Sun and Lemons: Getting over Information Asymmetries in the California Solar Market

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September 30, 2014

Abstract

Using detailed data of approximately 125,000 solar photovoltaic systems installed in California between 2007 and 2014 I argue that the adoption of solar panels from Chinese manufacturers and the introduction of a leasing model for solar systems are closely intertwined. First, cheaper Chinese panels allowed a leasing model to be profitable for contractors. But an asymmetric information problem exists in the market for solar panels. Solar panels are long-lived productive assets, where quality is important but costly for individual consumers to verify. Consumers can instead be expected to rely on brands and observed reliability. This led to a barrier to entry for cheaper panels from new, primarily Chinese manufacturers. The adoption of a leasing model by several large local installers solved the asymmetric information problem and led to the adoption of Chinese panels and in turn lower overall system prices.

*I would like to thank Endre Tvinnereim, Peter Berck, Henrik Horn, Thomas Tangerås and Sturla Kvamsdal for helpful comments and discussion.

1 Introduction

In the wake of the world-wide financial crisis that began in 2008, the Chinese government initiated a massive economic stimulus package. One of the side-goals of this package was to make China into a top producer and exporter of solar panels. New and existing Chinese manufacturers of solar panels were provided inexpensive loans and other forms of subsidy in order to substantially build-out capacity. Within a few years, Chinese solar power manufacturers were beginning to export panels at prices significantly lower than established manufacturers, especially those with production based in Europe and the US [Lacey, 2011].

In the California market, the adoption of Chinese panels led to a steep fall in the price of solar systems and coincided with a boom in installations. But I argue that the widespread adoption of Chinese panels is closely intertwined with the growth in popularity of a leasing business model among several large solar system contractors. With a leased solar system, homeowners do not own the solar systems that are placed on their roofs and do not usually need to provide the initial capital for the system, but instead are offered electricity from the panels at prices lower than electricity from the grid. Cheaper Chinese panels, along with generous subsidies, likely helped make a leasing model financially feasible for contractors to offer consumers and businesses. But a second mechanism is also likely at play. The introduction of a leasing model also helped overcome an asymmetric information problem relating to the uncertain quality of Chinese produced solar panels.

Solar panel systems are significant investments for households and businesses that need to last well over a decade in order to be financially profitable even with significant subsidies. At the same time, individual homeowners or small contractors would incur great costs in verifying the quality of the main component of a solar system: the solar panels. In this way the market for Chinese solar panels resembles the market for "lemons" in the seminal article by Akerlof [1970].

As Akerlof notes, with asymmetric information, rational consumers can be expected to prefer trusted brands and manufacturers. In the case of the solar power industry, this provides a barrier to entry to new, Chinese, manufacturers and some pricing power to established manufacturers. In turn, this information asymmetry could potentially have delayed or even blocked a switching to cheaper Chinese panels even if the quality of Chinese panels are competitive with that of established manufacturers.

Using a large sample of data from installations of solar panels in California between 2007 and 2014, I provide evidence that contractors were able to gain market share and significantly bring down total system costs by both switching to cheaper Chinese panels as well as introducing a leasing model for sales. I argue that these companies were successful in overcoming the information asymmetries by owning the panels themselves since they are able to absorb the information asymmetry and associated risk - verifying the quality of the panels as a wholesaler.

While the leasing business model appears to have been instrumental in allowing for a large market penetration of Chinese panels, the results also show that controlling for time and use of Chinese panels, contractors using a leasing model were able to charge a higher price than those that sold the system outright. This can be interpreted as an information rent for the contractors, though this result must be taken with a grain of salt since the reporting of cost information for leased systems may be unreliable.

I break the paper into roughly two parts. First, an overview of the market and its dynamics as well as a descriptive and exploratory analysis of the adoption of a leasing model and Chinese panels. I follow with both several simple regression models as well as a slightly more involved multilevel model that models the fall in system prices within contractors as a function of contractor level predictors of the change in percent of Chinese panels used and leased systems.

2 Litterature on the Economics of Solar Power

The economics of solar power is unique within power generation in that generation assets are often owned by individual consumers and businesses. Research on consumer investment behavior and adoption of solar systems has been growing. Borenstein [2008] attempts to value solar photovoltaic generation in California taking into account that production happens at mid-day when prices are higher and that on-sight production reduces transmission loss and may reduce future transmission costs. The author finds that the value of solar may be increased by up to 20% by its favorable timing and potentially up to 50 % if the system relied more heavily on price-responsive demand and peaking prices. Still the author finds that solar photovoltaics are much costlier than their benefits. However, the calculated cost level of photovoltaics are likely outdated as costs have fallen dramatically since the study's publication in 2008. The widespread adoption of leasing, as discussed in this paper, is evidence of the dramatically changed economics of solar power over the last several years.

Dastrup et al. [2012] argue that solar panels can not be considered a pure investment good, but are bundled also as a type of green conspicuous consumption. The authors back up this argument by showing how the installation of solar panels affects home prices in the San Diego area and finds evidence for a "solar price premium" and that this effect is positively correlated with how environmentally aware an area is. Bollinger and Gillingham [2012] study the adoption and spread of solar panels and attempt to estimate peer effects in solar power adoption using the same dataset -from the California Solar Initiative - as this article. They find evidence that the adoption of solar panels by homeowners in a zip-code will increase the probability that other households in that zip-code will install solar panels.

A working paper by Burr [2014] also uses data from the California Solar Initiative, but uses the data to compare the efficiency of production versus investment subsidies, finding the former to be more efficient. The author also finds that the social cost of carbon would need to be at least $120 in order for the subsidies provided to solar power in California to be welfare neutral. Another recent working paper by Hughes and Podolefsky [2014] find that rebates had a large effect on solar system installation in California. They also estimate that the rebates had the effect of reducing emissions by an amount roughly equivalent to a mid-sized natural gas plant.

In contrast to the existing literature, in this article the important issues of subsidy policy for and cost-benefit of solar panels are largely placed in the background. Instead, I focus on informational and industrial organizational aspects of the market and how they have contributed to the dramatic price declines as well as increased adoption seen in the period studied. Though policy analysis is not the main aim of this article, implications for both subsidy policy and trade policy do arise.

3 Data and Software

I use data on approximately 125,000 solar power installations in the state of California between 2007 and 2014. The data is publicly available at `http://www.californiasolarstatistics.ca.gov/` and a cleaned data set is available on my website `jmaurit.github.io\#solar_lemons`. The data includes all installations covered by the California Solar Initiative, which provided rebates for installation of solar panels on existing single and multi-family homes, commercial and governmental buildings. Large utility-owned projects are notably not included in this program. The data set includes information on the size of the system, when it was installed, the amount of subsidy provided, the location of the installation to the scale of zip-code, the contractor who installed the system and the type of panels and inverters used. Up until parts of the subsidy scheme began to expire in 2013, almost all solar panel installations came under the subsidy and are included in the dataset [Dastrup et al., 2012].

For data cleaning and manipulation I used the python package Pandas [McKinney, 2012]. I use the R statistical programming package for all analysis in this article [R Core Team, 2013]. I use the R packages ggplot2 and ggmap for plotting [Wickham, 2009, Kahle and Wickham, 2013], plyr for data manipulation [Wickham, 2011], texreg for table formatting [Leifeld, 2013], lme4 [Bates et al., 2014] for implementation of multilevel model and the STAN Bayesian programming language [Stan Development Team, 2014] for implementation of Bayesian multilevel model. All code for the analysis is also available at my website at `jmaurit.github.io\#solar_lemons`.

4 The California Solar Initiative and the Market for Solar Power

The California Solar Initiative was launched in January of 2007 and scheduled to last until 2016 or until the allocated funds of approximately 2.1 billion dollars were exhausted [California Public Utilities Commission, 2014]. As of the end of 2013, approximately 1500 megawatts (mW) out of a goal of 1940 MW was installed. The rebates covered customers of the largest three investor owned utilities - Pacific Gas and Electric Company, Southern California Edison, and San Diego Gas and Electric - combined representing approximately 70 percent of California's load. The amount of the incentives is complex, being based on size of installation, and how much capacity has already been installed. In general, the incentives were designed to decline over time as more capacity is installed.

In the period 2007 to 2014, prices of solar power systems fell dramatically. Figure 1 shows the average total solar power system cost per kilowatt (kW) over time. In addition to a sharp fall in the system costs, the figure also shows that subsidies have shrunk while new installed capacity has generally continued to increase. The drop-off in installations seen towards 2014 reflects the exhaustion of rebates for customers of the Pacific Gas and Electric Company. This drop-off does not reflect total installations, as the data only includes installations that benefited from the rebate. Previous to the expiration of some of the subsidies in 2014, the dataset likely includes nearly all installations [Dastrup et al., 2012].

Figure 2 shows total installations between 2007 and 2014 by zip code. Unsurprisingly, installations of capacity were largest around the large metro areas of San Diego, Los Angeles and the San Fransisco Bay Area. In part this reflects that the data does not include utility-owned installations, but in general, the majority of solar power capacity has been in the form of small,

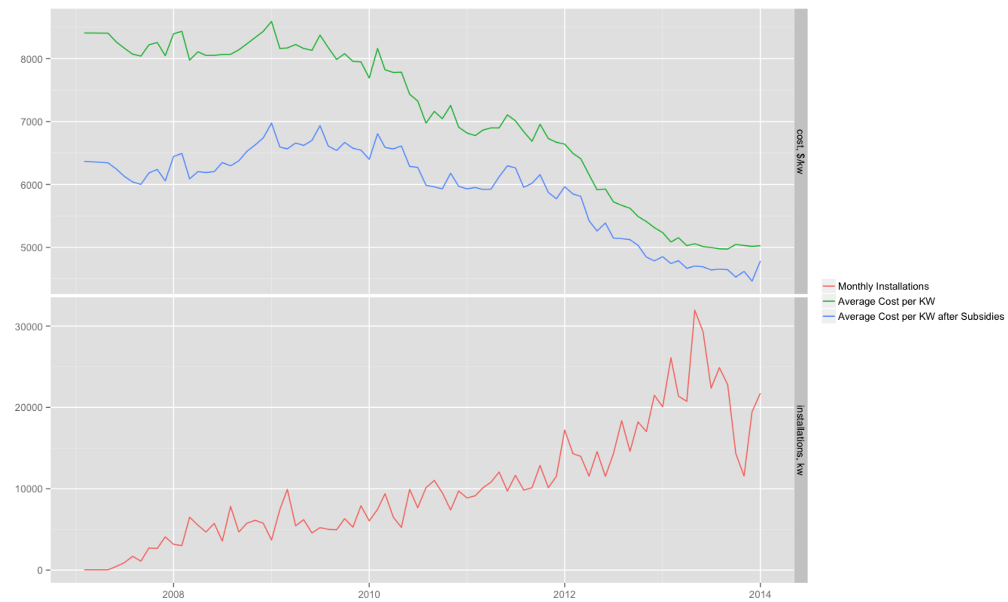

Figure 1: The cost of solar power systems have fallen dramatically over the time period studied. Subsidies have been reduced in kind, however installations have continued a general upwards trend.

distributed systems mostly installed on rooftops rather than large utility-scale installations.

A jitter plot is shown in figure 3 to visualize the distribution of system prices over time. This figure shows a pattern of an initial widening of the variance in prices and then a narrowing. But what also catches the eye are the solid bands at certain price points. The explanation for these clustered prices is that they consist of a single installer. In particular, the company Solar City has rapidly gained market share in the California solar market over the last several years. The bands of identical prices represent leased systems that are reported as having equal costs.

Comparing prices of leased systems to those that are sold out-right can be difficult because of the variation in what contractors report as the total cost for leased systems. Where the cost reported of a system that is sold out-right is simply the total price charged by the contractor, the cost of a leased system could be reported as either the Fair Market Value of the system, which is reported in tax filings or as an appraised sum of cost inputs. Some contractors will also include the cost of inverter replacements or roof replacements necessary for installation. These likely account for a few of the large price outliers.

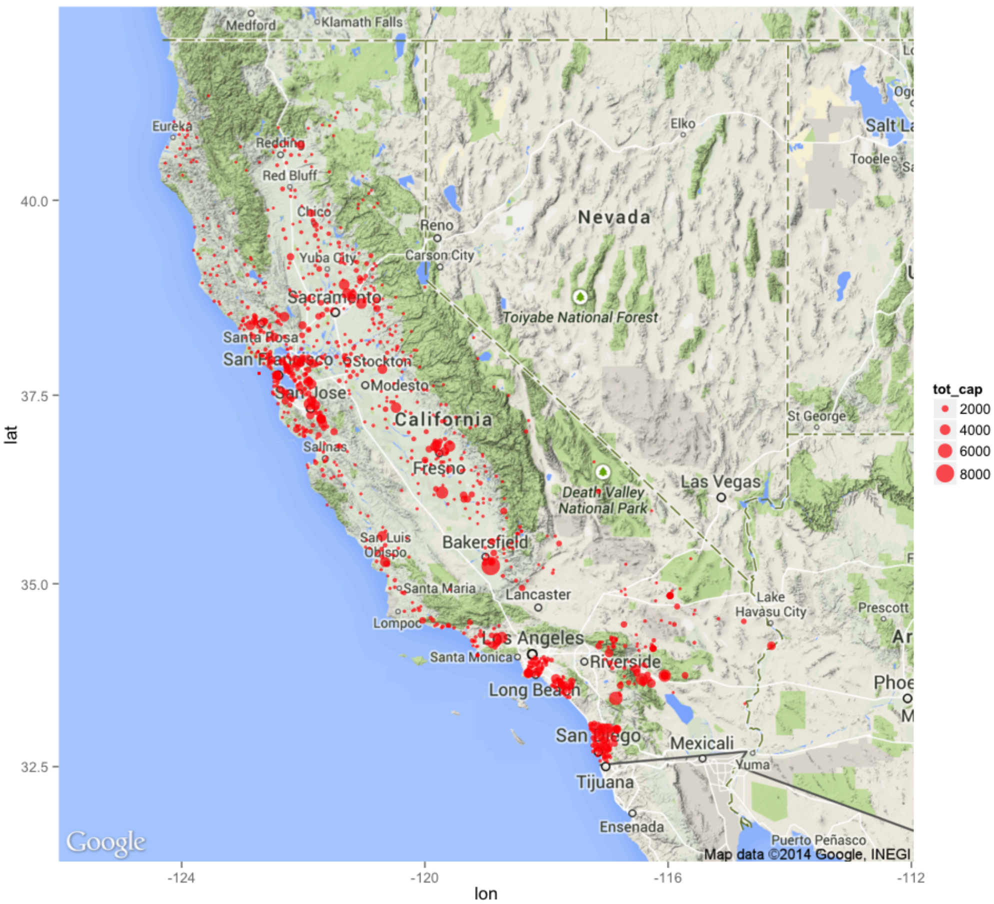

Figure 2: The figure shows the total installed capacity between 2007 and 2014 by zip code. Installations are concentrated around the big cities.

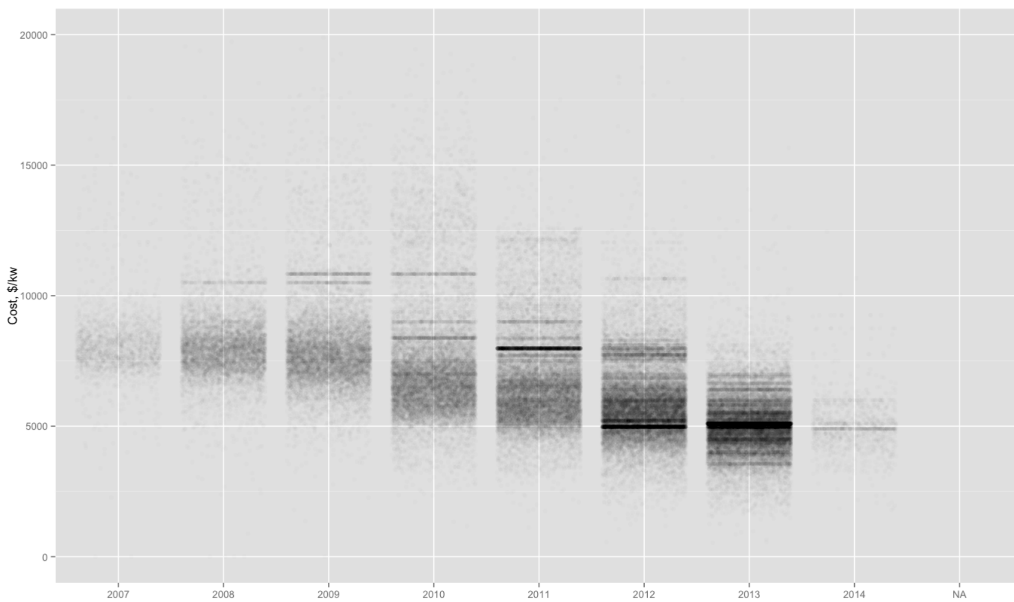

Figure 3: The jitter plot shows how the distribution of solar system costs has changed over time as well as how some of the reported costs of systems are clumped together. These are the reported costs of leased systems.

5 Lemons and the switch to Chinese panels

The steep drop in solar panel systems in the period studied and especially since 2009 has a seemingly simple explanation. The expansion of low-cost production in China led to a large fall in global panel prices. But the story becomes more complicated when looking at how the availability of cheaper Chinese panels affects the pricing of the total system costs, which are directly determined by choices made by local contractors.

First, solar panels are not a completely homogeneous, fungible commodity. Not all panels from all producers went down in price equally. Figure 4 shows the average price of installations by the nationality of the panel maker. While the price fell for installations using panels from all nationalities, those that used panels from China as well as South Korea and Taiwan tended to be cheaper than those from German, Spanish, US or Japanese manufacturers. [1] This suggests that the fall in system costs could be more if contractors switched from established western and Japanese producers to newer Chinese, Taiwanese and South Korean producers.

The lowering of system costs is not just a function of global economies of scale, but also of the decisions made by contractors and consumers at the local level of whether to continue using panels from a established and perhaps more trusted manufacturer, or switch to a cheaper, but unknown

[1] Some care should be used in interpreting data on nationality. I used the nationality of the panel producer, not necessarily the actual location of the panel production. Especially in the latter years, established western and Japanese producers have moved their production lines to China and other lower-cost countries.

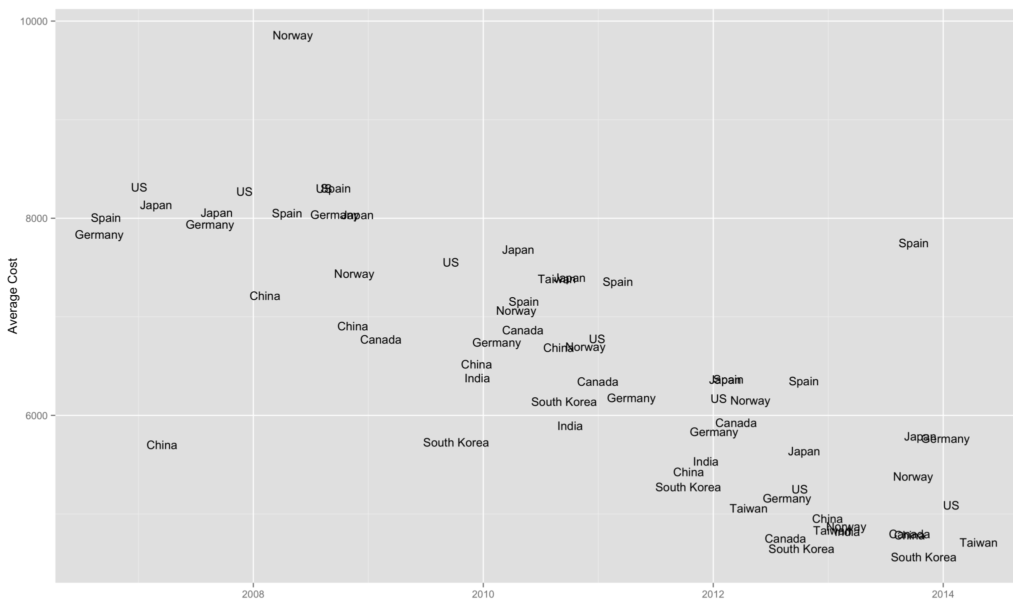

Figure 4: While the average cost of systems using panels from all nationalities came down in price, systems using Chinese, South Korean and Taiwanese panels tended to be cheaper.

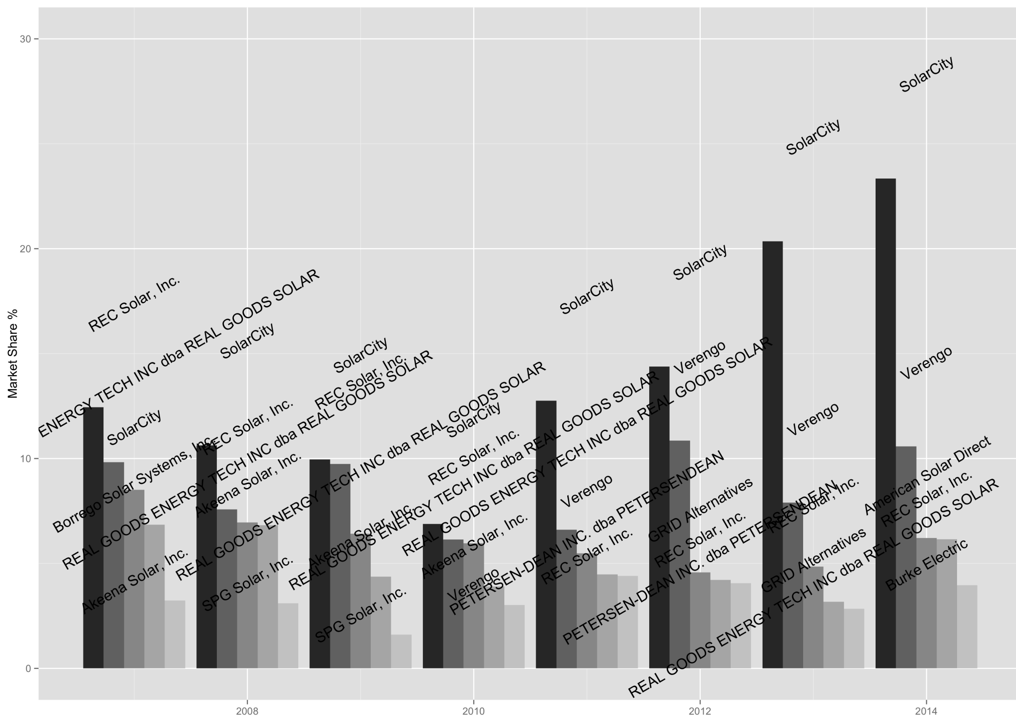

Figure 5: Marked concentration increased markedly over the period studied.

Chinese manufacturer.

As figure 5 shows, market concentration has increased markedly over the time period studied. In particular, two contractors were able to gain large amounts of market share - Solar City and Verengo.

Taking the example of Solar City, figure 6 shows the top panel manufacturers used by Solar City by year. In the years prior to 2010 - the top panel makers used by Solar City were BP Solar, Solar World, Kyocera Solar and Evergreen Solar - manufacturers based in Spain, Germany, Japan and the US. But a notable shift happens in 2011. Yingli Energy - a Chinese panel

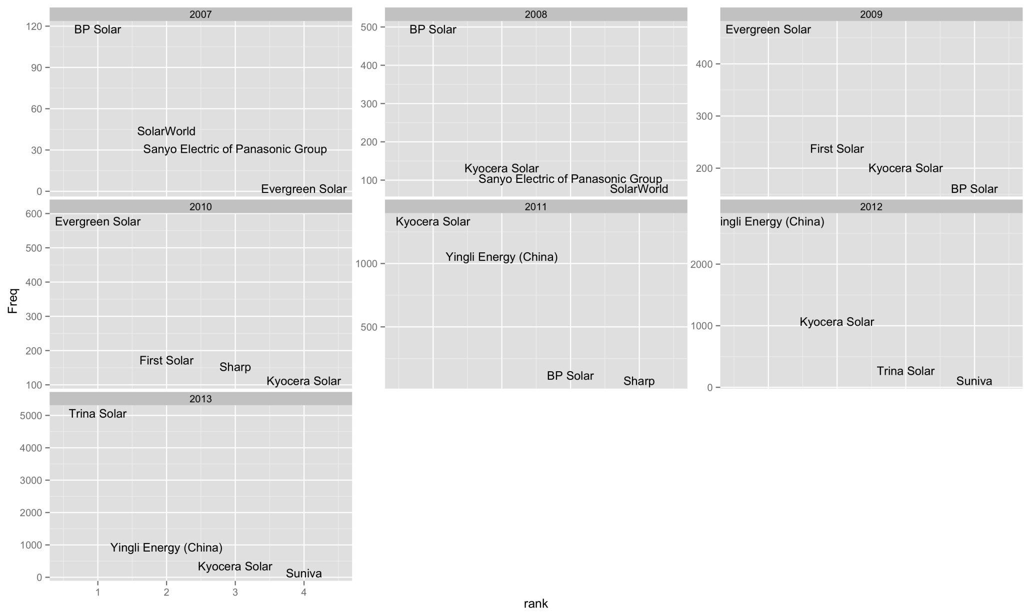

Figure 6: The top panel makers used by the leading solar system contractor, Solar City.

maker that previously had been almost entirely absent as a supplier, jumped to become Solar City's second largest supplier in California. In the following year it became their by far largest supplier. In 2013 another Chinese panel supplier - Trina Solar - became Solar City's largest supplier.

In the years after 2010, Solar City, as well as a few other contractors gained market share while they switched to Chinese panels. This dynamic is shown in figure 5 as well as in 7. However, as figure 7 also shows, Solar City was not a first mover. Many contractors switched over to using Chinese panels well before Solar City did so, but it appears that being an early adopter of Chinese panels and the price advantage that conferred did not necessarily lead to increased market share.

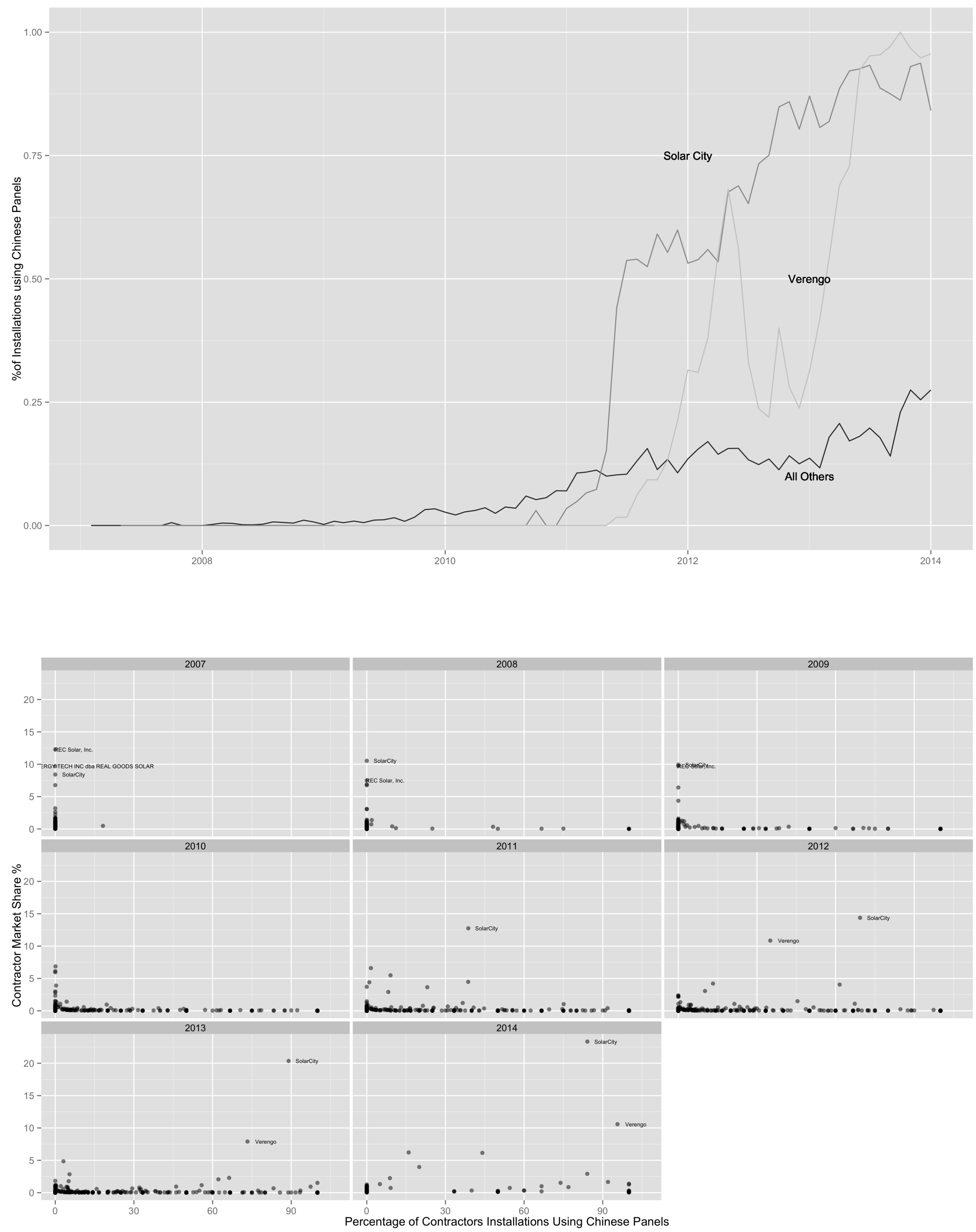

Figure 7: A few contractors, notable Solar City, were able to grab market share while switching to Chinese panels. However switching to Chinese panels alone does not sufficiently explain the increase in market share.

A host of factors could be responsible for why some contractors were able to gain market share other than the price advantage of switching to Chinese panels. Advantages in financing, management practices, to building on the existing advantages of scale could, and likely did play a role to a certain exist.

However, the data suggests an alternative explanation backed up by a simple economic intuition. Solar panels are long-lived assets that currently must last at least a decade in order to be financially profitable for the owner. More so, judging the quality of solar panels is beyond the technical abilities of the vast majority of consumers and thus most will rely on reputation and ratings of existing manufacturers. For example, figure 9 shows a screen shot of the website `http://solar-panels-review.toptenreviews.com/`, which provides reviews of solar panels based on past performance.

However, this presents a problem for manufacturers that have not had an earlier presence on the market - in particular, Chinese manufacturers. A lemons problem of asymmetric information arises. Consumers, with poor information on the quality of panels from unestablished Chinese manufacturers, will be weary of purchasing them. At a minimum they will demand a lower price than a comparable system with panels from an established manufacturer, and following the model by Akerlof, a market for systems using Chinese panels may even cease to exist entirely.

But a closer look at the data reveals that the firms that gained significant market share not only switched to Chinese panels but simultaneously switched to selling systems on a leasing model, as figure 5 shows. While

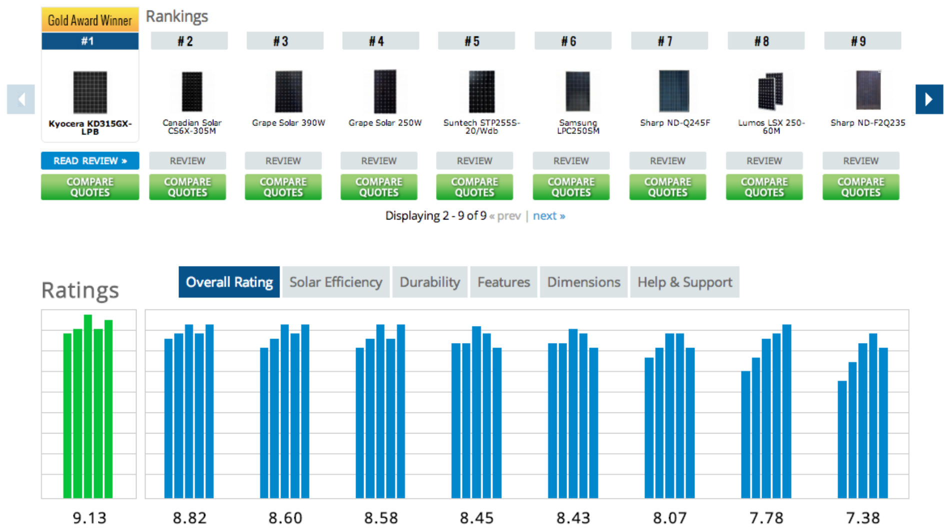

Figure 8: Websites are available providing reviews of various solar panels, however new manufacturers that have not been on the market and have not been tested in California would not have shown up here.

verifying the quality of panels from a previously unknown manufacturer is expensive, a large contractor can take steps like having experts test the quality of modules and visiting manufacturing facilities that ordinary homeowners and business would find prohibitive. Having verified the quality of the panels, the contractor can then offer to build the system, offering the building owner a rebate on their electricity bill while retaining ownership of the actual system.

Using a leasing system is also superior to issuing a guarantee in overcoming the information asymmetry. A guarantee issued by a contractor to a homeowner is good only as long as the contractor remains solvent. Since the solar contractors are themselves often new firms, such a guarantee may not

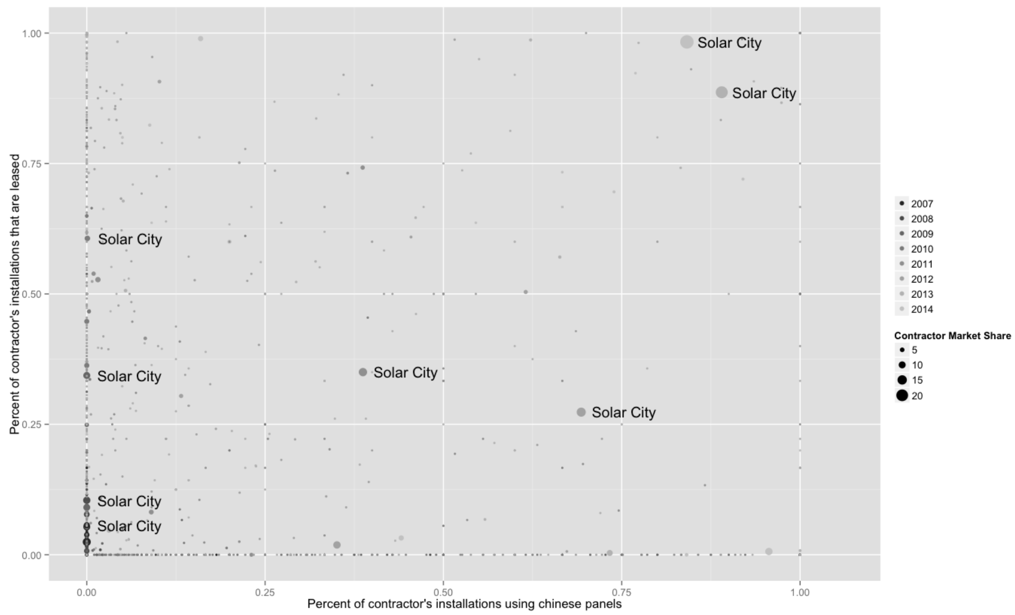

Figure 9: Contractors that gained market share, notably Solar City, did so not only by switching to cheaper Chinese panels but also by moving to a leasing model of sales.

be seen as sufficient.

If it were the case that the leasing model was introduced not just because using Chinese panels made it feasible but also because the leasing model itself solved an asymmetric information problem about the quality of Chinese panels, then a testable implication is that at any given time, leased systems will have a higher tendency to use Chinese panels than those that are sold outright. Figure 10 shows that this is generally the case.

However this implication has some subtleties. Once a large contractor has in effect verified the quality of Chinese panels by adopting them for use in their leased systems, then it can quickly become public knowledge. Other

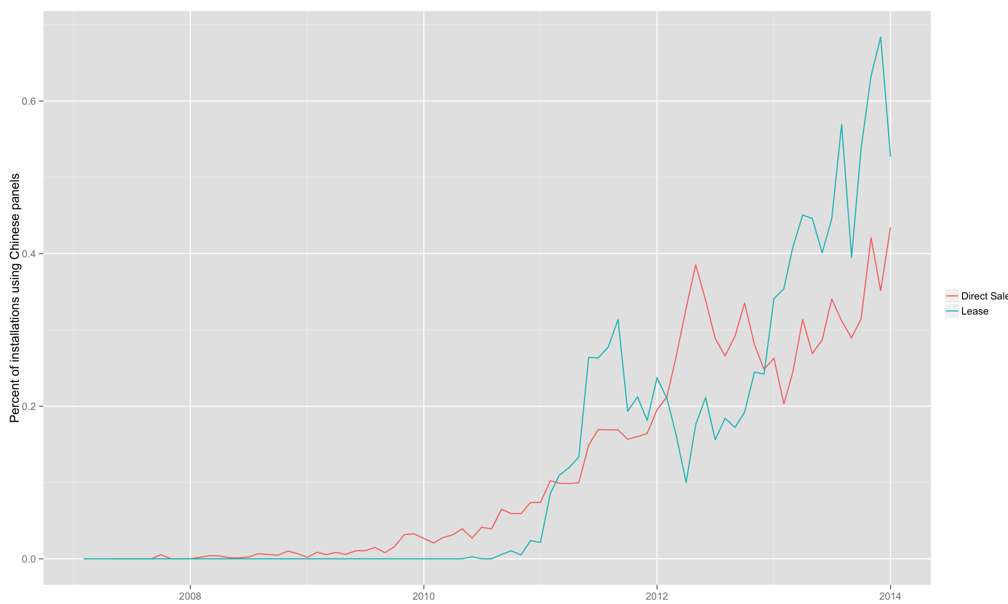

Figure 10: A higher percentage of leased solar systems tend to use Chinese panels. Once a large contractor has adopted Chinese panels and in effect verified their quality, then this can become public knowledge, leading to higher adoption of Chinese panels among systems that are sold outright.

contractors can then plausibly free-ride on this verification. We would then expect to see an increasing adoption of Chinese panels in systems that are sold outright, a pattern consistent with figure 10.

So far I have presented a descriptive evidence that adoption of Chinese panels and a leasing models in the California are closely intertwined and helped bring down prices and increase popularity of solar power systems. Contractors who use a leasing model can be expected to be able to collect an information rent compared to contractors who sell solar systems outright. I explore these predictions in the next session with regressions at the installation and contractor level as well a multilevel regression model.

6 Regression models

I begin with some simple regressions exploring the relationship between using Chinese panels and a leasing business model, as well as installation-level regressions of the correlations of adoption of Chinese panels and leasing on the fall in prices over time. At the contractor level, I run regressions looking at factors involved in gaining market share and lowering prices. I then provide a fuller analysis using a multilevel model - simultaneously estimating the effect of dynamic predictors at the installation and contractor level.

For the regression models I discard data where the system was self-installed, since the focus of this paper is on the strategies of contractors. For simplicity, I also only include data on installations from the top 50 panel producers. Of the initial approximately 124,000 installations in the data set, approximately 119,000 remain after these exclusions.

The most direct implication from the descriptive analysis presented above is that a link exists between switching to Chinese panels and using a leasing model. A simple logit model where the right-hand-side variable is whether or not a solar system is leased can be written as in equation 1.

$$logit(lease_i) = \alpha + \beta timeYears_i + nationality_i + \sigma timeYears_i * nationality + \epsilon \quad (1)$$

Here the variable $timeYears_i$ represents the time in year units, from January 1st, 2007 to when an installation i was installed. The reason time is measured from January 1st, 2007 is that this is when the California Solar Initiative officially opened and the earliest installation in the data set was installed shortly after. The $nationality_i$ represents a fixed effect for the nationality of the panel producer.

The results are best interpreted graphically, as in figure 11, but a table of estimated coefficients can be found in table 2. All coefficients are estimated to be statistically significant at the 5 % level.

Here the lines represent model results for the probability of a system being leased using panels from Chinese manufacturers as well as comparisons with German and Japanese manufacturers - countries with large, established solar panel industries. The jittered dots represent installations that are either

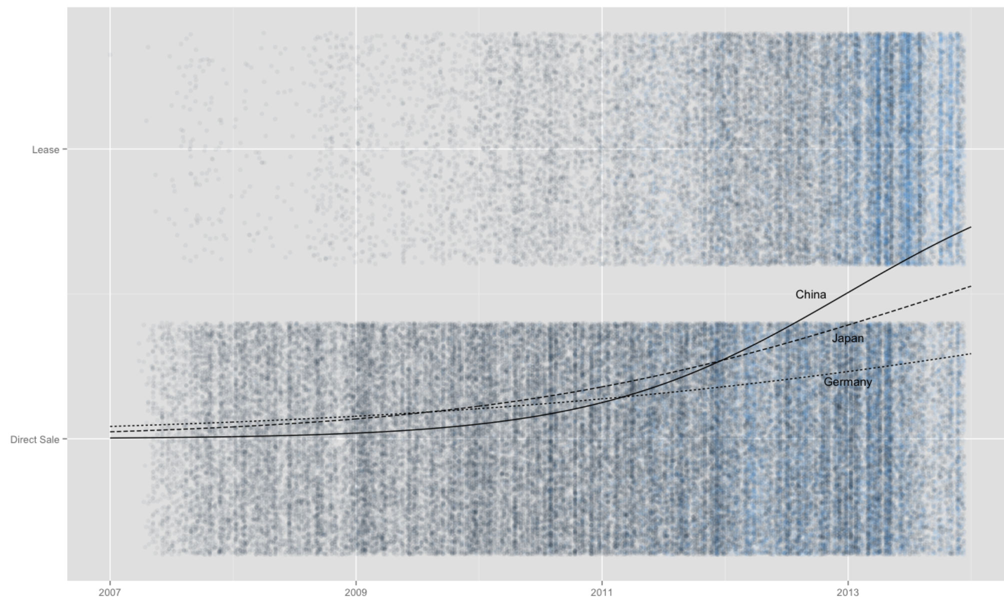

Figure 11: The figure shows model results from a logit model of the probability of a solar system being leased as a function of time since February of 2007, nationality of the panel maker and their interactions. Systems with Chinese panels, mostly absent from the market before 2010, were substantially more likely to be used in leased systems than panels from more established Japanese and German manufacturers.

leased or sold outright where a blue color represents the use of Chinese panels. While the probability of of using a leasing model increases over time for systems using panels from all countries, the probability increases sharply for those using Chinese panels.

The regressions above indicate significant conditional correlations between the use of Chinese panels and a leasing model. However, the hypothesis that emerged from the descriptive analysis above was not necessarily that using Chinese models required a leasing model, but rather that it could confer an advantage. In turn, combining the use of Chinese panels and a leasing model would be expected to lead to an increase in market share. A regression model to explore this hypothesis can be written as in equation 3.

$$marketshare_j = \alpha + \beta_1 percChinese_j + \beta_2 percLease_j + \quad (2)$$

$$\beta_3 percChinese_j * percLease_j + year + \epsilon \quad (3)$$

In these regressions, the data is aggregated to the contractor-year level, indexed by j. The variable *percChinese* represents the percent of all installations by a contractor using Chinese panels in a given year. Likewise *percLease* represents the percent of installations that are leased by a contractor in any given year. In addition interaction effects are included as well as year fixed-effects.

The results are presented in table 1. In the first column, year fixed effects are excluded. Here the coefficient on the main effect for using Chinese panels is not distinguishable from zero. This can be interpreted to mean that if a contractor does not lease solar systems, then increasing the percentage of Chinese panels is not associated with an increase in the market share. However the interaction term for percent Chinese with percent lease is strongly positive. The coefficient is easiest to interpret at the margin - given that a contractor uses only Chinese panels, a one percent increase in the share of systems they lease is associated with a one percent increase in market share.

	No F.E.	Year F.E.	excl. SCTY
(Intercept)	0.10***	0.41***	0.38***
	(0.01)	(0.05)	(0.03)
perc-chinese	−0.03	0.02	0.02
	(0.03)	(0.03)	(0.02)
perc-lease	0.31***	0.34***	0.31***
	(0.05)	(0.05)	(0.04)
perc-chinese:perc-lease	0.98***	0.91***	−0.04
	(0.14)	(0.14)	(0.10)
R^2	0.03	0.04	0.04
Adj. R^2	0.03	0.04	0.04
Num. obs.	6006	6006	5998

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Table 1: The results of these regressions can be interpreted to mean that given that a contractor uses only Chinese panels, a one percent increase in the share of leased systems leads to a one percent increase in market share. This effect, however, disappears when the leading contractor, Solar City is removed from the data.

In the third column I exclude the dominant contractor, Solar City from the data. The main effect for leasing remains essentially unchanged but the coefficient on the interaction term becomes insignificant. These results can be interpreted to mean that switching to a leasing model in general led to gains in market share, where the largest gains were made by a a few companies that simultaneously switched to using Chinese panels as well as a leasing model. This interpretation has intuitive appeal given the costs of verifying the quality of solar panels. Actions like sending experts to inspect production facilities would be prohibitively expensive for all but the biggest contractors.

An important potential outcome of introducing a leasing model, is that by gaining acceptance of cheaper Chinese panels, the leasing model was able to bring down solar system prices in California. To explore this I start with a simple model at the installation level. In the first column, I show results where I estimate the slope of log-costs over time with separate terms for whether systems were leased or used panels from Chinese manufacturers. The model can be written as in 4.

$$log(costPerKw_i) = \alpha + \gamma china_i + \tau lease_i + \beta timeYears_i + \sigma inter_i + \epsilon \quad (4)$$

Again, the model results are easiest to interpret in graphical form, presented in figure 12. A table of coefficients, all of which are estimated to be statistically significant at the 95% level, can be found in table 3 in the appendix. The model estimates that leased systems using Chinese panels enjoy a considerable cost advantage over non-Chinese systems, though that advantage has narrowed over time. The model results should be interpreted with care before 2011 as relatively few of the systems were both leased and used Chinese panels.

The results from the above regression provide evidence that both leasing and switching to Chinese panels played a significant role in lowering prices. However, the above installation-level model ignores the role of contractor-level variation. At the same time, models using data aggregated to the contractor-level ignores the substantial variation between installations by the same contractor. More so, the question of interest is not how the cost of leased systems using Chinese panels has changed over time, but rather how the cost has changed for contractors who change to using a leasing model

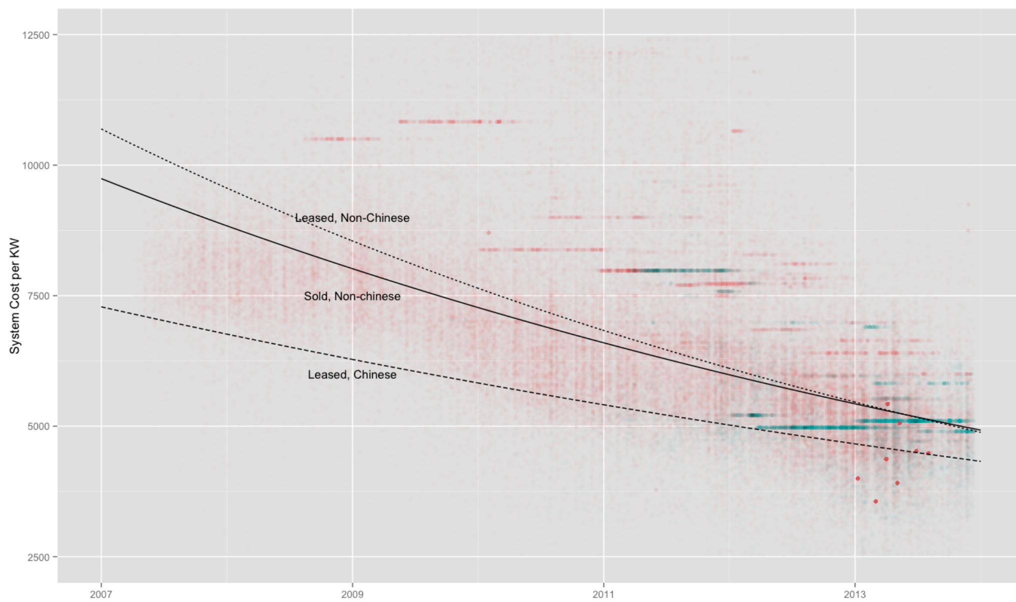

Figure 12: The figure shows model results from a log-linear model of solar system cost per kW as a function of time, whether a model was leased, and whether panels where from a Chinese manufacturer. The lines represent the model results while the dots represent the raw data on installations where a green color signifies installations that use Chinese panels. Systems with Chinese panels are substantially cheaper through the period studied, but only became widely popular after 2011.

and Chinese manufacturers.

Next I use a multilevel model in order to simultaneously model contractor level and installation level variation. [2] Following the notation from Gelman and Hill [2006] the model can be written as in equation 6. Here the cost-per-kilowatt for each contractor j is modeled as a function of an intercept and installation-level data on the time of installation as well as group level predictors, represented by the vector of variables U_j and where $B_j = \{a_{j[i]}, b_j[i]\}$. Intuitively, the estimated coefficients estimated for each contractor are pulled towards the conditional pooled average - these models are sometimes referred to as partial pooling models.

The contractor level

$$log(costPerKw_i) \sim N(a_{j[i]} + b_{j[i]}timeYears_i, \sigma_y^2), i = 1, ..., n \tag{5}$$

$$B_j \sim N(U_j G, \Sigma_B), j = 1, ..., J \tag{6}$$

I include data between the years 2009 and 2013 as this was the period with the most dramatic price fall and with the most industry dynamics. The variables of interest are the $b_{j[i]}$s, which can be interpreted as the average rate of price declines for each of the 278 contractors in the data set. G represents the vector of coefficients on the contractor level predictors U_j. The contractor

[2] Multilevel models are often referred to as mixed effects models or random effects models, especially in the economics literature. However the language here can be inconsistent and confusing. I follow Gelman and Hill [2006] and **?** in calling them multilevel models.

level predictors that are of interest are the change in percent of a contractor's installations that use Chinese panels between 2009 and 2013, and the change in the percent of a contractor's installations that are leased, as well as an interaction effect. Unlike in the single level models earlier, her the decision at the contractor level - a change to Chinese panels and a change to a leasing models can be modeled explicitly and aids in a causal interpretation.

Figure 13 shows the results of the multilevel regressions graphically. Since 278 separate coefficients are estimated for the within-contractor price terms, it is impractical to include a table of results. The first row represents results when only the main effects of the contractor level predictors are included in $U_j = \{changeChinese_j, changeLease_j\}$.

In the top left panel, the estimated coefficients on the slope of the price change for all contractors is plotted as points in order of the change in the percent of Chinese panels the contractor used. The line represents the estimated coefficient on the contractor-level predictor, $changeChinese_j$. Though substantial variation exists between contractors, the slope of the coefficient on $changeChinese_j$ is significantly negative. Contractors who switched to using Chinese panels saw, on average, a larger price drop.

In the top right panel, the estimated coefficients on the time variable are ordered in terms of the $changeLease_j$ variable. Here the contractor-level coefficient on $changeLease_j$ is estimated to be slightly positive. On the margin, companies that switched to using a higher percentage of leasing models, saw a smaller decline in prices than those that did not use a leasing

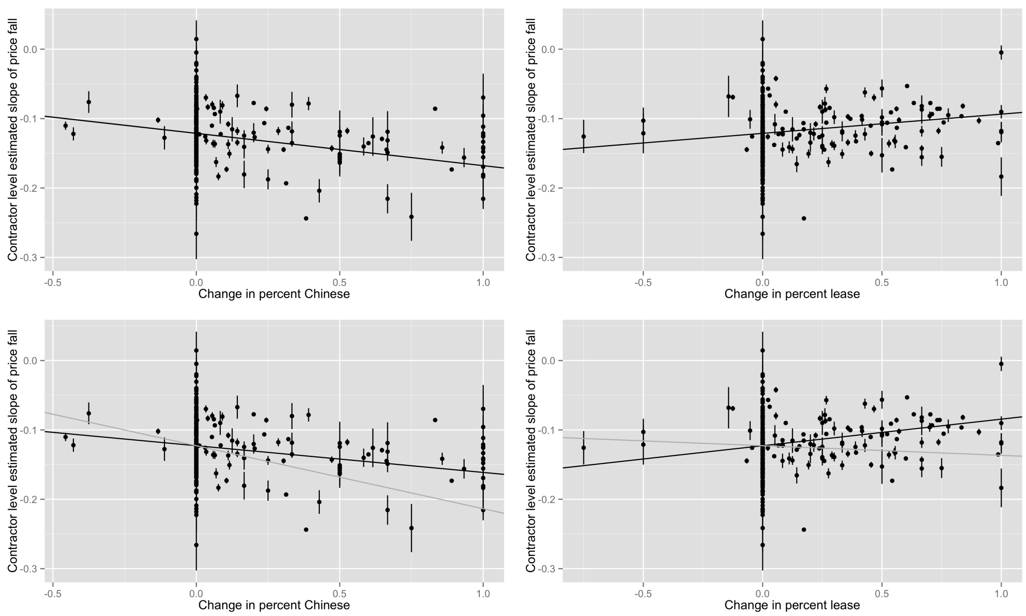

Figure 13: The top left panel shows that contractors that increased the share of installations using Chinese panels saw a steeper fall in costs over time. The lower left panel shows that those that also increased the share of leased panels, represented by the gray line, saw an even steeper fall in costs. The panels on the right show that all else equal, contractors that increased the share of leased installations saw less of a price fall, however those that simultaneously increased their share of installations with Chinese panels saw a steeper fall in prices.

model.

However, the contractor-level coefficient of interest is the interaction effect. In the bottom left panel, I show results from a regression model where I include an interaction term between $changeChinese_j$ and $changeLease_j$ to the vector of contractor-level predictors U_j. In the bottom left panel I show the estimated coefficient on the $changeChinese_j$ as the slope of the black line while the interaction term is added to produce the full effect in the gray line. The combination of changing to a higher percentage of leased systems and a higher percentage using Chinese panels led to a steeper drop in prices. In the bottom right panel, the slope of the black line represents the estimated coefficient on $changeLease$, where the slope of the grey line has the interaction term added. Where contractors that increased the percentage of leases while not switching to Chinese panels saw a smaller decrease in their prices over time, the opposite is true of those that did switch to Chinese panels.

One important note of caution in interpreting these results is that comparing reported costs of systems sold directly to homeowners and businesses to leased systems can be troublesome. The costs reported to systems sold directly are simply the total transaction price. On the other hand, contractors must self report the cost of a leased system. Because of federal tax incentives that are based on total investment costs, the contractors may have an incentive to overstate their costs. In fact Solar City is currently under investigation by the Internal Revenue Service for overstating costs [Solar City]. With this in mind, the results that show that companies that switched to a leasing model lowered their prices more can be taken as being conservative.

7 Conclusion

This paper has been exploratory and descriptive in its aims and scope, but the results have important implications for understanding the emerging solar power industry as well as for informing policies meant to encourage the adoption of solar power. Because solar power systems can be installed on roof-tops and that they in turn can compete with residential electricity prices, which are substantially higher than wholesale prices for electricity, solar power systems have become attractive for individual homeowners to install and operate. However, this also distinguishes solar power from most other forms of electricity generation. The decision of whether or not to invest is not made by an informed electricity utility executive, but rather regular home- and business-owners with limited industry knowledge and financial and engineering resources.

Uncertainty and information asymmetry becomes a major factor in the investment decision. This article has argued that the dramatic fall in solar power system costs in California between 2009 to 2013 can not be explained by new Chinese panel production in isolation. Instead, the simultaneous introduction of a leasing model helped overcome information asymmetries and uncertainty, at least partly related to the quality of Chinese and Taiwanese panels.

This article has not explicitly set out to explore solar power policy, but several implications do emerge from this research. In Germany, also a leader in solar photovoltaic installations, only homeowners who themselves own their own solar system can collect government production subsidies. The flexibility of Californias rules allowed for the introduction of leasing models and in turn lower overall prices.

Trade policy is also closely related to the subject of this article. In 2014, after the period studied in this article, trade sanctions were imposed by the US department of Commerce on Chinese and Taiwanese solar panels of at least 30 percent. The merits and fairness of these sanctions are beyond the scope of this article, however in the period studied the data clearly shows how competition from Chinese manufacturers drove down overall system costs and spurred increased installations. Subsidizing solar systems while at the same time imposing tariffs on imported panels seem like contradictory actions if the aim is to increase renewable energy production.

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A Regression Tables

	Prob. of Lease
(Intercept)	-4.00^{***}
	(0.17)
time_years	0.58^{***}
	(0.03)
nationalityChina	-1.87^{***}
	(0.21)
nationalityGermany	0.89^{***}
	(0.21)
nationalityIndia	-14.32^{***}
	(3.44)
nationalityJapan	0.31
	(0.18)
nationalityNorway	2.96^{***}
	(0.21)
nationalitySouth Korea	-4.75^{***}
	(0.61)
nationalitySpain	-0.53^{*}
	(0.24)
nationalityTaiwan	-10.30^{***}
	(2.37)
nationalityUS	-0.14
	(0.18)
time_years:nationalityChina	0.41^{***}
	(0.04)
time_years:nationalityGermany	-0.26^{***}
	(0.04)
time_years:nationalityIndia	2.85^{***}
	(0.68)
time_years:nationalityJapan	-0.03
	(0.03)
time_years:nationalityNorway	-0.47^{***}
	(0.04)
time_years:nationalitySouth Korea	0.76^{***}
	(0.10)
time_years:nationalitySpain	0.12^{*}
	(0.05)
time_years:nationalityTaiwan	1.53^{***}
	(0.37)
time_years:nationalityUS	0.14^{***}
	(0.03)
AIC	123058.44
BIC	123252.16
Log Likelihood	-61509.22
Deviance	123018.44
Num. obs.	118890

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Table 2: Full results for logit model of the probability of a sysmem being leased.

	Log Costs
(Intercept)	9.18***
	(0.00)
time_years	−0.10***
	(0.00)
lease	0.09***
	(0.01)
china	0.10***
	(0.01)
time_years:lease	−0.01***
	(0.00)
time_years:china	−0.03***
	(0.00)
lease:china	−0.40***
	(0.02)
time_years:lease:china	0.07***
	(0.00)
R^2	0.38
Adj. R^2	0.38
Num. obs.	118890

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Table 3: Full model results of log costs of installed solar systems.

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