Rooftop Revolution?: Comparative Effectiveness of State Policy Incentives for Encouraging Residential Solar Adoption in the United States

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Abstract:

Are state policy incentives effective tools for encouraging private citizens to invest in their own solar power generation systems? This study seeks to discover what state-level policy incentives are most effective in promoting the adoption of residential solar photovoltaic (PV) power systems.

The high cost of solar photovoltaic systems is one of the key factors preventing widespread adoption of residential solar power systems. As a result, state governments have come up with an array of different policy incentives to bring down both the short and long-term costs of installing solar power systems. Still, solar resources and incentives vary widely between the states. More information is needed to determine which of these policies or policy regimes is most effective, especially when controlling for several key factors including the availability of solar resources and state economic conditions.

This study will look at the rate of residential solar photovoltaic installations per state over a particular period of time (2009 – 2012). Linear regression analysis indicates that policy incentives are generally ineffective at influencing adoption rates when environmental, economic, and social factors are controlled. The most effective policy incentives appear to be net metering and rebate programs.

Keywords: solar energy, photovoltaic, policy incentives, state energy policy, solar adoption

Introduction

The high cost of solar photovoltaic systems is one of the key factors preventing widespread adoption of residential solar power systems. During the last decade, state governments have come up with an array of different 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, and net metering.

Still, incentives and adoption rates 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 resources (i.e. solar radiation) and state economic conditions.

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 study 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.

Review of Literature

Public policy has long had a close relationship with the adoption of renewable energy technology, including solar power. 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, among other things (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. However, the Reagan administration saw many of these policies dismantled, at least at the federal level.

In the absence of federal programs to encourage renewable energy innovation and diffusion, state and local governments began playing a greater role in the public policy process. 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, all states have some type of policy incentive for solar power installations geared toward either the residential, commercial, or utility sectors.

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 (PV) panels or solar thermal electricity plants (National Academy of Sciences, 2010). Solar PV involves the direct conversion of solar radiation into electricity while solar thermal uses the sun's heat to convert liquids to steam that generates power by turning a large turbine. While solar thermal electricity generation requires a large industrial facility to generate power, Solar PV 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 PV 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 only accounted for 488 megawatts of the 3313 total megawatts of new solar energy capacity 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 utilities. Additionally, while solar deployment in all three areas (residential, commercial, and utility) is increasing, new utility-scale projects are currently driving the large increase in solar capacity. Residential solar PV systems are often expensive to install, require trained professionals to install and connect the systems to the power grid, and have fluctuating pay-back periods due to the volatility of the price for energy and the fact that solar resources fluctuate with both the time of day and year.

Still, the number of residential solar installations continues to increase for a number of reasons. First, solar power is clean and effectively displaces power generated using fossil fuels, which pollute the atmosphere and contribute to climate change by emitting carbon dioxide (Tsoutsos, Frantzeskaki, and Gekas, 2005). Second, solar power installations, especially PV, 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 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 PV systems through policy incentives aimed at reducing the overall cost and shortening the time period to realize a return on investment.

Factors Affecting the Adoption of Residential Solar PV

A number of studies have addressed the spatial distribution of solar power systems. One of the most commonly identified explanatory factors for solar system distribution identified in the academic literature is the availability of solar radiation. 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. 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).

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 they point out the critical role of economic considerations.

While there continues to be an argument over the relative influence of environmental and economic conditions, other studies have also recognized the importance of social factors. In examining the geographic distribution of Solar PV adoption in California, Bollinger and Gillingham (2010) 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). 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) or because of their identification with pro-environmental values and association with environmental protection groups (Sawyer and Wirtshafter, 1985). Each of these studies provide evidence that important social factors, to the extent that they can be effectively and accurately modeled, should not be ignored.

Zaharan et al. (2008) created a national, county-level multivariate model to predict the spatial distribution of active solar-powered heating systems. They found that a variety of environmental, economic, and sociopolitical factors were required to explain the geographic distribution. Among the important explanatory variables in their model were solar radiation, temperature, median home value (proxy for wealth), urbanization, the percentage of residents in the peak phase of the lifecycle consumption curve (age), the percentage of residents voting Democratic, and local government involvement in the International Council for Local Environmental Initiatives (ICLEI). Strangely, the availability of policy incentives was not included in their model or analysis at any stage. This study illustrates the complex nature of the residential solar adoption decision but shows that there are still other factors that remain to be explored in this area.

Though several of the previously cited studies note the import role of tax incentives, none examine the vast array of other policy initiatives designed to incentivize the adoption of solar power systems. Moreover, all of the studies on residential adoption of solar technology include installation of any solar power technology. In fact, all of the studies with the exception of Zaharan et al. (2008) only focus on solar water heaters. None concentrate exclusively on Solar PV adoption. Meanwhile, many policy incentives enacted recently are geared specifically toward incentivizing Solar PV adoption.

Modeling Solar PV Adoption

The consumer decision-making process for purchasing a solar PV system can be conceptualized as similar to that of any large, durable goods purchase. The consumer has some sort of utility that he is attempting to achieve. This theoretical model has been applied to other pro-environmental, durable good purchases such as hybrid electric vehicles (Diamond, 2009). 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):

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

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, which is 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 power generation for society can be expressed as equation 2:

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

Solar PV adoption differs from automobile adoption in that the primary decision a consumer must make is whether to leave the established electricity provider (r = 0). Once this decision is made, the selection of an alternative form of energy generation requires another utility estimation. When aggregated, 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:

$$R_{stj} = f(p_j, x_j, \xi_j, \zeta_s; \theta) \quad (3)$$

In this case, U is no longer individual utility but instead represents the aggregate utility of solar PV purchasers at the state level. 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:

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

In order to estimate parameters, a standard linear regression model was used. The standard 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. The final model used in this study is given by the equation:

$$\log R_{stj} = a + \beta_1 \log Incentives_{stj} + \beta_2 \log Radiation_{st} + \beta_3 \log Income_{st} + \beta_4 \log GSP_{st} + \beta_5 \log Urban_{st} + \beta_6 \log Liberal_{st} + \varepsilon_{it} \quad (5)$$

A description of each of the variables including the different types of incentives used in this study can be found in the following section.

Types of Residential Solar Policy Incentives

There are a variety of state-level policy initiatives that use different mechanisms to incentivize the purchase and installation of solar PV systems. Ultimately, these incentives serve to affect the consumer price of purchasing solar power systems, though in a number of different ways. Some of the key differences in these policies are described below.

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 solar PV power systems. Alternatively, a state may decide to offer a personal income tax credit. Finally, other states provide a property tax exemption for the increased value of a property due to solar equipment installation. The type of tax incentives offered by a particular state depends heavily on the type of tax structure within the state. For instance, many 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 incentives is to reduce the overall cost of solar PV systems, yet they require the installer to pay all of the cost upfront and thus do little to reduce the initial investment required.

Grant and Loan Programs

On the other hand, grant and loan programs are aimed specifically at reducing the upfront cost of solar installations. Grants provide small amounts of money that are not required to be paid back. As a result, grant programs are rare and difficult to qualify for. In contrast, 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. Loan terms and maximum borrowing limits vary from state to state, and 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) financing, 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.

Rebates

Rebates are another way to decrease the overall cost of solar PV systems without reducing the upfront cost. Once solar power equipment is installed and certified by a government agency or private certifier, state governments will grant purchasers a cash rebate. Rebate amounts can vary substantially from state to state and often are distributed over the course of multiple years, diminishing the effectiveness of the cost reduction effort. Still, it is important to recognize that rebates do play a role in shortening the time required to realize a return on investment (ROI).

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 two of the most common. Feed-in tariffs involve long-term contracts (15 – 20 years) guaranteeing a price slightly above market rates. The purpose of these policies is to provide power companies with an adequate supply of renewable energy to purchase in states with Renewable Portfolio Standards. Because the terms of these contracts differ so widely across states, it is difficult to compare them. Still, they remain an important policy tool, especially in European countries like Germany where they have been tremendously effective at increasing the nation's available solar power resources.

Net Metering

Lastly, net metering is a policy that allows residential solar power producers to sell their power back to the grid, often at market rates. The details of net metering policies at the states differ widely. In some states, the size of eligible Solar PV systems is restricted, as low as 10 to 25 kilowatts. 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. Yet, net metering proves to be quite popular in the United States with only 5 states having no policy for net metering.

Hypotheses and Research Question

While past studies have extensively examined the effectiveness of tax incentives and provided scant evidence about a few other policies aimed at influencing the adoption of residential solar PV systems, none have provided a comprehensive and comparative examination of state-level policy efforts. Are state policy incentives effective tools for encouraging private citizens to invest in their own solar power generation systems? This study seeks to discover what state-level policy incentives are most effective in promoting the adoption of residential Solar PV power systems.

Based on evidence from previous studies, this study will attempt to create a multivariate model to predict increasing adoption rates at the state level. Because national policy currently focuses primarily on research and development and supply-side incentives while local policy efforts are too diffuse and vary widely between different cities and counties, states provide the best geographic unit to test the effectiveness of policy incentives. The null hypothesis for this study is that state incentives do not influence adoption rates. However, it might be the case that states with many different types of solar incentives give citizens the best opportunity to become solar power adopters, leading to higher adoption rates. The extant research on this topic leads me to formulate the following hypothesis:

H1: States with more policy incentives for solar adoption will have significantly different rates of adoption than states with fewer incentives, controlling for other factors.

When it comes to evaluating the individual policy incentives, net metering stands out as different than the other incentives. While most incentives provide a defined financial benefit, net metering policies instead set up a framework for individuals with installed solar power systems to connect to the grid and sell their power back to the grid, without the guarantee of any specific amount of money. As mentioned earlier, net metering policies vary in several dimensions between states. One such way is the maximum size of the system allowed. It stands to reason that net metering policies that allow residential customers to hook up larger systems to the grid would be more attractive because the more power a customer is allowed to generate, the more money he can make selling power back to the grid. Thus, I formulate the following additional hypothesis:

H2: States with higher maximum limits for net metering will have significantly different adoption rates than states with lower limits, controlling for other factors.

Finally, previous research has not sufficiently identified the role of state policy incentives. Even more importantly, research has not compared the effectiveness of incentives to one another. Therefore, I propose the following research question:

RQ1: Which policy incentives, if any, are most effective in influencing residential solar PV adoption?

Data and Methodology

Utilizing data from multiple sources, a state-level data set was constructed. The dependent variable was based on the number of solar photovoltaic installations per state recorded as a part of the Open PV Project (https://openpv.nrel.gov/), a collection of voluntary data on new solar photovoltaic installations identified by state and zip code and maintained by the National Renewable Energy Laboratory. Because of the small number in many years, the installations were aggregated over three years (Jan. 2009 to Jan 2012), resulting in a three year, cross-sectional dataset. All policy incentives examined in this study were present over the entire time period.

The main independent variables, data about the policy incentives in each state, came 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. Most policy variables were coded using a dummy variable coding scheme where 0 indicates the absence of a particular policy and 1 indicates its presence. There were several exceptions to this rule. Because all but three states had some sort of net metering policy, the maximum size limit for the PV system in each state was used. For loan programs, the maximum loan about was used.

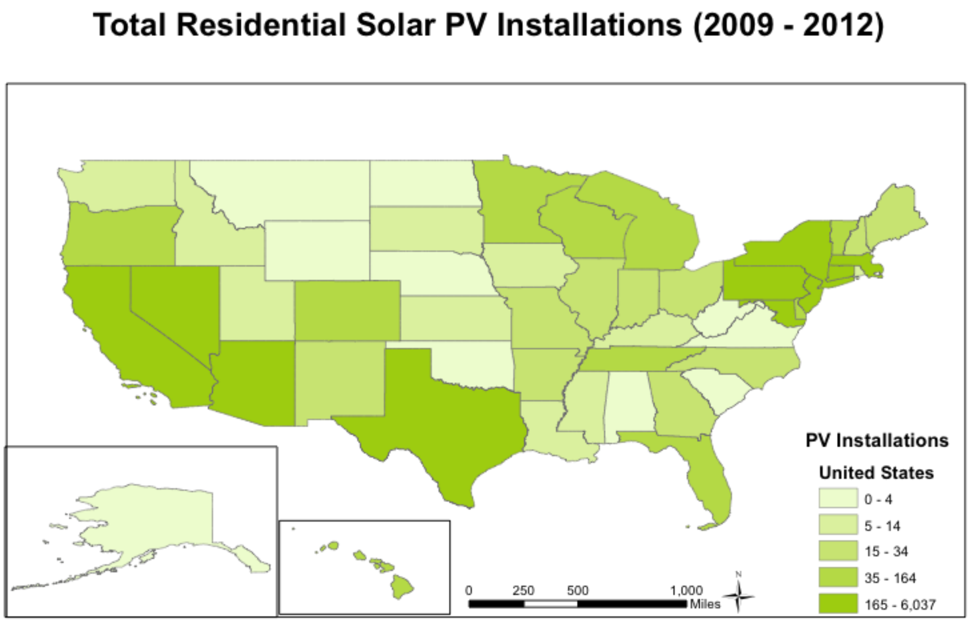
All control variables and geographic shape files came from either the U.S. Census Bureau American Fact Finder or the National Solar Resources Database. Demographic data for states were calculated using three-year averages because of the multi-year, cross-sectional nature of the data. Important control variables include environmental (solar radiation), economic (gross state product, average income), and social (percent urban population, party control of state politics, average age, percent voting for President Obama in 2008) factors.

Results

Based on the data about residential photovoltaic installations from the Open PV Project, I created several choropleth maps showing the geographic distribution of residential installations per state and solar radiation in the United States. The numbers represented by the shaded areas in the map (Figure 1) are the total number of installations occurring in the three-year period from January 2009 to January 2012. The five different classes of installations represent different quintiles, an approach which seemed to best represent the distribution of the data, with only a few states having high numbers of installations.

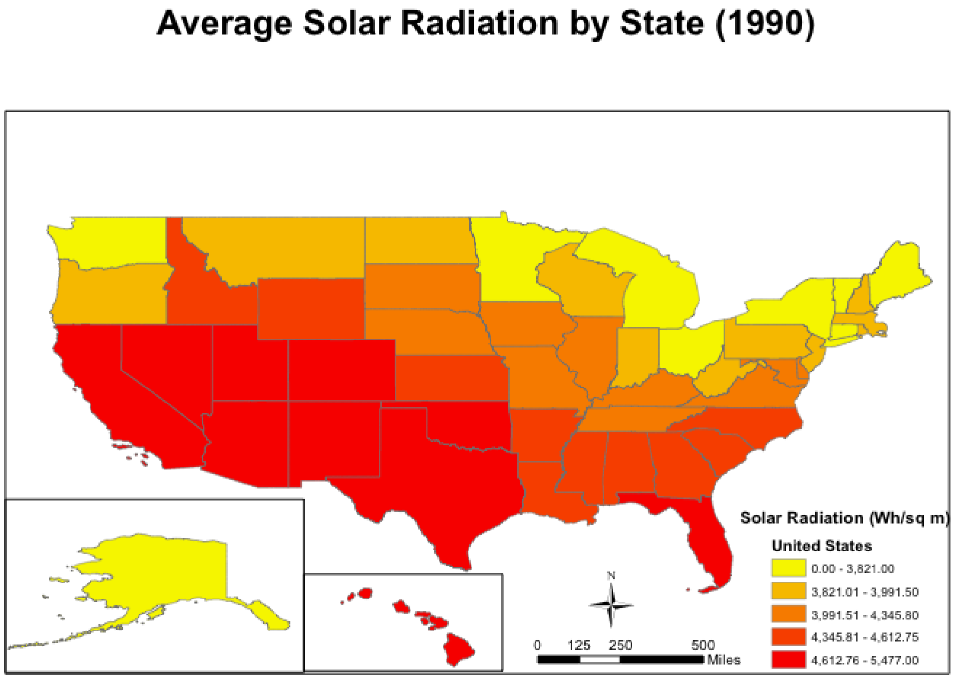
There appear to be three high areas of installation activity: the Southwest stretching from California to Texas, the Great Lakes region, and the Northeast Atlantic region. Additionally, several states outside these clusters showed high numbers of residential solar PV installations including Tennessee, Florida, Colorado, Oregon, and Hawaii.

Figure 1: Residential Solar Photovoltaic Adoption by State (2009 – 2012)



Still, this map only illustrates the raw distribution of installations without accounting for any of the key independent variables identified in the literature. One of the most important of these variables is solar radiation, also known as insolation. Using data compiled by the National Solar Resources Database, specifically yearly global horizontal solar radiation (GLO), average insolation values were computed for each state including measurements and estimations from 1961 to 1990. In most cases, state averages were computed using data from multiple sites within each state. Insolation is measured in watt-hours per square meter (Wh/m^2). Figure 2 shows the distribution of solar resources across the United States.

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



The map illustrates that most of the solar resources are located in the Southwest and Southeast Sunbelt regions. However, a cursory comparison of this map to the map of installations creates doubt that solar PV installations could be explained completely by the level of solar radiation in a particular area. For instance, the Northeast and Great Lakes regions are relatively poor when it comes to solar radiation. Conversely, while the Southeast has abundant solar resources, the adoption of solar PV remains low.

The inability of solar insolation to explain the geographic distribution of residential solar PV adoption leaves in play two possibilities. First, the distribution of residential solar PV could be explained by the other factors identified in the literature that have been shown to influence solar adoption decisions such as a state's economic conditions and social factors like political leanings of the residents. Second, adoption behavior could be influenced by the different types of policy initiatives offered by the state to incentivize residential solar PV adoption. Only a multivariate model can determine whether one or both of these possibilities is likely.

Regression model

Three model specifications were made for this study (Table 1). Model 1 is the base level specification. Of all the independent variables included in this study, excluding policy factors, three appeared to have the greatest effect on adoption: solar radiation, income, and liberalism. This is in line with expectations from previous research. These three variables explain 41.05 percent of the variation in adoption rates.

Meanwhile, model 2 adds one policy variable, a count of the total number of policy incentives available within a state. This variable was statistically insignificant and its inclusion actually decreased the explanatory power of the model.

Finally, model 3 replaces the total policy variable with individual variables for the different policy incentives. Only two policy incentives were statistically significantly related to adoption rates, net metering and rebates. Still, the inclusion of these variables in the model, along with the presence of feed-in tariffs that was not statistically significant, improved the explanatory power of the model by 18 percent. It's also important to recognize that the inclusion of the policy variables decreased the explanatory power of income, making it statistically insignificant.

Table 1: Multiple Regression Results for the Log-Log Model of Adoption Rates by State

	Model 1 (Base Model)	*Model 2 (Total Policy)[1]*	*Model 3 (Comp. Policy)[1]*
Solar Radiation	3.95927 (1.530304)*	4.625576 (.2546462)*	4.602751 (1.340677)**
Income	3.641725 (1.422462)*	3.35837 (1.578457)*	2.144555 (1.230718)
Liberalism	4.295415 (1.138822)***	4.31584 (1.253475)**	2.776428 (1.144609)*
Total Incentives	----------	.1281869 (.254646)	----------
Net Metering[2]	----------	----------	.1608876 (.0717558)*
Rebate[3]	----------	----------	1.990385 (.4478001)***
Feed-in Tariff[3]	----------	----------	-.5769285 (.4541656)
constant	-89.36174	-89.3333	-70.53939
N	49	49	49
Adj. R^2	0.4105	0.3795	0.5954

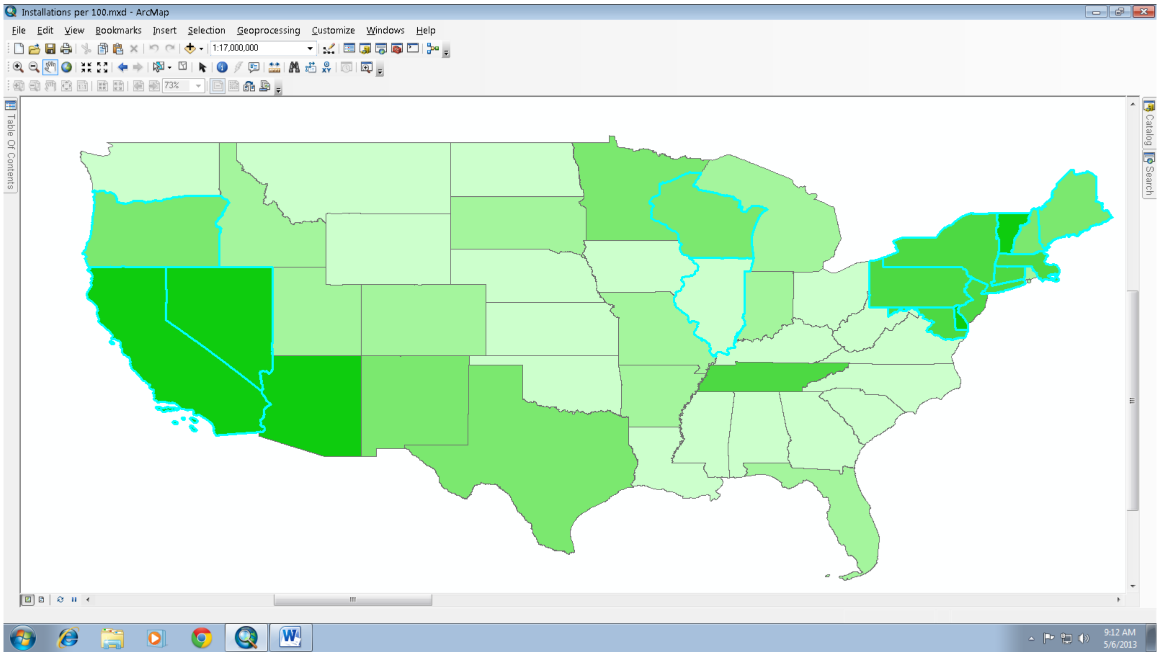
1. Models included log transformations of other non-significant control variables including gross state product and percentage of urban population.
2. Non-log continuous variable.
3. Non-log dummy variables.
* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

There appears to be a positive relationship between the size of the solar PV system eligible for net metering and adoption. A 1 percent increase in the maximum eligible size of a solar PV system corresponds to a 16 percent increase in adoption rate. Because states without a net metering system were coded as zero for this variable, it was not possible to log-transform the variable.

The presence of a rebate program was included in the model with a dummy variable. As the variable moves from 0 to 1, there is a statistically significant increase in adoption. However, because of the log transformation of the model, the coefficient cannot be interpreted directly. Giles (2011) indicates that the interpretation of a dummy variable in a semi-logarithmic model can be given by the formula $100[\exp(\beta) - 1]$. Following this technique, moving from 0 to 1 for rebates corresponds to a 631 percent increase in adoption, on average. While this number seems large, it is important to consider what this means given actual data values. A state with 12 adoptions per 100,000 people has a 600 percent higher adoption rate than a state with 2 adoptions per 100,000 people. The important takeaway is that states with rebate programs tend to have higher adoption rates.

Figure 3 is a choropleth map showing the states with rebate programs (those in the selection) juxtaposed against those without rebate programs, all imposed over the map for the adoption rate. Rebate programs exist in each of the previously identified high adoption clusters. They are especially prevalent in the Northeast where solar radiation resources are generally low. Only Illinois has both a rebate program and a low adoption rate.

Figure 6: States with Rebate Programs for Solar PV Installation



Discussion and Analysis

Understanding how policy incentives influence the adoption of residential solar power systems is a critical question for policymakers both in the United States and abroad. Many states have invested substantial sums of money in these programs, but there remain questions related to the overall effectiveness of these programs as well as their relative effectiveness.

In the United States, it appears that state policies aimed at incentivizing residential solar PV adoption are largely ineffective at influencing adoption. Hypothesis 1, which stated that states with more incentive policies would have more adoption, was unsupported by the data. Instead, solar radiation, average income, and liberalism among the population were all stronger predictors of adoption. Additionally, very few of the individual policy incentives showed statistical significance.

On the other hand, hypothesis 2 concerning net metering was supported. States that allow large solar PV systems to qualify for net metering tend to have higher adoption rates than states with more restrictive requirements. This speaks to the important role of grid connectivity in state policy approaches. It is possible that net metering could be a first step that enhances the effectiveness of other policy incentives.

Another successful policy incentive seems to be a rebate program, though the reason for this remains a mystery. Perhaps rebates represent a happy middle ground between the upfront nature of sales tax exemptions and the long-term payback of market incentives such as feed-in tariffs? Additionally, qualification and processing of rebates may seem less daunting than navigating the state tax code to qualify for exemptions or deductions. Understanding the reasons for the effectiveness of rebate programs requires additional investigation. Future studies should examine how changes in policy, as well as critical exogenous factors, influence adoption rates in order to make conclusions about a causal relationship between policy incentives and adoption rates. Still, the fact that rebates remained significant when controlling for important environmental, economic, and social factors cannot be overlooked or dismissed.

Limitations

This study has a number of important limitations that must be mentioned. First, it uses state-level data to investigate the geographic distribution of the dependent variable. This is problematic for a number of reasons. States vary widely in area, and variables like income and insolation are better measured over smaller areas instead of averaged over an entire state. Furthermore, state-level comparisons present the problem of limited variation due to the small population size, as the maximum number of cases can only be 50. When cases are dropped, as was the situation with North Dakota, or when divided into more than two categories, the precision of the data analysis becomes questionable. Still, the decision to make the state the unit of analysis was made because of the investigation of state-level policy incentives. Despite the small population size, model diagnostics show that Gauss-Markov assumptions have been met, including normality, homoskedasticity, and independence; thus the regression results are robust.

Second, most of the policy variables are dummy variables accounting for the existence of particular types of programs. Following the example of others like Diamond (2009), future studies of state policy incentives should account for the actual financial value of the incentive. Furthermore, there appear to be economic variables that ought to be considered including the retail energy price and the installation price of solar PV systems, which may vary geographically. These have not been considered in previous studies. Future studies should also consider how these variables changing over time influence adoption rates. Diamond (2009) uses panel regression to account for the fact that most of these variables change substantially over time.

Also, this study does little to understand why certain incentives might be more or less effective. For example, distrust in the state agency tasked with collecting tax revenue or granting tax credits may influence how many people take advantage of tax incentives. Additionally, this study makes no account for differences in marketing and communication efforts between the states that may account for more program participation.

Finally, this study does nothing to account for the effect of regional climate agreements or other policies above and below the state level that may make solar power systems more desirable. For instance, the Regional Greenhouse Gas Initiative (RGGI) is a multi-state compact between several states in New England and the Mid-Atlantic regions where member states agree to achieve reductions in greenhouse gas emissions. This could account for the high adoption rates in the Northeast, independent of state policy incentives. Future studies should take fuller account of local, state, regional, and national policy incentives to get a better idea of the true effectiveness of any individual incentives.

Conclusions

Overall, this study asked whether state policy incentives designed to reduce the costs associated with adopting a residential solar PV power system were effective in this objective. It appears that the initial answer is a qualified no. When controlling for environmental, economic, and political factors, policy incentives are not generally effective. Additionally, this study sought to discover which policy incentives, if any, were most effective. For this question, the data analysis presents a clear answer. When controlling for external factors, net metering and rebates were the only two state policy incentives to remain statistically significantly related to solar PV adoption rates. Policy makers should consider evaluating their incentive programs in light of this new evidence. Perhaps states with net metering size restrictions could consider expanding their programs. States that spend most of their money on tax incentive programs might consider shifting these funds to rebate programs to increase their effectiveness. Still, expectations should be tempered considering the factors that appear to remain the most important are political and environmental. Ultimately, much more work must be done to give proper guidance to policy makers.

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