FINAL REPORT

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"The Influence of Novel Behavioral Strategies in Promoting the Diffusion of Solar Energy"

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Executive Summary

How can we reduce the soft costs of residential solar installations? This question is critical for meeting the SunShot Initiative's goal of bringing the cost of residential photovoltaics (PV) down to $0.05 per kilowatt hour by 2030. To explore novel approaches to reduce soft costs, we developed a systematic, evidence-based project using an unprecedented series of large-scale field experiments. These field experiments were based around the grassroots marketing Solarize campaigns designed to scale up residential solar, fostering learning-by-doing and economies of scale to reduce soft costs.

The Solarize program in Connecticut, SolarizeCT, was designed to increase the installation of residential solar photovoltaic systems using two central strategies:

1. Intensive, grassroots marketing that was tied into local social networks; and
2. Time-limited discounts for groups along with a structure of the discounts such that more savings were available when more people signed up (group pricing).

Our Solar Energy Evolution and Diffusion Studies (SEEDS) project funded the expansion and study of Solarize between 2012 and 2015. During these three years, the number of homes statewide with solar grew from about 800 to over 12,500, with the Solarize campaigns associated with this project directly responsible for approximately 20 percent of this growth. There were also extensive second-order impacts of this work, including similar Solarize campaigns run around the country that received guidance based on our work and may not have happened otherwise.

We not only analyzed the effectiveness and cost-effectiveness of a generic standard Solarize campaign, but we also explored variations of the Solarize campaigns that unfolded in towns across the state. We investigated five distinct treatments, varying features of the campaigns such as the length of the campaign and the availability of installers; comparing these treatments allowed us to measure the specific value of different approaches. For instance, might a 12-week campaign be as productive as a 20-week campaign while also being more cost-effective? Our project was thus the first of its kind to rigorously estimate the effectiveness, cost-effectiveness, scalability, and persistence of behavioral strategies that, by leveraging social interactions, aim to accelerate the diffusion of solar technology. These findings are of great interest to any group—policymakers, solar industry practitioners, academics—working on novel approaches to the adoption of solar photovoltaics.

The high-level findings of this project can be summarized in the following bullet-points, which are expanded upon further below, in the rest of this draft, and in the six completed papers from this project.

- Solar installations display a 'contagious' nature and social connections are one of the most powerful levers for providing information about solar and fostering diffusion of the technology.
- The peer influence is even stronger when solar panels are visible from the street, demonstrating one mechanism by which solar peer effects act and suggesting marketing approaches to increase visibility.

- Solar ambassadors were critical to the success of the program and the most successful solar ambassadors installed solar through the program, highlighting the importance of trust and credibility in the program.
- The Solarize campaigns were highly successful, increasing the adoption rate well over 100% and leading to over 35 additional installations per municipality on average and lowering prices by 20%. They were successful in both randomly-selected and approached municipalities and municipalities that actively were interested in a campaign.
- A variant of the campaigns that removed tiered group pricing in favor of a single competitive bid was less expensive to run and achieved similar results (and subsequently, any new campaigns SmartPower runs have a single bid).
- Another variant of the campaign that shortened the length to 12 weeks from 20 weeks was successful, but required substantial effort and it fostered less word-of-mouth. Moreover, the increase in the rate of new installations was less persistent than it is after the longer campaigns.
- Further variants of the campaigns that allowed for multiple installers in the campaigns brought in lower prices for customers and similar levels of installations, but were somewhat more difficult to run.

One of our core findings is the ‘contagious’ nature of solar installations. Awareness of and information about solar diffuses through networks, making social connections one of the most powerful levers—or ‘vectors of contagion’—for boosting adoption. One way this plays out is through “peer effects” in neighborhoods: we found that over a six-month period the presence of one solar rooftop project increased the average number of installations within a half-mile radius by nearly 50 percent. This peer influence grew even stronger when panels were visible from the street. In short, increasing the visibility of solar, both physically and psychologically, proved a key channel for increasing adoption.

The public face of a campaign was crucial to its success, as well. Campaigns enlisted trusted citizens who volunteered to contribute to the solar outreach. Local politicians who lent their name to a campaign, for instance, bolstered its credibility. Recruiting the right core volunteers—solar ambassadors, as they are known in Solarize—was also essential to a campaign’s success. Solar ambassadors were recruited based on their centrality in the social network of their community: they tended to be well-known and respected. They were also passionate about not just the environment, but Solarize specifically. One of our intriguing findings is that ambassadors who themselves installed solar panels were more effective than counterparts who did not—demonstrating that in this context “actions speak louder than words.”

Successful Solarize campaigns delivered tremendous benefits to businesses and local economies. On the business side, Solarize CT generated a statewide “20–20 rule.” Most campaigns ran for roughly 20 weeks and reduced the average cost of solar by 20 percent. This resulted in more than three times the number of rooftop installations in participating communities. Moreover, there is evidence that many of the campaigns, show persistence and a higher growth rate after the campaigns. For example, persistence of higher growth is particularly notable after a variant that allowed for multiple installers in the campaign.

As a result, we estimate that installers across Connecticut would see on average just over 30 additional new contracts due to a Solarize campaign. Nearly every installer that took part in Solarize CT hired new employees for a variety of positions, like electricians and sales representatives. One solar installer even created a standing Community Solar division in its company, dedicating resources to development of and participation in community solar programs.

Our findings, which led to a raft of academic journal articles and manuscripts, have already been put to practical use refining Solarize campaigns across the country. Our work led to the publication of a widely-disseminated practical guidebook: Solarize Your Community: An Evidence-Based Guide for Accelerating the Adoption of Residential Solar. This handbook provides not just straightforward explanation of the major findings from our research, but, importantly, step-by-step instructions for creating and managing the most effective Solarize campaign for any interested layperson.

Articles in a range of distinguished media outlets—The Washington Post, Forbes, and The Atlantic, to name a few—have also brought national attention to the research. Findings on the 'contagious' nature of solar installations even informed Google's Project Sunroof, motivating them to develop their software to now allow users to view which houses in a neighborhood have already installed solar.

This research endeavor succeeded by bringing together a cross-sectoral coalition of groups from public, private, and nonprofit sectors to create a foundation for a robust solar market that no single actor could have achieved in isolation. Further, it contributed to a scaling up of the solar market and lower prices for solar for customers. The results had second-order benefits, with independent communities running Solarize projects (e.g., Solarize Norwalk), churches running similar campaigns (e.g., the Unitarian Church in CT), similar campaigns run in Vermont and Pennsylvania, and private enterprises have begun taking part (e.g., Dividend Solar). In this way, the research undertaken directly supported the goals of the SunShot Initiative to broaden the diffusion of solar technology and further bring down costs.

Introduction

The price of solar panels has plummeted in recent years, but installation rates have not experienced an equivalently rapid rise. In part, this is because costs unrelated to hardware can make up the majority of a system's price tag: 55 percent of the total cost in the U.S. in 2015 was unrelated to the solar panels themselves. What, then, are the most effective methods for reducing these "soft" costs? How can we scale up solar markets, to foster learning-by-doing and economies of scale to reduce these soft costs?

These questions were the primary drivers of our project, which set out to rigorously identify novel modifications to the dynamic system governing the adoption of residential solar energy. From this focus, and through social network modeling of our results, we have been able to extract groundbreaking lessons on technology diffusion that can be generalized beyond residential solar.

The diffusion of any new technology takes place within a fluid and multidimensional environment; small alterations to the system may lead to dramatic changes in the market. Recent evidence has found that social interactions are one key intervention point that directly affect solar adoption, with more interaction generally precipitating more solar installation. Innovative behavioral strategies can thus be designed to take advantage of these effects and speed up the diffusion of solar energy. At the same time, recent developments in social network theory, which combines economics, marketing, and the diffusion of innovation literature, can help develop more robust models of residential solar demand during the time period of the diffusion of this new technology.

The goal of this project was to use field experiments to understand the mechanisms underlying *how* interventions around social interaction work, quantifying *when* and *why* they work, and how they can be *generalized* to foster a *sustainable* market for solar energy in the United States. This line of inquiry helped to establish a new and rich field of research on solar that has so far witnessed little exploration. One further objective in our work was to push forward the science of modeling the demand for residential solar during a time of rapid diffusion of the technology. We did this by taking metrics from social network theory and using them to develop a mathematical framework to model the demand, and thus diffusion of solar PV.

We framed this research around four specific questions, touched on above:

1. *How well do a variety of novel behavioral strategies work and why*? We were interested in the average treatment effect as well as how this treatment effect varied depending on the characteristics of potential adopters. Behavioral strategies under investigation included: community rewards/incentive programs, social media efforts, different approaches to facilitated community group pricing, and the full Solarize package—including solar ambassadors and coordinated projects with local leaders.
2. *Which strategies are the most cost-effective*? We were interested in identifying the strategies—or package of strategies—that gave the greatest "bang-for-the-buck."
3. *To what extent are the strategies scalable*? We recognized that some communities—those that are wealthier, for instance—would likely be more amenable to our

approaches than others. An important goal was to quantify the extent to which challenging environments influenced the diffusion of solar PV. To this end, we ran programs in communities that represented all socioeconomic conditions and we conducted a randomized trial across Connecticut to understand whether the Solarize approach works independently of a community's interest in the program.

4. *How persistent are the effects from behavioral strategies*? We believe it is important to understand whether "seeding" an area through treatments led to continued adoptions of solar PV over time, or whether the effects tended to dissipate.

The results of this study offer clear recommendations to both policymakers and businesses. Policymakers looking to accelerate the adoption of solar energy now have firm evidence on several promising approaches, both behavioral and logistical, along with details on costs and expected outcomes. Stakeholders in the business community, meanwhile, can use our results to better inform market development efforts and more precisely target marketing outreach, both of which can dramatically reduce customer acquisition costs, which are a large fraction of the soft costs of solar (in many cases in the range of $2,000-$3,000 or more in the Connecticut market).

The work behind these findings unfolded over several years and involved three sets of randomized experiments, along with surveys, data analysis, and model development.

We began our study analyzing the Connecticut Green Bank-supported Solarize programs that had begun in August 2012. These consisted of four towns in the fall of 2012 (Round 1) and five towns in the spring of 2013 (Round 2). These towns were all compared to a set of control communities to assess the effectiveness and cost-effectiveness of the "generic" or standard Solarize program, which we called "Solarize Classic."

The first wave of randomized field experiments took place in the fall of 2013 (Round 3). Towns interested in Solarize were randomized into three groups. The first group was a Solarize Classic campaign run for comparison. The second and third tested two hypotheses: (1) whether changing the length of a campaign would be more cost-effective (campaigns we called "Solarize Express") and (2) whether allowing for multiple installers rather than a single chosen installer would lower costs further and lead to more installations (campaigns we called "Solarize Choice"). As before, we set aside similar communities as controls for comparison purposes.

The second wave of experiments, conducted in spring of 2014 (Round 4), was designed once more to run parallel with a round of the Solarize Classic (for comparison). This time, the investigation was structured to answer questions of scalability. Because the towns in the previous work had chosen to join the Solarize program, we were interested in understanding how successful the Solarize program would be for the "average" town that did not opt-in to the program. Thus, we selected communities at random across Connecticut and approached them to see if they would be interested in a standard Solarize campaign (everything else was held identical). We called these "Solarize Select" campaigns. After the previous successes in the first rounds, SmartPower was successful at convincing five of the six approached communities to participate in a campaign. This process allowed us to determine how effective Solarize campaigns can be if a town does not voluntarily take part, eliminating the bias present in towns that are naturally inclined toward solar adoption. Again, we set aside similar communities as controls for comparison purposes.

The third wave of randomized field experiments was conducted in the winter of 2015 (Round 5). For this wave, we randomized towns into three groups. One group received Solarize Classic. The second group received a version of Solarize that tested the hypothesis of whether facilitating a Solarize campaign through an online software platform (EnergySage) that allows multiple installers to bid for any customer's installation would lower prices further and lead to more installations. We called these campaigns "Solarize Online." The third group received a version of Solarize that tested the hypothesis that the tiered group pricing schedule (i.e., customers all received a lower price if the town reached higher levels of installations based on a set schedule of pricing tiers) was not essential for the success of the program. Monitoring the tiers took substantial staff resources at the Connecticut Green Bank, so this version had the potential to be more cost-effective. We called these campaigns "Solarize Prime."

Table 1 below summarizes the different campaigns that were run and Figure 1 below it shows a map of Connecticut where the towns that received campaigns are shaded based on the colors in the table.

VARIATIONS OF SOLARIZE CT

MODEL	TOWN MOTIVATION	LENGTH OF CAMPAIGN	PRICING OFFER	# INSTALLERS	QUOTE COMPARISON
Classic	Competitive Application	20 Weeks	Tiered	1	N/A
Select	Selected At Random	20 Weeks	Tiered	1	N/A
Express	Competitive Application	10-12 Weeks	Tiered	1	N/A
Prime	Competitive Application	20 Weeks	One Low Price	1	N/A
Choice	Competitive Application	20 Weeks	Tiered	2-3	In-Person
Online	Competitive Application	20 Weeks	N/A	5+	Online Platform

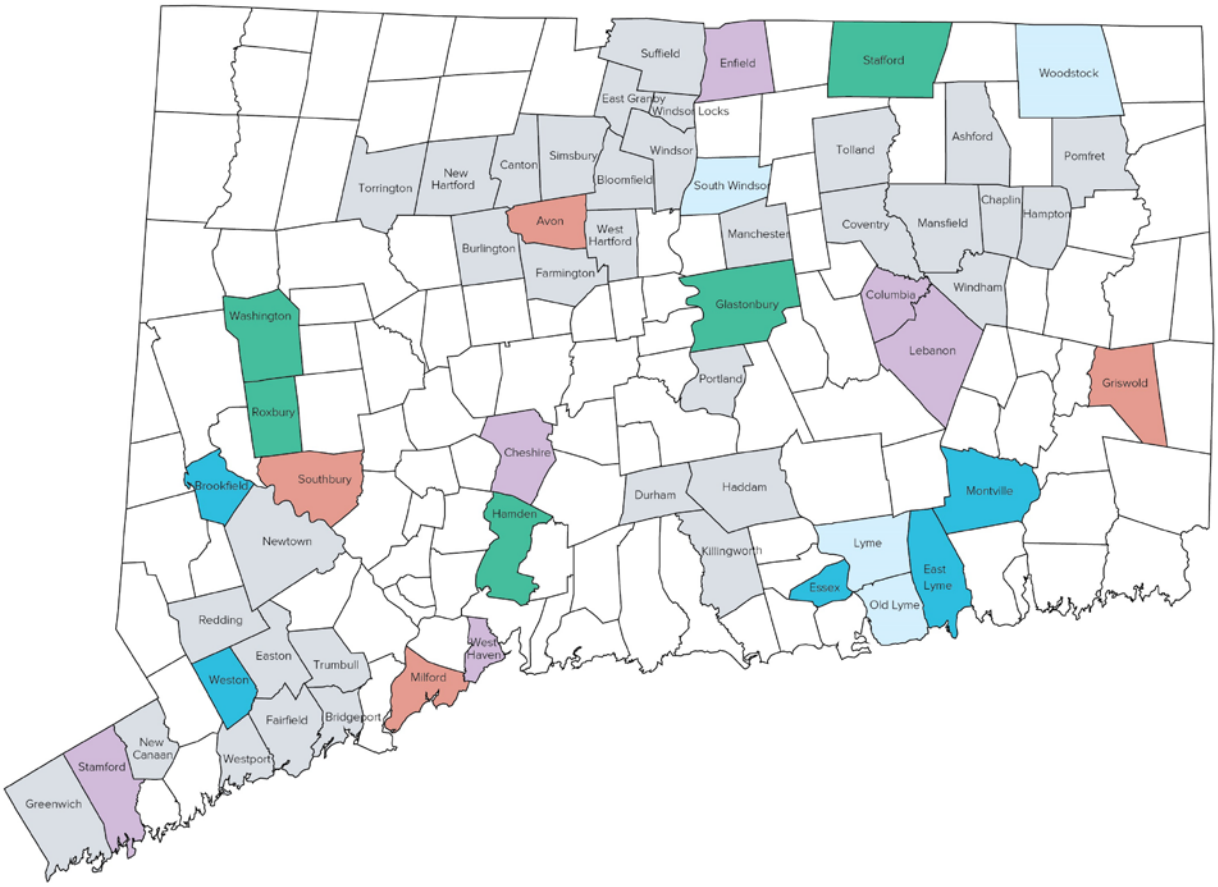

Table 1 and Figure 1: Field experiments run and studied under the SEEDS project.

Along with these experiments we performed a series of online surveys with people who adopted solar and with people who expressed interested but did not in the end adopt solar. Yale graduate students also conducted in-person interviews with lead volunteer coordinators—"solar ambassadors"—in each town. These surveys and interviews helped us trace out partial social networks by determining whom solar ambassadors and eventual adopters spoke to about solar. These surveys, along with an analysis that used satellite imagery to determine solar panel visibility, allowed us to assess whether visibility played an additional role in the adoption of solar PV. With this multifaceted approach, we were able to disentangle the relative importance of deliberative or direct communication from associative or indirect cognition, which has important implications for how the diffusion process works and what strategies can be most effective and cost-effective in different circumstances.

By following the uptake of solar in towns after the campaigns wrapped up, we also worked to answer the "persistence" question. Why did some towns see a "tipping point" and have a higher growth rate after the campaigns, while some towns went back to the pre-Solarize growth rates? The final phase of the project consisted of monitoring solar installations after the campaigns, and writing up the results for a variety of different venues.

The next section provides a brief overview of the Connecticut solar market. This is followed by sections discussing our key research findings and the impact of the project.

The Connecticut Solar Market

Connecticut has a rapidly expanding solar industry. It is home to over 347 megawatts (MW) of installed capacity and 183 companies along the solar value chain, including 68 installers and developers.[1] Figure 2 shows the annual solar installations in Connecticut over time. In 2016, the state had more than 2,100 jobs in the solar industry—an increase of 11 percent over the number from 2015.[2]

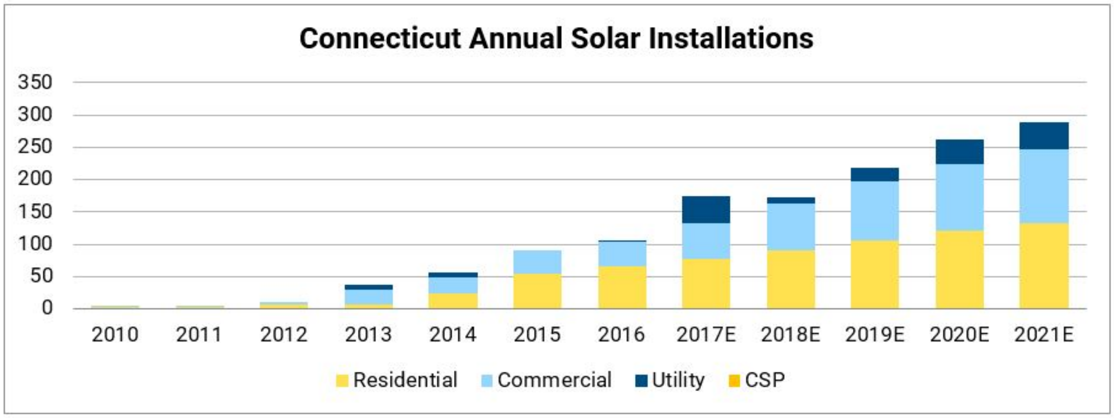

Figure 2: Connecticut solar installations since 2010 and SIEA forecasts.
Source: http://www.seia.org/state-solar-policy/connecticut

Over the same period of time, from 2015 to 2016, the United States as a whole witnessed a 24.5 percent growth in solar jobs—a growth rate approximately 17 times faster than that of the overall U.S. economy.[3] These jobs have arisen predominantly in the installation and project development sectors. Compared to country as a whole, Connecticut ranks dead center in its total number of solar-related jobs; compared to the rest of New England, it ranks second (see Table 2).

[1] http://www.seia.org/state-solar-policy/connecticut
[2] http://www.thesolarfoundation.org/wp-content/uploads/2017/02/National-Solar-Jobs-Census-2016-Appendix-A.pdf
[3] http://www.thesolarfoundation.org/national/?mc_cid=eaf6332238&mc_eid=%5BUNIQID%5D

State	Solar Jobs		
	2015 Jobs	National Rank	Jobs Per Capita Rank
Connecticut	1,951	25	18
Maine	330	43	35
Massachusetts	15,095	2	2
New Hampshire	731	36	17
Rhode Island	941	34	11
Vermont	1,367	31	3

Table 2: Solar jobs in Connecticut compared to other states.
Source: http://www.thesolarfoundation.org/wp-content/uploads/2016/02/Solar-Jobs-Census-Compendium-2015-Low-Res.pdf

The State of Connecticut has taken a proactive approach to the establishment of a market for solar power. The Connecticut legislature has issued a Renewable Portfolio Standard that requires 27 percent of retail electricity sales be supplied by renewable sources by 2020, with a specific carve-out for solar (e.g., a specified percentage of the RPS that must be met by solar generation). This carve-out is supported by the Connecticut Green Bank, which will offer residential solar PV incentives for consumers until either December 31, 2022 or 300 MW of residential solar installations, whichever comes first. These are referred to as Solar Home Renewable Energy Credits (SHRECS).[4,5]

Connecticut also supports net metering for grid-connected systems up to 2 MW. Excess generation is carried over as kilowatt-hour credit for one year. If the credit is not used by the end of the year, then customers are reimbursed at the wholesale cost for the avoided power generation. Connecticut also allows systems of up to 3 MW owned by state, municipal, or agricultural customers to be virtually net metered.[6] Over the course of 2015, the state further accommodated residential solar interconnection with two measures: municipalities were authorized to exempt small-scale renewable energy projects, including solar power, from building permit fees; and all municipalities were required to have a building permit application process for residents interested in installing residential solar photovoltaic systems.[7]

For commercial consumer specifically, the Green Bank developed and administers the Commercial Property Assessed Clean Energy (C-PACE) program, which provides support to property owners who wish to invest in building energy upgrades, including solar systems.[8] Similarly, for residential consumers, the Green Bank has developed the Smart E-Loans program by which homeowners can qualify for no-money-down low-interest financing for residential solar and energy efficiency home upgrades.[9]

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[4] http://nesemc.com/resources/policies/by_state/NESEMC%20Solar%20Policy%20Survey%20-%20Connecticut.pdf
[5] https://www.cga.ct.gov/2015/aCt/pa/pdf/2015pa-00194-r00HB-06838-pa.pdf
[6] http://www.ct.gov/deep/cwp/view.asp?a=2715&q=558644&deepNav_GID=1626
[7] http://programs.dsireusa.org/system/program/detail/4958
[8] http://www.ctcleanenergy.com/YourBusinessorInstitution/CommercialPropertyAssessedCleanEnergyC-PACE/tabid/642/Default.aspx
[9] http://programs.dsireusa.org/system/program/detail/1407

In combination with the falling cost of solar, these policies paired with Solarize have contributed to a dramatic increase in the number of monthly installations. Figure 3 plots the average installations rate and the price over time for residential solar PV systems in Connecticut. The period of the Solarize campaigns we have studied is shaded. This figure shows a clear spike in installations during the Solarize period, which converted the Connecticut solar market from a small-scale market to a much larger-scale market. Prices continued their downward trend during this time as well. The academic papers from this research endeavor explore these trends in much more detail and estimate the causal effect of the Solarize programs on adoptions and prices in the towns treated in the field experiment.

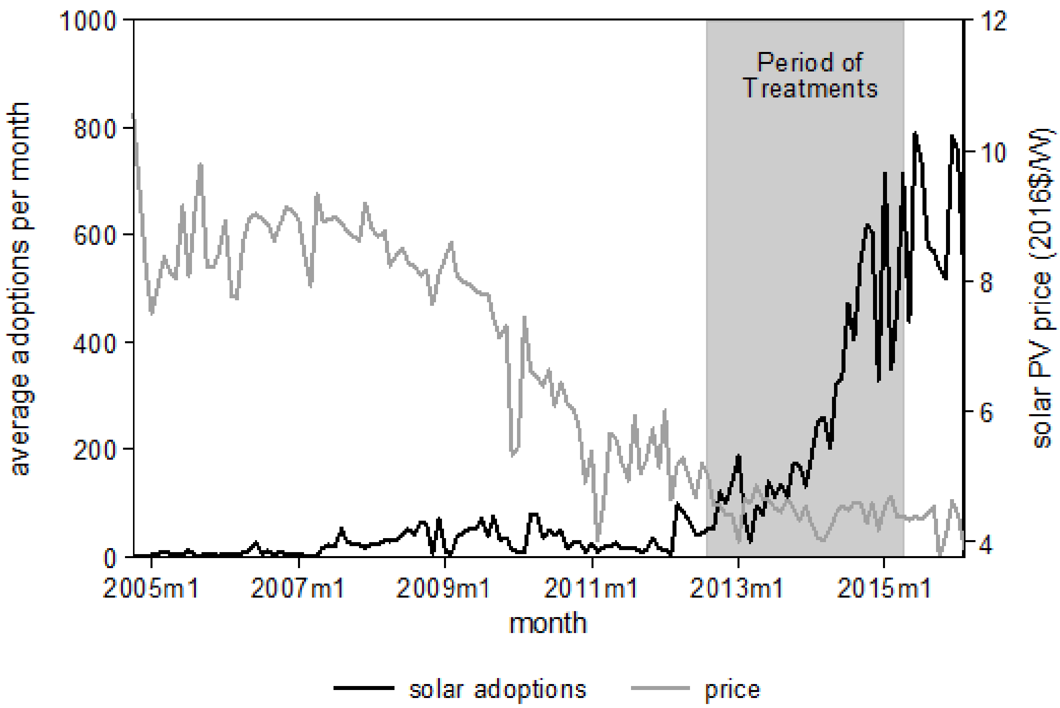

Figure 3: Connecticut residential solar PV adoption rates and prices
Source: Gillingham & Bollinger (2017)

Key Research Findings

In 2012, roughly 800 homes in Connecticut had solar panels on their rooftops. Three years later, the number of homes had jumped to more than 12,500, a trend that was seen in Figure 3 above. Besides allowing for an important set of studies, the Solarize campaigns were directly responsible for about 20 percent of this growth.

As a starting point, the key effects of Solarize Classic are clear in the following Figure 4. The figure presents the results from all five rounds of Solarize Classic. The shaded areas are the Solarize campaign periods. The cumulative residential solar adoptions prior to the campaigns were very much in line with the control towns that did not receive the campaigns but were otherwise similar. During the campaigns, there was an enormous spike in signed contracts, which on average leveled off after the campaigns (we explore the heterogeneity in why some towns exhibited continued growth after the campaigns in one of our papers). Specifically, Solarize more than tripled the number of installations in each community, significantly expanding the size of the market. (One out of five households that signed a contract through Solarize had never before considered installing panels.) Further, we see a analogous effect in solar prices, with similar prices before the campaign, but much lower installation prices—approximately a 20-30% decline—during the campaigns. Our research aimed to answer the question: How did the campaigns do this?

Figure 4: Residential cumulative solar adoptions and prices
Source: Solarize Your Community

Getting the word out, persuasively

Solar ambassadors—passionate volunteers who spearhead outreach activities and organize other volunteers—were critical to the success of a campaign; towns in Connecticut with strong volunteer leadership demonstrated consistently higher solar adoption rates.

One of the most powerful predictors of an effective ambassador was that he or she signed up for an installation through their Solarize campaign. ("Effective" in this case means that the most number of people referenced him or her as a factor in their decision to install solar.) This move proved far more telling of successful ambassadorship than other environmental behaviors like composting, owning a hybrid vehicle, or having doublepaned windows, which is consistent with the well-known notion that “actions speak louder than words” (Kraft-Todd et al. 2017). Surveys and interviews also found that ambassadors who conceptualized their role as part of a job rather than as ancillary volunteer work were more influential when talking with other town residents.

When first meeting with potential customers, highlighting the economics of going solar was the most important point of persuasion. Communicating the discount provided through Solarize plus the prospect of saving money on energy bills tended to pique interest. From there, customized reasons for going solar helped nudge people further. For instance, a number of Connecticut residents were frustrated with the local electric utility in the wake of power outages cause by Hurricane Sandy; solar ambassadors were able to make a compelling case for solar by framing it as a way of gaining independence from the utility.

The importance of tailoring messages to individuals is paralleled by the need to consider particular community demographics. For instance, analysis of the Solarize CT campaign found that younger groups were most sensitive to price, which meant that the discount offered through Solarize attracted them to installations. Pricing mattered less and less moving up age brackets; older segments of the population were, instead, more persuaded by the trustworthiness provided by town sponsorship among politicians and vetted installers.

As is shown below in Figure 5, to publicize the Solarize campaign, workshops, town events, town websites, and local print newspapers were the most effective sources. While social media was not used often, it was surprisingly among the least effective method for spreading the word. This may be because the campaigns are designed around in-person word-of-mouth.

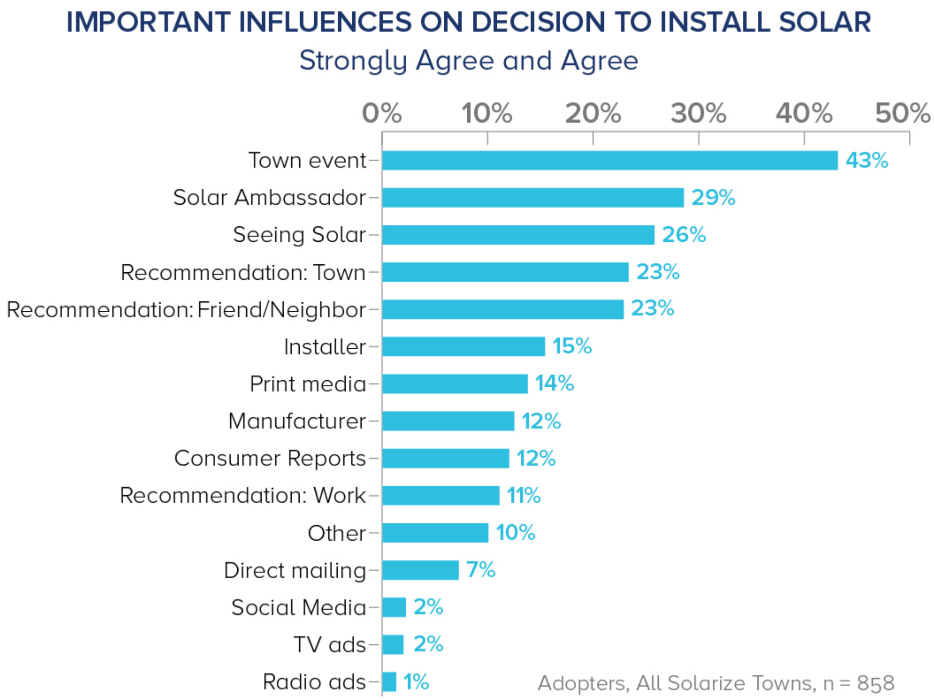

Figure 5: Important influences used to publicize the Solarize campaign
Source: Solarize Your Community

Prominent visual displays like banners and yard signs also kept the campaign front-of-mind for residents. In towns where local regulations restricted public signage the lack of a constant visual reminder measurably limited the success of the campaign (See detailed results on the findings in the previous paragraphs in the Solarize Your Community Guidebook).

Catalysts and Barriers

Our research also identified specific catalysts and barriers to solar adoption in Connecticut. When it comes to catalysts, variables in the built environment, such as housing density and share of renter-occupied dwellings, were more influential on adoption rates than household income or political affiliation. Interestingly, small and midsized centers of housing density proved just as important, if not more important, than larger centers as the main players for the diffusion of solar rooftop systems (Graziano and Gillingham 2015). Establishing friendly competition between towns also proved a good method for motivating customers and campaign organizers.

On the barriers side of the equation, the unsuitability of a house's location topped the list of concerns in the survey results. But, close behind that, nearly 70 percent of people surveyed highlighted the current cost of solar as a barrier. While siting issues are difficult to overcome, two methods proved especially useful for reducing costs and unlocking solar for households (see the Guidebook for more details on these findings).

First, as detailed in the section on Connecticut's solar market, the Connecticut Green Bank accelerated consumer financing by developing innovative financial tools and risk-reduction mechanisms in partnership with local lending and capital partners. Second, offering a variety of vetted solar installers to local markets, as opposed to a single installer, increased competition, and demand while lowering prices. Specifically, selecting multiple installers for a campaign led to an average drop in price roughly twice the size seen during single-installer campaigns; this benefit persisted even after the campaign ended. The increased competition also brought 2-4 more active installers to municipalities, an increase of 50-100 percent over the single-installer campaign (Bollinger et al. 2017).

Motivating action

Finally, we found two key components for moving prospective customers from an interest in solar to actual installation. First, social diffusion had a marked effect on citizens' final decisions to go solar: one of the key factors determining whether a given house installs solar is the actions and influence of peers (Graziano and Gillingham 2015). This is the 'contagious' nature of solar. In reviewing a six-month period we found that the presence of one solar rooftop project increased the average number of installations within a half-mile by nearly 50 percent—an effect that weakened as the date of installation grew more distant. This peer influence effect proved even stronger if the panels were visible from the street. By their very nature, Solarize campaigns exploit this finding by using social networks and public forums to concentrate peer-to-peer discussion and action around new solar installations.

Reinforcing this finding, a follow-up survey asked those who installed solar to "rate the importance of each factor in their decision to install solar PV," with the following possible answers: extremely important, very important, somewhat important, not at all important. Of 14 total factors, those that were rated by the highest percentage of respondents as "extremely important" all had a social learning element to them: "town information event," "friend or neighbor's recommendation," "recommendation of someone you interact with in your town," and "seeing solar on another home or business." This survey result provides suggestive evidence that the Solarize behavioral intervention is working exactly as intended: by fostering social learning (Gillingham and Bollinger 2017). Campaigns should thus create as many opportunities as possible for people to meet and talk about solar; they should also bolster this diffusion effect by highlighting installations as they go up through signage and local events.

Second, the urgency of the campaign, with its strict (generally 20 week) deadline, was essential to getting buy-in. In most towns, there would be a spike in signed contracts just near the end of the campaign, when word-of-mouth was the most intense. When customers knew that the discounted pricing lasted for a limited time they were more likely to purchase solar.

A full 20 weeks may not be necessary. In the 12-week "Express" version of Solarize that we tested, we found an average treatment effect of 6.10 adoptions per month per 1000 owner-occupied homes, versus 6.35 for the contemporaneous Classic campaigns, a negligible difference (Bollinger et al. 2017). The success of Express may be due to the fact that the deadline served to motivate consumers sufficiently to adopt in the shorter time frame. It also should be noted that the same total resources were spent on each Express campaign as a Classic campaign, so the resource intensity was much higher and Express was not more cost effective.

There is also some risk when cutting the campaigns too short. In Express, the survey data showed that consumers were less likely to hear about Solarize from other solar customers and rated information from peers as less important, and ultimately we found lower post-Solarize adoption rates as a result. Looking in more depth at post-campaign adoption rates across all the campaigns, we found direct evidence for 'tipping', in which the post-campaign adoption rates were significantly higher in towns that ran more successful campaigns difference, as shown in Figure 6 (Bollinger et al. 2017). We also found that this effect was moderated by the strength of network ties in the town (data which came from our survey data).

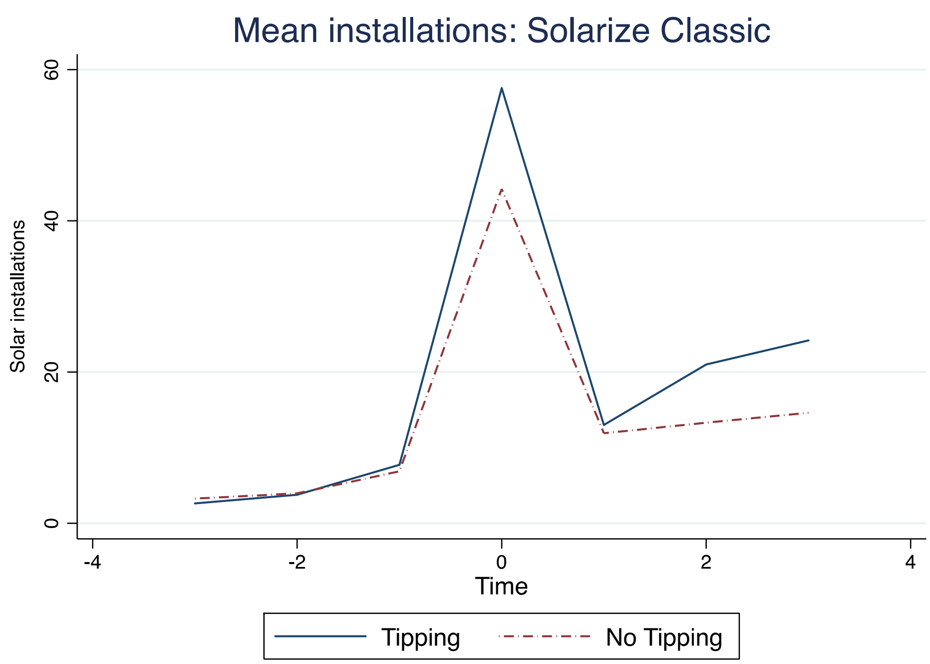

Figure 6. Solar adoptions for Tipping versus Non-Tipping Towns Based on Six Month Periods Around the Campaign Period (t=0)
Source: Bollinger et al. (2017)

One interesting, and financially relevant, note related to the social diffusion of solar is that the group-pricing model did not have the effect that we had anticipated. Offering tiered discounts to an entire community based on the number of contracts signed—more contracts, deeper discount—theoretically provides an incentive for early adopters to convince others to adopt, and to let everyone know how many people in the community have adopted. In this sense, it is intended to build social pressure and create a social norm around solar PV. In fact, the pricing structure—whether tiered or a flat discount—was not critical to how people learned about Solarize, as we found from testing “Solarize Prime.” While removing group pricing lessened the effect of word-of-mouth from peers who were extrinsically motivated to convince others to install solar, it strengthened the importance of word-of-mouth from other sources, leading to the same result on-balance. For policymakers, this suggests that that the additional administrative and monitoring costs associated with group pricing aren’t necessary for an optimized Solarize campaign (Gillingham and Bollinger 2017).

Finally, we found that Solarize was effective not only in towns that proactively signed up for it, but also in those towns to which it was randomly assigned (“Solarize Select”). Though the treatment effect in these locales was roughly cut in half, it still boosted installations over non-participating towns by about 100 percent (Gillingham and Bollinger 2017).

Table 3 provides a summary of our findings over each of the variants of Solarize.

MODEL	HOW IT WORKS	BENEFITS	CONSIDERATIONS
Classic[11]	• 20 Weeks • Tiered Pricing • One Installer	• 20 weeks allowed communities time to plan and execute their campaigns • Single installer simplified choice for customers and simplified coordination for campaign organizers • Tiered pricing encouraged a peer-to-peer effect with customers striving to reach the highest tier • Proven model nationwide	• With a single selected Solarize installer, residents did not have a choice of installation company if they wanted to take advantage of the Solarize discount • Smaller installers needed to expand capacity quickly to meet higher demand
Express[12]	• 12 Weeks • Tiered Pricing • One Installer	• Suggestive evidence that Express was more effective per week, but less effective in aggregate (neither difference is statistically significant). Theoretically, Express campaigns could save implementation costs. (This was not the result of Solarize CT) • Word of mouth played a much smaller role in leading people to adopt	• Express did not deliver the expected cost savings: SmartPower and CT Green Bank had to increase their administrative support and increase their investment in coordination efforts to meet the earlier deadline • Towns needed to invest in up-front planning to make marketing effective during the short campaign • All installers who participated in an Express program reported that the timeframe was too short
Choice[13]	• Multiple Installers • One Low Price	• Compared to Classic, Choice towns were more successful in terms of the percentage increase in total number of installations. Several installers competing for business appeared to play a key role in this uptake dynamic • Solarize Choice towns had the lowest prices – the average system price in Choice towns was 2.65$/W compared to 2.72$/W in Round 3 Classic towns • Choice experienced sustained price discounts post-campaign • Customers felt confident that they were getting a good price with participation of multiple installers • Strong growth rates were observed post-campaign, suggesting that the campaign brought installers in touch with more residents	• Installers and Solar Ambassadors reported that choice created confusion for some customers • More coordination effort was required • Installers highlighted the need for strong guidelines to execute effectively. A number of installers reported poor customer experience, lost leads due to overwhelming or conflicting information, and increased cost of customer acquisition

MODEL	HOW IT WORKS	BENEFITS	CONSIDERATIONS
Select[14]	• Towns Selected At Random To Join	• Allowed residents to experience the benefits of a Solarize campaign even if their towns did not have the time or resources to commit to the application process • For some towns, the "you've been chosen" message was motivating as a special opportunity • Results show that Solarize can still be effective in randomly selected municipalities	• Whilst still effective, results show a lower effect when municipalities do not opt-in on their own; level of interest/ resources may be lower
Prime[15]	• One Low Price • Single Installer	• Simplified the decision-making process for residents: one installer and one price • Word-of-mouth from community members declined in effectiveness but was offset by other word-of-mouth channels (friends, coworkers, etc.)	• Limited homeowners' choice to a single installer • Without the pressure of tiered pricing, with discounts contingent on numbers signed up, residents may have been less inclined to encourage others in their towns to install with them
Online[16]	• Compare Quotes Online • Multiple Installers	• Gave residents more choice and provided them with easily accessible information to make decisions • Customers were able to easily compare quotes with apples-to-apples assumptions • Residents were able to utilize the assistance of an online solar coach to help guide them in their decision • Competition among installers reduced prices—a reduction that persisted even after the campaign ended	• More limited installer visibility and engagement • With many participating installers, it was reported that some customers felt an overload of information; onus on customer to compare installer quotes • Potential technical barriers associated with user access of online platform for customers who are not very tech-savvy

Table 3. Findings from each of the field experiments run in the project.
Source: Solarize Your Community Guidebook

In addition to these findings from the field experiment, a major contribution of this project is the development of new mathematical modeling approaches for the demand for solar PV during a time when it is rapidly diffusing. We develop an approach for estimating the parameters of this demand that acknowledges the process of diffusion of the new technology. The findings from this work suggest an elasticity of demand for solar PV in Connecticut of -0.65, which is a policy-relevant number for it is useful for modeling the effects of subsidy policies at the early stage of a solar market (Gillingham and Tsvetanov 2017).

Some Counter-intuitive Findings
Overall, the project can be considered an unqualified success: every one of the campaigns run brought in many solar adoptions. In the process of running the campaigns, we found that our initial hypotheses were not always verified.

Perhaps the most notable counter-intuitive result stems from Solarize Prime, as was mentioned above. We hypothesized that tiered group pricing would bring in further installations by motivating households and ambassadors to help the entire group get down to the lower tier price. However, the results from analyzing Solarize Prime show that removing group pricing makes little difference in the total number of adoptions and persistence of the growth in the market afterwards. This finding is particularly useful because tiered group pricing adds logistical difficulties and makes the campaigns more difficult to run.

Another surprising finding that influenced the campaigns is that sometimes between the decision to launch a campaign in a community and the actual launch date, a political/elected official's popularity or credibility can radically change. If the Town letter—usually a big driver of sign-ups for the campaign—goes out with the endorsement of an elected official whose reputation has been tarnished, we found that the letter actually is not very effective and can even work against the campaign gaining traction. Thus, in some cases, it may be better for the Town letter to go out with the Town letterhead, but signed by the Clean Energy Task Force or Town Council instead of a controversial official, for example. This is an interesting real-world finding because usually one would hypothesize that the personal touch of having the signature of a known official is unequivocally helpful.

Another insight arises based on the seasonality of local resident participation in outreach events. Counter to what one might expect, we find that attendance in winter workshops on solar is generally higher than ones held in the late spring or summer. This may be because Connecticut residents are used to cold weather and driving in snow, and also because the summer is so short and many people are traveling.

Lastly, one might have hypothesized that there would be a single ‘optimal’ way to design a Solarize. Our results indicate that there is no single optimal approach. The results are unequivocal that a single competitive bidding process is useful. They also clearly indicate that the campaigns must be long-enough to build word-of-mouth; 12 weeks is too short and requires an intensive effort to make up for the lost word-of-mouth. However, we show that allowing for multiple installers lowers prices for consumers further while still bringing in roughly the same number of installations; but this comes at the cost of making it more challenging to run the programs (e.g., there is a benefit to having the municipality completely *trust* the single installer and this must be overcome when there are multiple installers).

Impact of the SEEDS Project

By quantifying the effect of specific aspects of Connecticut’s Solarize campaign, our project created a number of clear and measurable outcomes.

Findings from SEEDS have been used to streamline Solarize campaigns across the country—clear second-order benefits. For instance, campaigns around the country now tend to have a competitive bidding process for a single bid, rather than a tiered group pricing process, as had been the norm before. Further, campaigns now tend to be slightly shorter (just below 20 weeks) since we showed that reducing the length can improves cost-effectiveness, but running them much shorter is highly resource intensive and lessens the effectiveness of building word-of-mouth.

It is also likely that many of the campaigns that have been occurring around the country would not have happened without the publicized research from this project. For example, campaigns were run in Norwalk, CT and Fairfield, CT based on the initial success of the Solarize CT campaigns. Multiple campaigns were run in Vermont and New Hampshire that were inspired and assisted by the work of this project. The 'Solarize with Faith' campaigns run in five houses of worship, including Unitarian, Episcopal, and First Church of Christ churches. Further, the success of this project was also the reason why SmartPower was approached by Dividend Solar to underwrite several further campaigns around the country. Finally, the Heinz Foundation and Allegheny County Clean Air Fund was inspired by our project to support Solarize Allegheny for three years to increase the adoption of solar in the Pittsburgh area.

Multiple articles in a range of distinguished media outlets—*The Washington Post*, *Forbes*, and *The Atlantic*, to name a few—also brought national attention to Solarize campaigns. Findings on the 'contagious' nature of solar installations have informed key decisions by Google Project Sunroof, too: by allowing users to view which houses in a neighborhood have already installed solar, Google is exploiting the influence of peer effects on solar adoption (see articles in The Atlantic, Mashable, Inverse, Mother Nature Network, CleanTechnica, TechSpot, and many more)

Our work was called out in the Clean Energy States Alliance guidebook on planning and implementing a Solarize campaign and led to the wide dissemination of our own guidebook—steeped in rigorous research results—published by the Yale Center for Business and Environment: Solarize Your Community: An Evidence-Based Guide for Accelerating the Adoption of Residential Solar. This handbook not only provides straightforward explanation of the major findings from this research, but, importantly, step-by-step instructions for creating and managing the most effective Solarize campaign for interested laypeople. The Huffington Post wrote about the guidebook's release.

Finally, it is impossible to overstate the importance of research efforts such as this one for meeting the goals of the SunShot Initiative. Our results support the SunShot cost goals in two key ways:

1. First, this work provides quantitative evidence on the value of strategies to accelerate the diffusion of residential solar energy. Successful strategies are now readymade for use by policymakers and businesses interested in fostering the adoption of solar energy. To the extent that there is learning-by-doing in which the costs of solar decline with cumulative installations, efforts to accelerate the adoption of solar energy will directly lower the cost of solar technology.
2. Second, the behavioral strategies that were tested in this project are largely aimed at leveraging social interactions to increase adoptions of solar energy. One of the most significant "soft costs" in the price of an installation is the consumer acquisition cost. To the extent that installers found new customer acquisition

eased by adopting the strategies ground-truthed in the SEEDS project, we have directly reduced consumer acquisition costs, providing further support for reaching the SunShot cost goals.

Future Work

While this project answered many questions about how solar diffuses, and how solar interactions can be leveraged to increase solar diffusion, there are still many more questions that warrant future research.

One area worthy of further study is how to bring in community shared solar into the mix. Will the programs be even more successful with community solar as an option for households that are unable to install solar because their rooftops are not viable? This may be particularly important for low and moderate income households. More broadly, understanding how low and moderate income households respond differently than the average population to campaigns such as Solarize—and how Solarize campaigns can be tailored to reaching low and moderate income households—are important questions for future research.

Another area worthy of further study would be to examine extending the Solarize model to other products. SmartPower has already done some work relating to energy efficiency, but we see the most promise in a more highly-visible clean technology, such as electric vehicles.

Project Partners
U.S. Department of Energy Sunshot Initiative SEEDS grant Principal Investigators:
Kenneth Gillingham, Yale School of Forestry & Environmental Studies (PI)
Bryan Bollinger, Duke University, Fuqua School of Business.

The U.S. Department of Energy SunShot Initiative is a national effort to drive down the cost of solar electricity and support solar adoption. SunShot aims to make solar energy a low cost electricity source for all Americans through research and development efforts in collaboration with public and private partners. Learn more at energy.gov/sunshot.

The Connecticut Green Bank was established by the Governor and Connecticut's General Assembly on July 1, 2011 through Public Act 11-80 as a quasi-public agency that supersedes the former Connecticut Clean Energy Fund. As the nation's first state "Green Bank", the Connecticut Green Bank leverages public and private funds to accelerate the growth of green energy in Connecticut.

SmartPower is the nation's leading non-profit marketing firm dedicated to promoting energy efficiency and renewable energy and has extensive experience with hundreds of community-based energy campaigns and Solarize projects across the country. SmartPower provides participating communities with technical assistance, campaign strategizing and outreach, and media planning.

The Yale Center for Business and the Environment joins two world-renowned graduate schools—the Yale School of Management and the Yale School of Forestry & Environmental Studies—with a network of internal and external leaders working at the interface of business and the environment. We catalyze research and cultivate partnerships that advance business solutions to global environmental problems.

+ 20 Solarize installation companies and 58 towns

Further Detail on the Partnerships and How They Contributed to the Final Product

What motivates people to install rooftop solar panels? Which incentives can rapidly boost the adoption of this technology? Which programs are persistently effective, and which are most easily scaled?

Supported by a grant from the U.S. Department of Energy a multidisciplinary set of partners came together to test these questions by examining the uptake of solar through the Solarize CT program. Out of this collaboration, we have produced a guidebook for community and business leaders, active citizens and policymakers detailing the most effective strategies for accelerating the adoption of residential solar.

The Yale School of Forestry and Environmental Studies and **Duke University**, in collaboration with the **CT Green Bank** and **SmartPower**, conducted a series of rigorous controlled field trials to better understand the adoption of residential solar.

The Yale Center for Business and the Environment coordinated the partnership and worked with a team of students to facilitate the research, assist with the data analysis and create the guidebook.

The Connecticut Green Bank, a state-level institution devoted to expanding the region's clean energy sources, accelerated consumer financing options by developing risk-reduction mechanisms in partnership with local lending and capital partners.

SmartPower, a social marketing firm, provided insight and support for Solarize CT, creating high impact on-the-ground community campaigns.

Publications from the Project

This project has led to seven manuscripts for publications (more than were promised in the proposal). The manuscripts develop new models and provide numerous policy-relevant conclusions that undergird the discussion above. Below we provide the reference and link to each manuscript, as well as the abstract for reference.

Further, the link to the "Solarize Your Community" Guidebook is available here: http://news.yale.edu/2017/04/18/national-guidebook-maps-way-toward-tipping-points-solar-adoption

We also have a SEEDS website on the Yale Center for Business and the Environment website that discusses the entire project: http://cbey.yale.edu/programs-research/solar-energy-evolution-and-diffusion-studies-seeds

Graziano, M. and K. Gillingham (2015) "Spatial Patterns of Solar Photovoltaic System Adoption: The Influence of Neighbors and the Built Environment." *Journal of Economic Geography* 15(4): 815-839.

Abstract:
The diffusion of new technologies is often mediated by spatial and socioeconomic factors. This article empirically examines the diffusion of an important renewable energy technology: residential solar photovoltaic (PV) systems. Using detailed data on PV installations in Connecticut, we identify the spatial patterns of diffusion, which indicate considerable clustering of adoptions. This clustering does not simply follow the spatial distribution of income or population. We find that smaller centers contribute to adoption more than larger urban areas, in a wave-like centrifugal pattern. Our empirical estimation demonstrates a strong relationship between adoption and the number of nearby previously installed systems as well as built environment and policy variables. The effect of nearby systems diminishes with distance and time, suggesting a spatial neighbor effect conveyed through social interaction and visibility. These results disentangle the process of diffusion of PV systems and provide guidance to stakeholders in the solar market.

Accessible at:
https://academic.oup.com/joeg/article/15/4/815/2412599/Spatial-patterns-of-solar-photovoltaic-system

Gillingham, K. and T. Tsvetanov (2017) "Hurdles and Steps: Estimating Demand for Solar Photovoltaics." Revised and Resubmitted to *Quantitative Economics*.

Abstract:

This paper estimates demand for residential solar photovoltaic (PV) systems using a new approach to address three empirical challenges that often arise with count data: excess zeros, unobserved heterogeneity, and endogeneity of price. Our results imply a price elasticity of demand for solar PV systems of -0.65. Counterfactual policy simulations indicate that reducing state financial incentives in half would have led to 9 percent fewer new installations in Connecticut in 2014. Calculations suggest a subsidy program cost of \$364/tCO2 assuming solar displaces natural gas. Our Poisson hurdle approach holds promise for modeling the demand for many new technologies.

Accessible at:
http://environment.yale.edu/gillingham/GillinghamTsvetanov_SolarDemandCT.pdf

Kraft-Todd, G., B. Bollinger, K. Gillingham, S. Lamp, D. Rand (2017) "Credibility-Enhancing Displays Promote the Provision of a Non-Normative Public Good." In Review at *Nature*.

Abstract:
We examine the adoption of non-normative (i.e., rare or unpopular) public goods by applying the cultural evolutionary theory of credibility-enhancing displays (CREDs), whereby behavior is more powerful than speech when influencing others' beliefs. By this logic, people who themselves engage in public-good enhancing behaviors will be more effective advocates than those who merely extol the behaviors' virtues. As predicted, a field study promoting residential solar panel installation implemented across 56 towns (1.4 million residents) found that community organizers who themselves installed solar panels through the program recruited 61.0% more residents to install solar compared to community organizers who did not. These results were replicated in two pre-registered online experiments (N=700), which also provided support for our proposed CREDs-based mechanism and against competing causal hypotheses.

Accessible at:
http://environment.yale.edu/gillingham/KraftToddetal_CREDs.pdf

Gillingham, K. and B. Bollinger (2017) "Social Learning and Solar Photovoltaic Adoption: Evidence from a Field Experiment." Yale University Working Paper.

Abstract:
A growing literature points to the importance of social interactions and nudges in influencing economic outcomes. This study investigates a large-scale behavioral intervention designed to actively leverage social learning and peer interactions to encourage adoption of residential solar photovoltaic systems. Municipalities receive a municipality-chosen solar installer, group pricing, and an informational campaign driven by volunteer ambassadors. We find a treatment effect of 37 installations per municipality, an increase of over 400 percent, and no evidence of harvesting or

persistence. The intervention also lowers installation prices but cannot explain the treatment effect. Additional randomized controlled trials show the importance of selection into the program and the lack of importance of group pricing. Our results suggest that this program may improve social welfare through economies of scale and lowered consumer acquisition costs.

Accessible at:
http://environment.yale.edu/gillingham/GillinghamBollinger_SocialLearningPV.pdf

Bollinger, B., K. Gillingham, and S. Lamp, S. (2017) "Long Run Effects of Competition on Solar Photovoltaic Demand and Pricing." Yale University Working Paper.

Abstract:
The relationship between competition and economic outcomes is a first order question in economics, with important implications for policy and social welfare. This study presents the results of a field experiment examining the impact of exogenously-varied competition on equilibrium prices and quantities in the market for residential solar photovoltaic panels. We alter the specifications of a large-scale behavioral intervention by allowing either one or multiple firms to operate through the program in randomly-allocated markets. Our findings confirm the classic result that an increase in competition lowers prices and increases demand, both during the intervention and afterwards. Using the campaign to exogenously shift the long-run number of competitors, we estimate an elasticity of between -0.11 and -0.14 for the effect of the number of competitors on equilibrium prices after the campaigns conclude. The persistence of these effects in the post-intervention period highlights the value of facilitating competition in behavioral interventions.

Accessible at:
http://environment.yale.edu/gillingham/Bollingeretal_RCTCompetition.pdf

Bollinger, B., K. Gillingham, S. Lamp, and T. Tsvetanov (2017), "Word-of-Mouth and Tipping in Durable Good Adoption." Yale University Working Paper.

Abstract:
Social learning is a key factor in the diffusion of new technologies. In this pager, we explore the mediating role of social learning via word-of-mouth (WOM) in durable good adoption. The context is the Solarize Connecticut program, a grassroots marketing campaign in which municipalities receive a municipality-chosen solar installer, group pricing, and an informational campaign driven by volunteer ambassadors. Combining rich solar installation data with an extensive survey of solar adopters, we study heterogeneity in campaign effectiveness. We find that campaigns in which adopters learned about the program through their friends and neighbors and/or other solar adopters were significantly more effective than campaigns in which adopters learned about the program from other channels. We complement our main

analysis with an experiment in which we randomly assigned five towns to be in a shorter 'Express' version of the campaign (run concurrently with size other 'Classic' campaigns) in which we find a negative indirect effect from the shorter campaigns due to a significant reduction in WOM. Finally, we provide direct evidence for 'tipping', in which the post-campaign adoption rate is significantly higher in towns that ran more successful campaigns. We also find that in municipalities with strong network ties, an additional one percent of market growth during the campaign leads to additional 0.3% growth in the post-campaign period.

Accessible at:
http://environment.yale.edu/gillingham/Bollingeretal_Tipping.pdf