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Diffusion of Innovations: Interplay of Social, Economic, Technological, and Policy Drivers in the Solar Industry

Summary of UT Austin Student Capstone Research Projects

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The University of Texas at Austin's *Policy Research Project* (PRP), a nine-month (two semesters) capstone, is a keystone of the core curriculum at the LBJ School of Public Affairs. In PRPs, small groups of students, under the mentorship of a faculty director, take on real-world problems that require special knowledge and skill sets. PRPs expose students to challenges in formulating and executing research, and in communicating academic research and related complex data to broader stakeholder communities and decision makers. The PRP structure is an innovative and effective approach for integrating research within the teaching and training of graduate students who are preparing themselves to address important real-world problems at the intersection of society, economics, technology, and policy.

The project summaries below describe seven papers developed during September 2017 – May 2018 as part of a PRP on "*Diffusion of Innovations: Interplay of Social, Economic, Technological, and Policy Drivers in the Solar Industry*." Twenty graduate students, drawn from the LBJ School's Masters in Public Affairs and Masters in Global Policy Studies programs and the Jackson School Geoscience's Energy and Earth Resources program, participated in this PRP. Dr. Varun Rai, Associate Professor and Associate Dean for Research at the LBJ School, directed the PRP, with support from his research team including: Dr. Ariane Beck, Dr. Ashok Sekar, D. Cale Reeves, and Erik Funkhouser. Clients for the project included the U.S. Department of Energy (Casey Canfield), Lawrence Berkeley National Laboratory (Ben Hoen, Galen Barbose Joachim Seel, Naïm Darghouth, Ryan Wiser), and National Renewable Energy Laboratory (Benjamin Sigrin, Eric O'Shaughnessy).

The seven projects separately addressed one of the following topics: (1) low- and middle-income PV adoption, (2) modeling economic and information intervention design, (3) evaluation of DOE's Solar in Your Community Challenge, (4) property value impacts near large-scale solar facilities, (5) solar market maturity and evolution of business models, (6) social media data for predicting PV adoption, and (7) individual-level variation in adoption of innovations. Many of the papers relied on data collected and curated by Lawrence Berkeley National Laboratory, including data embedded within the annual *Tracking the Sun* and *Utility-Scale Solar* reports. Each of the seven teams in the PRP prepared a research paper (the full set of papers can be downloaded here). The PRP culminated with a full-day conference at UT Austin in May 2018 to present findings from the seven projects in this PRP to a broad audience of about 75 experts from academia, national labs, industry, and government from across the country.

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Comparative Impact of Solar Programs on Low- and Middle-Income PV Adoption

Student Team: Olivia Loa, Maryam Rasti, Sam Bennett
Client: Lawrence Berkeley National Laboratory

This team's research explored income differences between households that adopt PV through property assessed clean energy (PACE), Solarize and third-party ownership (TPO) and those that adopt PV outside of those programs. The analysis focused on three states: California, Connecticut, and Oregon. The project included a descriptive component, comparing incomes for various customer groups (including Solarize and PACE customers), in addition to econometric modeling to understand whether TPO, Solarize, and PACE programs drove PV deployment into new demographic groups. An important assumption of the analysis was that the income of PV adopting households equates to that of the corresponding census block group.

The team found that TPO systems and PACE-financed PV systems tend to be in lower income areas, indicating that these models have been effective in reaching lower income markets. PV adopters using TPO had average household incomes that were $2,000-$9,000 per year lower than other PV adopters in the three states analyzed. In California, PV adopters using PACE financing had average household incomes that were $8,000 per year lower than other PV households. Perhaps not surprisingly, lower income adopters tended to purchase smaller-sized PV systems than higher-income households.

Solarize programs, on the other hand, tend to correlate with higher income areas, indicating that though Solarize may be effective in reducing installed prices, higher income areas were those benefiting from those lower prices. This does not imply that Solarize is ineffective in lower income areas, but rather that the Solarize programs analyzed in this project may have been specifically targeted toward higher income areas, with an *ex ante* expectation of higher chances of success. Further analysis is needed to assess the effectiveness of Solarize programs in reaching lower income markets, all else equal. The robustness of these results could also be improved by using household-specific income estimates (rather than census income levels at the block group level).

Economic and Informational Intervention Design: An Agent-Based Modeling Approach

Student Team: Amara Uyanna, Matthew Haley
Client: UT Austin

For novel technologies such as distributed PV, effective approaches to accelerating adoption must facilitate a complex household-level decision-making process characterized by both economic and informational barriers. Using an empirically grounded and validated agent-based model (ABM) of single-family household PV adoption, the project team simulated a range of information-based strategies including recruiting interested individuals to "champion" installing solar and connecting current solar owners to potential adopters. These strategies aim to increase adoption by explicitly leveraging information exchange at the local level, which is known to be an important driver of PV adoption. Results of the information-based strategies are compared to the results using a simple economic-based strategy (subsidized adoption).

Three key findings emerged from the analysis. First, information-based strategies that break free of existing social networks and create new "weak ties" among previously unconnected individuals appear to

be more effective than interventions that rely solely on existing personal connections to spread information. Second, when potential adopters are already densely connected and information flows freely between individuals based on pre-existing relationships, providing additional new information is necessary to increase adoption. Third, simulated information-based strategies can increase adoption with a reasonable estimated return-on-investment compared to a simulated economic-based strategy.

These findings yield two conclusions. First, information-based strategies have the potential to play an important role in PV adoption where potential adopters face informational barriers to adoption. Those interested in PV adoption may usefully continue designing, implementing, and evaluating strategies that explicitly leverage information exchange among peers. Second, information-based strategies should aim to form new ties and information exchange between individuals rather than solely leveraging pre-existing relationships. When encouraging new connections is not possible, new information—as in training—might instead be provided. Future research could explore the effectiveness of combinations of information-based and economic-based strategies when applied simultaneously.

Solar in Your Community Challenge: A Midpoint Assessment

Student Team: Marisa Calder, Hayden English, William Frankel
Client: U.S. Department of Energy

The U.S. Department of Energy's Solar in Your Community Challenge (SIYCC) program (May 2017 to October 2018) aims to expand solar electricity access to low- and moderate-income households and community organizations. One specific option is community solar, which is a complement to the residential rooftop PV market and provides a means by which households that cannot or opt not to put solar on their roof can still participate as virtual behind-the-meter PV adopters. The SIYCC was intended to catalyze the design and testing of various PV deployment models across more than 150 projects in the U.S., varying in approaches to customer engagement, subscription, utility engagement, and other factors. The program also seeks to develop expertise across the range of communities selected to participate.

In this project, the team explored SIYCC's progress toward its goals to date. The research process began by developing a logic model detailing the processes and outcomes for each of the program's activity streams. Because the analysis was conducted at the midpoint of the program's lifecycle, a key outcome of interest – installed PV capacity – was left out of the assessment. Instead, key outcomes of interest included scores by coaches given to the teams in periodic program reviews, resource utilization (services requested, funds spent, etc.) on a marketplace available to program participants, and several other progress-related outcomes such as capacity building (i.e. external knowledge acquisition), status of site selection, permitting, and so on. For the analysis, program administration data were matched with data from a survey of program participants (171 communities). The response rate for the survey was about 30% (51 of 171 SIYCC teams).

The research found that a high proportion (65%) of teams were using knowledge from external resources (largely from within their region), 89% of teams had identified installation sites, and roughly 35-50% of the teams had at least partial agreements in place for permitting and financing. Overall, the mean progress of teams in the survey sample toward final project goals (PV installation) was 39%. Most insightfully, program funds (specifically, blitz and seed funds) and vouchers were found to correlate with higher average rates of marketplace resource utilization, frequency of team meetings, and project progress as reported by coaches. A key limitation of the findings is that the data were collected at a midpoint of the program lifecycle. In addition, teams that responded to the survey tended to be more active (i.e. received green or yellow progress from coach); thus, the survey results are biased toward communities that

received more funding and were assessed to be generally more successful at the midterm evaluation point. An assessment after the program has concluded will provide an opportunity to revisit the initial findings, and expand the scope of inquiry to include impacts on PV deployment and variation across program models.

Analysis of Property Value Impacts Near Large-Scale Solar Facilities

Student Team: Eugenie Schieve, Leila Al-Hamoodah, Kavita Koppa
Client: Lawrence Berkeley National Laboratory

This research investigated where large-solar installations (> 1 MW) are located, the housing and income characteristics of the surrounding areas, and whether the installations are perceived to affect nearby residential property values. The team approached these questions using geospatial analysis and a survey of property assessors. Geospatial analysis examined both housing density and median income surrounding these facilities, while the survey gauged local assessors' opinions of the impacts of these installations on residential property values.

The survey found some evidence that property value impacts might exist, though that assertion was only shared among a minority of respondents. Importantly, the survey also found that having first-hand assessor experience near a solar installation significantly reduced the size of those estimated negative impacts. Based on the regression analysis, and using the estimates derived from only experienced assessor responses, the project team found that, on average, homes within 100 feet of a solar project are estimated to have a reduced value of 2.2% (e.g., a $300,000 home would have its value reduced by $6,600). The analysis further suggests that this effect fades by around 0.04% for each additional 100 feet a home is located from the project. The project team stressed that these results are based on assessor opinions, and should be corroborated with empirical analysis.

Based on the location of already-installed large-scale PV systems in the U.S., the geospatial analysis found that lower income households tend to be located near larger facilities, although relatively few homes in total are likely to be impacted because of the relatively small number of households (of any income) near these systems. The estimated median income of households within 3 miles of 100 MW facilities was $34,000, for example, as compared to the national median of $57,000 and the median near 1 MW solar facilities of $60,000. The team estimated that in total there are only 794 households (of any income) within 100 feet of existing large-scale U.S. solar facilities, 2,507 within 500 feet, 6,348 within 1000 feet and 34,710 homes within ½ mile—a very small number of homes in total, and in comparison to the entire country wide housing stock. From these totals, and estimating an average house sale frequency, there appears to be enough data to attempt an empirical analysis, such as a hedonic pricing model. Such an analysis could more-reliably estimate the existence, direction and magnitude of property value impacts than the assessor-focused analysis summarized here.

Solar Market Maturity and Evolution of Business Models

Student Team: Jingwei Meng, Jenny Sauer
Client: National Renewable Energy Laboratory

The solar PV adoption model changed significantly in the mid-2000s with the emergence of various PV financing products, such as solar leases and power purchase agreements (PPAs). These financing products improved PV access for traditionally under-served populations, especially cash-constrained customers. Previous research has focused on the demand-side drivers of PV financing trends (e.g., customer adoption

of various financing products), but has not explored the decision-making of PV installers and financiers when choosing where and when to offer various products—what we term 'supply side' factors.

This project studied these supply-side factors, focusing on where and when various financing products have been offered by PV installers. Using a proprietary data set of PV financing quotes from over 2,000 installers across 24 states, the project explored how different PV financing products have emerged in different markets over time.

The project team found that different installers choose to offer different types of financing products (e.g., leases, loans, PPAs), and that decisions by installers to offer different types of financing products can affect customer access to PV, since some customers may not receive a full set of financing offers leaving them with cash purchase as the only option. Moreover, installers offer different types of products in different geographic markets, with differences in product offers partially explained by differences in market maturity. Specifically, nascent markets generally start with cash offers as the only option before PPAs quickly ramp up. Installers in mature markets were more likely to offer PPAs and pre-paid financing products than installers in nascent markets, and financing trends in nascent markets appear to lag behind similar trends in mature markets. Importantly, *in the sample analyzed*, by 2016 PPAs were the only non-cash financing product available to customers in both nascent and mature PV markets. Moreover, contrary to broader supply-side PV financing trends that have moved away from PPAs in recent years, results reveal that installers in this sample increased offers of PPAs in 2016, suggesting that these installers may have a different operational strategy compared to the large vertically integrated firms not in the sample.

Do Google Search Trends Allow us to Better Understand Adoption of Residential Solar?

Student Team: Ghida Ismail, Cho Lai, Ryan Williams
Clients: National Renewable Energy Laboratory and Lawrence Berkeley National Laboratory

Researchers have mined data on people's online activities to "nowcast" economic or market trends for the past 10 years. In this project, the team tested whether Google search trends can nowcast residential PV adoption. Specifically, the team conducted an empirical analysis to assess the explanatory power of Google search trends for two solar PV markets in U.S.—California and Connecticut—over the years 2004 to 2016. Of the large variety of search terms explored (~100 different terms were tested), "solarcity" performed the best in predicting subsequent adoption (other terms that also performed adequately include "solar cost", "Sunrun", "solar panel", and "solar tax credit"). More specifically, searches for "solarcity" explained much of the variability in month-to-month statewide residential solar adoption in California, though less so in Connecticut. In addition, the research identified a lag between search trends and actual adoption (4-7 months), likely reflecting the natural lag between information search and actual adoption. However, the term "solarcity" became insignificant in predicting adoption when included in a regression model that contained other relevant explanatory factors of adoption such as incentives and socio-demographic variables. This suggests that one might use search trends as a replacement for these other variables, but that search trends alone may not independently add much additional ability to nowcast solar adoption. This finding was confirmed by the high correlation coefficient (>|0.5|) of the search term "solarcity" with these other variables.

Note that SolarCity (the installer) has merged with Tesla, so the search term "solarcity" may not be a good predictor of PV adoption (even in California) going forward. Nonetheless, the findings suggest that Google search trends have the potential to help nowcast residential solar PV adoption, perhaps especially in cases

where other relevant correlates are not readily available. Further analysis, including more states and adding 2017 adoption data, is needed to more fully understand the contours of the potential. Furthermore, data permitting, a more granular analysis (e.g., at the county level) may shed additional insights.

Individual-Level Variation in Adoption Timing: An Analysis of Innovativeness across Technologies and Domains

Student Team: Luisa Alejandra Tello, Who Gwon Lee, Ryan Carlino
Client: UT Austin

The diffusion of innovations (DOI) framework posits that there are five types of potential adopters of new innovations, based on their time of adoption—innovators, early adopters, early majority, late majority, and laggards. Understanding the characteristics of each of these five adopter-types helps in designing targeted strategies to increase adoption levels. This research asked a novel question to further understanding of the DOI framework: do consumers consistently fall in the same adopter-type across various innovations? If so, what characteristics (personality, product attributes, etc.) define the "consistent consumer"?

To address these questions, the team conducted a survey on Amazon Mechanical Turk of U.S. consumers (n=898), focusing on whether and when each consumer adopted ten possible innovations (smartphone, DVD player, HDTV, computer, Amazon Prime, social media, e-book, digital camera, and tablet) across three technology domains (communication, entertainment, and productivity). From the survey responses, adoption curves were developed for each innovation based on when respondents adopted the innovation. The adoption curves for all ten innovations mirrored S-shaped curves as expected in the DOI framework. The degree of consistency (of being a certain adopter type) was measured as the number of consumers who were in the same adoption category across all innovations—a feature that would be extraordinary rare if by chance alone.

The research found almost no consistency among consumers across all ten technologies. However, when categorized by domain, 223 consumers consistently fell in the same adoption-type in the communication domain (highly unlikely by random chance), while only ten consumers were consistent in the productivity and entertainment domains. No consistency was observed when innovations were classified into low or high cost. Future research will explore alternative definitions of consistency, for example by not looking at exact adoption-category matches, but rather looking at the range of deviations from mean adoption categories at the individual level. Another fruitful direction for research would be to explore which socio-demographic and personality traits help explain why consumers were consistent in the communication domain but not in the productivity and entertainment domains.

For the full set of papers, see:

https://emp.lbl.gov/student-capstone-projects-solar-energy

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