also weigh the advantages of having upfront liquidity with the disadvantages of long-term interest payments and decide that financing solar PV equipment with a loan does not make good financial sense. Whatever the reason, future studies must continue to include and evaluate the effectiveness of loan programs in the residential sector.

Blindly spending more money on incentive programs is a suboptimal strategy compared to targeted spending on programs that have a proven record of success.

When the potential value for solar incentive programs was calculated for each individual program, several continually achieved statistical significance, yet when the value of all the programs was taken together, the variable did not achieve significance. This serves as a preliminary indication that low rates of solar PV diffusion cannot be simply addressed by increasing budgets. For policy makers, it's often easy to just increase funding across the board when programs aren't producing expected results. However, the results of this study, along with others like it, indicate that the better strategy is targeted spending on programs that have demonstrated their effectiveness, primarily rebates, grants, and property tax exemptions. A possible solution for increasing the budgets for these programs is to divert money from programs that have not proven to be effective like income tax credits, sales tax exemptions, and subsidized loan programs. Alternatively, states could raise money to fund these programs through energy consumption taxes, which according to this study would be maximally effective by simultaneously increasing electricity prices and increasing funding for effective solar incentive programs.

Increasing incentive funding is less effective at influencing higher adoption rates compared to increases in electricity prices through taxation or efficiency-related decreases in the retail installation cost of solar PV systems.

Analysis of the marginal effect for various policy strategies to influence solar PV adoption demonstrates that increasing cash incentives would not be as effective as a comparable increase in the electricity price or decrease in the retail installation price. Previous studies of other environmentally friendly products, namely hybrid-electric vehicles, have shown that adoption rates are most heavily influenced by the price of the incumbent technology, or in the case of hybrid-electric automobiles, its primary input gasoline. It appears from this data that a relatively small increase in electricity prices would generate as much adoption behavior as substantial increases in incentive funding levels. Perhaps this is because the increase of a dollar in the consumer's electric bill is analogous to a penalty that consumers will seek ways to avoid while financial incentives are a benefit that only become real once the consumer has considered installing a solar PV system. Whatever the reason, it is clear that cash incentives do not provide the biggest bang for the buck for policy makers looking to influence solar adoption, even though they do have a likely effect at the margin. Still, this study does not consider a scenario in which incentives are completely eliminated, as is currently under debate in a number of states. It is also important to realize that these policies are not mutually exclusive and in fact can be pursued simultaneously. It is possible that raising tax revenue by increasing the energy consumption tax and subsequently using that money to fund solar cash incentives could be even more cost effective for state governments.

Program creators and managers should not forget to emphasize marketing and consider other market related factors.

Previous studies have overlooked market characteristics that could favor or hinder efforts to increase solar PV adoption. One important factor is whether the solar incentives are effectively marketed to potential solar consumers. While states make great efforts to create and effectively implement solar incentive programs, it is a certainty that individuals cannot use programs they do not know exist. This study made the first effort at measuring the prominence of state energy departments' efforts to market their programs to the public. The results showed that the states where information was easy to find on the department's website also had the highest installation rates. This measurement is far from comprehensive and in no way presupposes a causal relationship, but it does provide a springboard for future work in this area.

Further studies should also continue to consider the role played by utilities in supporting or opposing solar incentives as well as the availability of licensed solar PV installers. The complex nature of the equipment and installation process necessitates the presence of such experts in a geographic area. Limitations on installers' ability to quickly install solar PV systems will undoubtedly affect the installation rates in a particular area. Since this study began, utilities and other private companies have greatly expanded the option for solar leasing. Under this arrangement, households are paid a flat rental rate for the utilities to place solar panels on their homes. The individuals never own the solar panels or any relevant renewable energy certificates; however, property owners incur no upfront costs to have solar panels on their homes and make money from charging rents on day one. Future studies should examine the effect that the proliferation of solar leasing programs has on decisions to purchase solar panels and overall solar PV diffusion.

Lastly, policy makers should consider whether some of their policies are hindering their ultimate goals of increasing solar diffusion. This study provides evidence that one such policy, a mandatory green power option offered by utilities to their customers, may actually hinder the diffusion of distributed solar PV in the residential sector. Green power options act as a competitor to solar PV for the consumer. They have no upfront cost and do not require the installation of equipment, yet the consumer derives similar psychic benefits from engaging in pro-environmental behavior. Policy makers should consider selecting one of these options but not both.

8.7 Conclusion

Beneath the backdrop of state fights over solar incentives and state government efforts to save money in the wake of the Great Recession, this study adds to the literature on the effectiveness of incentives for solar photovoltaic diffusion in the residential sector. It takes the approach that the decision of a consumer to purchase solar PV technology is inherently similar to the decision-making process for other large durable goods purchase, namely, that purchase decisions will occur if the utility gained from the purchase outweighs the cost. As a result, the diffusion for solar PV is theorized to follow a logistic curve, as with the diffusion of any new technology.

Scholars theorize a host of different factors that contribute to either the utility or the cost of such a purchase. Some emphasize monetary factors while others include an array of cognitive and affective dimensions to the consumption decision. Whether through engaging in communication efforts, changing the physical environment, or providing financial incentives, public policy can influence the calculations that lead to the decision to purchase or not purchase solar PV systems. Because the incumbent system for electricity generation imposes costs to all of society in terms of air pollution and carbon emissions that contribute to global climate change, the government has a role to play in socializing the costs of finding viable alternative sources of energy. However, these programs cost taxpayers money, and governments must be certain that they are maximally effective.

Previous studies have attempted to evaluate the effectiveness of policy incentives for solar PV, controlling for many factors that also influence the purchase decision, but few studies have focused exclusively on the residential sector. Though smaller than they commercial or utility sectors in terms of total installed capacity, the residential sector accounts for the most installations and continues to grow. Moreover, it is the most relevant sector for the application of consumer theory because purchases of solar PV in the residential sector more closely resemble the purchase of other large, durable goods. Previous studies have also failed to include newer policy incentives including performance-based incentives such as feed-in tariffs and solar renewable energy credits. Additionally, previous studies have not included characteristics of the market environment for solar in each state including accounting for efforts at marketing the incentive programs, the support or opposition of electric utilities, and the presence of licensed solar equipment installers. Lastly, they have been unable to control for the effect of declining prices for solar installations not related to incentives offered by the state.

Using the knowledge gained from Consumer Choice Theory and the Theory of Environmentally Significant Behavior as well as previous empirical study results, this study proceeded to model the aggregate solar PV consumption decisions at the state level. A cross-sectional time series model, or panel model, using both random and fixed effects specifications was employed. The random effects model was chosen specifically so the effect of several time invariant characteristics could be assessed, particularly the effect of solar radiation resources.

The results of the quantitative model showed that rebates, grants, and property tax incentives were all associated with higher levels of solar PV installations. Other types of policy incentives including income tax incentives, sales tax exemptions, and performance-based incentives were not related to more solar PV adoption. It is likely that the residential sector differs substantially from the other sectors and that many of these policies could be effective for commercial enterprises seeking distributed solar power or utilities seeking to build a large solar PV generation facility. Looking at market characteristics proved fruitful, suggesting that marketing efforts enhance the effectiveness of incentives and that installations rates are substantially different in states with utilities that support distributed solar through offering their own incentive programs compared to states where they are not supportive. Despite the inclusion of these new factors, approximately one-third of the variance in installations per capita remained unexplained, indicating the need for further work in this area.

Most importantly, this study confirmed that government programs can effectively drive demand for a pro-environmental consumer good, even among people that do not possess a strong environmental or liberal ideology. It illustrates that economic conditions matter and that consumers see solar PV as an alternative to the incumbent system of electricity generation and distribution. Additionally, increasing either the cost of electricity or decreasing the pre-incentive solar installation cost has a greater effect, dollar-for-dollar, than increasing the amount of money available for cash incentives or property tax exemptions; although, all of these strategies would be an effective way to increase the demand for solar PV systems. Moreover, by identifying programs that are effective and those that are not, this study will allow policy makers to target funding toward programs that work and potentially save money by defunding programs that are ineffective.

As with most research, this study generates more questions than it answers. However, this study plays a vital role in advancing the knowledge on solar photovoltaic diffusion and answers a number of important questions about the government's role in the solar market and how it can more effectively achieve its objectives, in light of how large groups of individuals make their purchasing decisions. It provides continued evidence that the government can provide small nudges that have a tremendous influence on behavior without imposing substantial harsh and unwieldy regulation. It might be too early to declare a rooftop revolution, but targeted incentive policies set at the right level have the potential to change the way electricity is produced and consumed within the United States and might allow the U.S. to improve environmental quality and mitigate the impacts of global climate change.

Appendix A

The table in this appendix, Table A.1, presents the results of the final panel regression model described in Chapter 6. It contains all relevant party variables, economic covariates, socio-demographic covariates, and market characteristics. The coefficients for the statistically significant covariates are fully described in the text of the chapter.

As with the other two panel models, this model was run in four different specifications, each accounting for solar PV incentives in a different way. The details of these specifications can be found in Chapters 4 and 6. Specifications a and c were run under random effects assumptions while specifications b and d contain state and year fixed effects. The justification for these different panel model assumptions is based on the results of Hausman Test results presented in Chapter 6.

Table A.1: Final Model Comparison for Solar PV Installations Per Capita

	Model 3a (re)	**Model 3b (fe)**	**Model 3c (re)**	**Model 3d (fe)**
net_meter	.771 (0.401)^{t}			
rebate	1.519 (0.599)*			
property_tax	0.488 (0.246)*			
income_tax	-0.050 (0.348)			
sales_tax	0.100 (0.485)			
fit	-0.112 (0.569)			
srec	0.530 (0.571)			
loan	-0.804 (0.267)**			
grant	2.503 (0.583)***			
rps2	0.146 (0.426)			
solar_rps	-0.236 (0.537)			
total_policy		0.511(0.182)**		
nm_max			0.025(0.005)***	0.024 (0.006)***
ln_rebate			0.190 (0.073)**	
ln_property			0.083 (0.045)^{t}	
ln_income			-0.031 (0.055)	
ln_sales			0.004 (0.063)	
ln_fit			0.011 (0.087)	
ln_srec			0.022 (0.073)	
ln_grant			0.293(0.081)***	
ln_incentive				0.028 (0.068)
ln_epricereal	1.708 (0.602)**	1.609 (0.910)^{t}	1.931 (0.652)**	1.949 (0.828)*
ln_inpricereal	-1.340 (0.535)*	-1.298(0.590)*	-1.358 (0.535)*	-1.999 (0.483)***
ln_gdppc	1.196 (1.006)	3.274 (1.715)^{t}	1.613 (1.184)	1.910 (1.525)
ln_age25	5.694 (3.370)^{t}	7.047 (3.732)^{t}	7.054 (3.221)*	8.554 (4.135)*
ln_age45	8.352 (4.480)^{t}	8.874 (5.245)^{t}	8.692 (4.684)^{t}	11.316 (4.988)*
ln_college	-1.565 (1.431)	0.054 (1.718)	-0.586 (1.520)	-0.355 (1.831)
ln_black	-0.439 (0.180)*		-0.390 (0.162)*	-0.390 (0.172)*
ln_conservative	0.046 (0.120)		0.038 (0.120)	0.025 (0.129)
ln_environment	0.316 (0.268)	0.277 (0.285)	0.248 (0.271)	0.339 (0.283)
ln_insolation	4.382 (1.356)**		5.200(1.407)***	
marketing	-0.106 (0.107)	-0.144 (0.140)	-0.232 (0.118)*	-0.214 (0.127)^{t}
installers			-0.000 (0.003)	0.003 (0.002)^{t}
utility_support	0.048 (0.028)^{t}	0.067 (0.036)^{t}	0.063 (0.040)	0.057 (0.038)
gpo	-0.481 (0.449)	-0.757 (0.554)	-0.736 (0.433)^{t}	-0.836 (0.504)^{t}
R^2	0.5739	0.3031	0.6028	0.2478

[1] t = p<0.05, one-tailed; * = p<0.05, two-tailed; ** = p<0.01; *** = p<0.001

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Biography

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