



Using Residential Solar PV Quote Data to Analyze the Relationship between Installer Pricing and Firm Size

Eric O'Shaughnessy and Robert Margolis
National Renewable Energy Laboratory

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Executive Summary

The vast majority of U.S. residential solar photovoltaic (PV) installation companies are small local firms, yet a few large firms dominate the industry. In 2015, the largest 10% of installers accounted for nearly 90% of residential systems installed, and the largest 1% of installers accounted for more than 60% of systems. PV market literature has produced conflicting results on the effects of installer size on price behavior. In this report, we develop a novel approach using residential PV quote data, rather than installed system price data, to study the effects of installer size and market structure on price behavior. The methodological advantage of quote data is that customer and site characteristics remain constant across multiple quotes made to the same customer, allowing us to effectively control for otherwise unobservable customer- and site-level differences.

Through a paired difference approach, we match quotes from large installers (those that installed more than 1,000 systems in any year from 2013 to 2015) with non-large installer quotes made to the same customers. We find that large installer quotes are \$0.33/W (about 10%) higher, on average, than non-large installer quotes offered to the same customer (Figure ES-1). The difference falls to \$0.21/W after controlling for systematic differences between large and non-large installer quotes, but it remains statistically significant. Large installers offered a higher quote price than a corresponding non-large installer in about 70% of pairings.

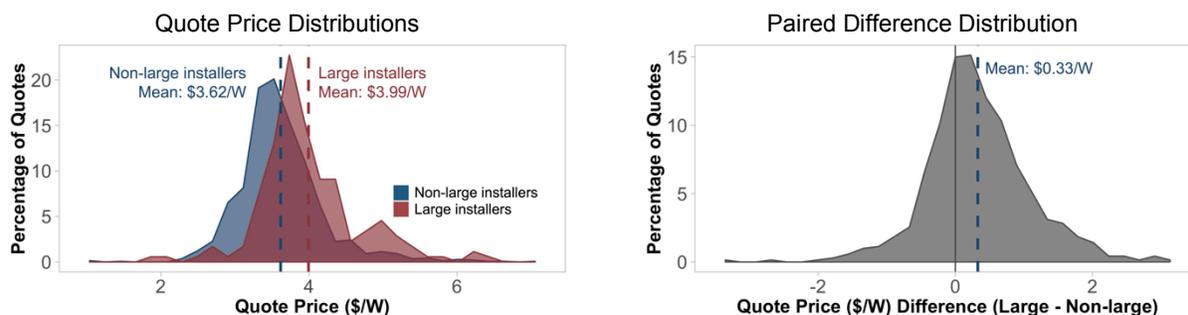


Figure ES-1. Quote price distributions of non-large and large installers (left pane) and paired difference distribution (right pane)

Our results suggest that low prices were not the primary value proposition of large installer systems, at least for quoted customer-owned systems during 2014–2016 in 27 states and Washington, D.C. These findings may support several hypotheses. Large installers may bid higher prices due to imperfect competition in the customer quote collection process. At the same time, customers may attribute a variety of additional values to large installers, such as higher quality and trustworthiness. Large installers may differentiate their services, such as through superior warranties and inverter replacement terms. Some customers may accept higher prices even if lower prices are available from smaller installers.

The results corroborate previous findings that market structure affects PV prices, and they suggest that increased price transparency may promote further price reductions. Our results suggest that some residential PV customers may forego lower prices for the opportunity to work with a large installer, but also that customers could benefit from obtaining more quotes before deciding to install a system.

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1 Introduction

The vast majority of U.S. residential solar photovoltaic (PV) installation companies are small local firms, yet a few large national-scale installers dominate the industry. In 2015, the largest 10% of installers accounted for nearly 90% of residential systems installed, and the largest 1% of installers accounted for more than 60% of systems.¹ Market research has shown conflicting results for the effects of installer size and market structure on PV system installed prices (Barbose et al. 2015; Gillingham et al. 2016; Nemet et al. 2017; Pless et al. 2017). In this report, we develop a novel approach using residential PV quote data from a third-party quote provider, rather than installed system price data, to examine installer pricing behavior in the context of installer size. An improved understanding of installer pricing behavior is crucial to further analysis of the effects of installer size and competition on PV market prices and, ultimately, deployment.

Large PV installers have been instrumental in the evolution of the PV industry in the United States and abroad. Large installers have developed and implemented market innovations such as power purchase agreements and leases that have accelerated PV deployment (Drury et al. 2012; Feldman et al. 2013). Large installers have reduced installation costs through accumulated experience (Gillingham et al. 2016; Nemet et al. 2017), and these cost reductions benefit the industry as a whole through knowledge “spillovers” to other installers (Ghemawat and Spence 1985; Irwin and Klenow 1994). Further, customers may attribute additional values to large installers such as trustworthiness and reputational values (Klein and Leffler 1981; Shapiro 1983; Rao and Monroe 1989).

The effects of installer size on PV prices are not well understood. Several studies indicate that more experienced installers offer lower prices, consistent with learning-by-doing cost reductions (Gillingham et al. 2016; Nemet et al. 2017; Pless et al. 2017). However installers also offer lower prices in markets with more competitors (Gillingham et al. 2016), and smaller installers are more likely to install low-priced systems (Nemet et al. 2017). To understand why installer size should affect PV prices at all, we first review the relevant literature on firm pricing behavior.

1.1 A Primer on Installer Pricing Behavior

PV installers, like all firms, must develop price strategies that are simultaneously financially sustainable and competitive. The question of this study is whether installer size affects installer pricing behavior. Empirical and theoretical literature provide some insights about the role of firm size and market structure on pricing behavior, where market structure refers to the organizational characteristics and degree of market concentration in an industry. Table 1 summarizes some of the more consistently noted differences between the pricing behavior of small and large firms. Results from firm-pricing literature and several economic theories provide useful frameworks for examining installer price behavior.

¹ These values are based on data from *Tracking the Sun* (Barbose and Darghouth 2016).

Table 1. Sample of Literature Findings on Large versus Small Firm Pricing Behavior*

Large Firms	Small Firms
<ul style="list-style-type: none">• More homogenous price behavior ^a• Preference for setting prices to ensure a minimum return ^{b, c}• Opportunity to earn premiums in nascent markets ^b• More likely to use market share goals to determine pricing ^d• Align pricing with brand reputational concerns ^e	<ul style="list-style-type: none">• More heterogeneous price behavior ^a• More responsive to market conditions and policy changes ^{f, g}• More likely to use cash flow goals to determine pricing ^d• More likely to cite fair pricing (i.e., fair price for the customer) as an important price driver ^c

* Some studies provide conflicting results; these characteristics are an illustrative sample of the literature.

^a van Dalen and Thurik (1998), ^b Lanzilotti (1958), ^c Shipley (1981), ^d Jobber and Hooley (1987), ^e Chowdury (2010), ^f Haynes (1964), ^g Kosmopoulou et al. (2016).

In general, firm-pricing behavior literature and economic theory support two diametrically opposed but plausible relationships between installer size and pricing. First, large installers could be associated with higher prices if PV markets are imperfectly competitive and installers can exercise market power. Alternatively, large installers could be associated with lower prices if these installers reduce costs through economies of scale and learning and pass these savings through to customers. We explore both hypotheses here.

1.1.1 The Market Power Hypothesis

Most residential customers obtain PV quotes through small-scale bidding processes in which a limited number of installers submit quotes to install the customer's system (Davidson and Margolis 2015). The customer quote collection process is imperfectly competitive from an economic theory perspective because installers can bid higher prices without necessarily losing customers due to competition (McAfee and McMillan 1987; Rothkopf and Harstad 1994; Maskin and Riley 2000; Lorentziadis 2016).

Market power refers to the ability of a firm to sustainably charge prices higher than what would be possible in a perfectly competitive market. All installers, large and non-large, can exercise some degree of market power due to the nature of customer quote collection. However it is possible that firm size affects an installer's ability to exercise market power. We explore two hypotheses why installer size may affect market power: large installers may face fewer competitors, and large installers may have customer acquisition advantages.

First, large installers may face fewer competitors on average than non-large installers. In bidding processes, bidders generally offer higher prices when fewer rivals submit bids (Holt 1980; Kagel and Levin 1986; McAfee and McMillan 1987; Levin and Smith 1994). However installers typically do not know how many competitors will submit bids to a given customer. In markets where at least one large installer is active, small installers are more likely to compete against at least one other installer (the large installer) than large installers. In other words, large installers may expect to compete against fewer rival bidders for any given customer than small installers. Consistent with the bidding literature, this fact would incentivize large installers to bid higher prices than small installers.

Second, large installers may have customer acquisition advantages. In markets for high-technology products such as PV, inexperienced customers may rely on various heuristics such as brand names, reputations, and advertising to evaluate product quality (Scitovsky 1950; Nelson 1974; Shapiro 1983; Milgrom and Roberts 1986; Tirole 1988; Rao and Monroe 1989). Installers have an incentive to differentiate their products through customer acquisition practices such as branding and advertising. Large installers with larger customer acquisition budgets and longer-established reputations may be able to more successfully differentiate their products than non-large installers. A perceived quality of large installer systems, whether real or illusory, could allow large installers to bid higher prices.

Research to date provides mixed signals on the exercise of market power in the U.S. PV installation industry. Barbose et al. (2015) suggest that varying degrees of competition between local markets could explain some of the spatial variation in installed PV system prices. Gillingham et al. (2016) find that installers offer lower prices in markets with more competitors, consistent with the notion that installers bid lower prices when competing with more rival bidders. Paradoxically, however, installers also offer lower prices in more concentrated markets (Gillingham et al. 2016; Nemet et al. 2017; Pless et al. 2017). Gillingham et al. (2016) hypothesize that low costs achieved through learning by large installers offset any price increases from the possible exercise of market power in concentrated markets. Pless et al. (2017) posit that lower prices in more concentrated markets could suggest that some incumbent firms use below-cost pricing strategies to deter potential competitor entry. Alternatively, low prices in concentrated markets could reflect price wars by dominant firms.

1.1.2 The Cost Reduction Hypothesis

Prices in perfectly competitive markets reflect marginal costs of production. Therefore, even in imperfectly competitive markets, prices should roughly follow costs. Further, economic theory suggests that, over some range of production, large firms can reduce cost through increasing output—the phenomenon known as economies of scale. To the extent that large firms are also longer-established firms, firm learning theory suggests that large firms should achieve cost reductions through accumulated experience or “learning” as well. In competitive markets, lower costs should manifest in lower prices.

Multiple studies show an association between installer experience, in terms of number of cumulative systems installed, and lower prices (Gillingham et al. 2016; Nemet et al. 2017; Pless et al. 2017). Low price offerings by more experienced installers may indicate installer cost reductions through learning or economies of scale (Gillingham et al. 2016; Pless et al. 2017).

However, Nemet et al. (2017) find that installers with lower market share are more likely to install low-priced systems. Further, when installer experience is measured in terms of the number of installations in the past 3 months—rather than total cumulative installations—the authors find that firms installing fewer recent systems are more likely to install low-priced systems than are firms installing a larger number of recent systems.

1.2 A Novel Approach Using Customer Quotes

Research to date and economic theory suggest that installers may reduce costs through long-term learning and experience, but that current installer size and market share may have counteracting effects on how these cost reductions are passed through to customers. The relationship between installer size and PV system prices remains unclear. One source of this uncertainty is that PV price research to date has relied on installed system prices from a limited number of data sets. These studies control for price-determining factors like system size and module efficiency, but, owing to data limitations, they do not control for customer-level factors such as roof characteristics and customer preferences.

We study the relationship between installer size and PV system prices by using quote data rather than installed-price data. Multiple quotes made to the same customer may vary in substantive ways that can affect the quote price, such as variations in system size, module brand, and installation timeline. However, customer and site characteristics—such as innate customer preferences and roof characteristics—remain constant across multiple quotes made to the same customer. The methodological advantage of comparing multiple quotes made to the same customer is the ability to control effectively for otherwise unobservable customer- and site-level differences (Figure 1). Our approach is to analyze data for customers who received quotes from both large and non-large installers. Systematic differences in prices quoted to the same customers could suggest different pricing behavior between large and non-large installers.

The remainder of the report is organized as follows. Section 2 describes our data and methods. Section 3 presents the results of the analysis. Section 4 discusses the results and provides key takeaways.

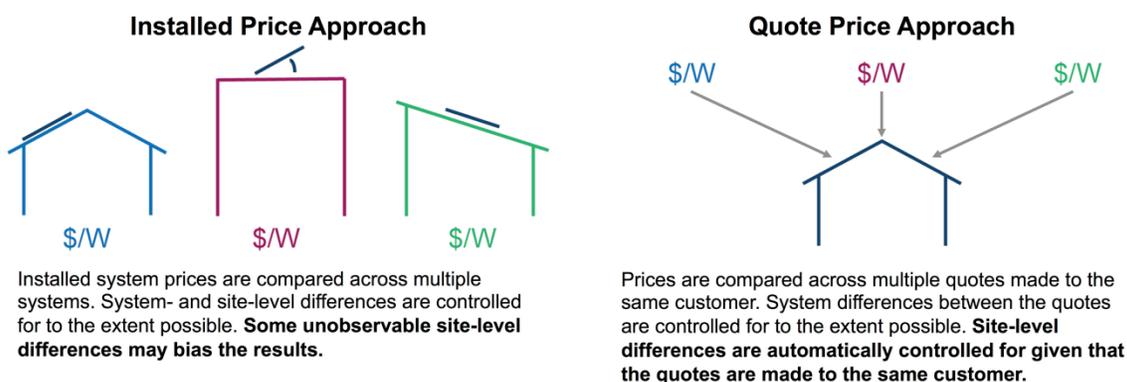


Figure 1. Quote-price approach compared with installed-price approach for PV price research

2 Data and Methods

For the purposes of this study, a *large installer* is any installer that installed more than 1,000 systems in any given year from 2013 to 2015 based on data from Lawrence Berkeley National Laboratory's *Tracking the Sun* data set (Barbose and Darghouth 2016).² This threshold applies to less than 1% of installers. For simplicity, all installers that do not meet this definition are referred to as *non-large* installers.

2.1 Data

Residential quote data were obtained from EnergySage, a third-party quote provider. Prospective customers create an account with EnergySage and provide basic information about their home and electricity needs. EnergySage shares this information with prospective installers in its network so they can develop quotes, and EnergySage conveys quotes from installers to customers. All installers in the EnergySage network must have at least 3 years of experience and be certified by the North American Board of Certified Energy Practitioners.

EnergySage prompts customers to voluntarily upload quotes received by installers outside of the EnergySage installer network.³ Throughout this report, an *internal quote* refers to a quote administered by EnergySage, and an *external quote* refers to a quote received outside of EnergySage. On average, customers receive an internal quote about 2 weeks after receiving an external quote.

Non-large installers provided about 95% of internal quotes, while large installers made about 36% of external quotes. This property allows us to compare a large number of large installer quotes with non-large installer quotes made to the same customers.⁴ Our paired data set (see Section 2.3) consists of customers who received at least one quote from both a large and a non-large installer. Each large installer quote can therefore be paired with at least one non-large installer quote.

About 95% of all quotes we reviewed during data collection included a system purchase option (giving the customer the option to own the system), while about 5% of quotes only offered a lease (allowing the customer to lease the system from a third-party system owner) or power-purchase agreement (allowing the customer to buy system output from a third-party system owner). To provide a consistent metric for comparison across quotes, leases and power-purchase agreements are excluded from the analysis. Thus all comparisons are based on a quoted system purchase price.

² The range was chosen to capture installer scale for the period just preceding and covering the date range of the quote data (2014–2016). *Tracking the Sun* data for 2016 were not yet available.

³ The voluntary upload introduces a potential self-selection bias, but we have no reason to believe that customers who received an external quote and chose to upload the quote vary systematically from customers who received an external quote but did not upload it.

⁴ We use various measures to control for potential differences between internal and external quotes that could confound comparisons based on installer size. See Section 3.

After dropping quotes without a system purchase option, our full data set consists of 1,588 quotes made to 351 customers. These include quotes from 27 states and Washington, DC, made between February 2014 and October 2016. Table 2 describes the full data set, which we use in the analysis along with the paired data set described in Section 2.3.

Table 2. Full Data Set Composition

# of quotes	# of customers	# of large installer quotes	# of non-large installer quotes	# of internal quotes	# of external quotes
1,588	351	176	1,412	1,287	301

2.2 Paired Difference Approach

A paired difference statistical approach evaluates differences between paired observations in two groups. In this case, the two groups are non-large and large installer quotes. Let D_i represent the difference in quote prices between a large installer quote and a non-large installer quote made to customer i :

$$D_i \left(\frac{\$}{W} \right) = \text{large installer quote}_i \left(\frac{\$}{W} \right) - \text{non large installer quote}_i \left(\frac{\$}{W} \right)$$

Consistently positive/negative values of D could suggest that large installer quotes are generally higher/lower than non-large installer quotes. We explore the existence of a trend through the following hypothesis test:

Null hypothesis: No systematic difference (D) between large and non-large installer quotes

$$H_0 : D = 0$$

Alternative hypothesis: Large and non-large installer quotes vary systematically

$$H_A : D \neq 0$$

We test this hypothesis with a paired difference t test (\bar{D}):

$$t_D = \frac{\bar{D}}{SE(\bar{D})}$$

Where \bar{D} is the sample mean of paired differences and $SE(\bar{D})$ is the standard error of paired differences.⁵ The test statistic t_D defines our basic test. Note that the alternative hypothesis is

⁵ More formally, let q_{im} represent the n^{th} quote made to customer i . The difference in quotes between the m^{th} quote and the n^{th} quote made to customer i can be written $q_{im} - q_{in}$. The mean difference (\bar{D}) and standard error of the differences ($SE(\bar{D})$) in quote prices made to n customers is then:

$$\bar{D} = \frac{\sum_{i=1}^n (q_{im} - q_{in})}{n} \quad SE(\bar{D}) = \frac{s_D}{\sqrt{n}}$$

two-sided (i.e., the test statistic is a two-sided paired difference t-test). In other words, we test the alternative hypothesis that large installer quotes are either lower or higher than non-large installer quotes without imposing prior expectations about the sign of the difference. Figure 2 provides a graphic depiction of our method.

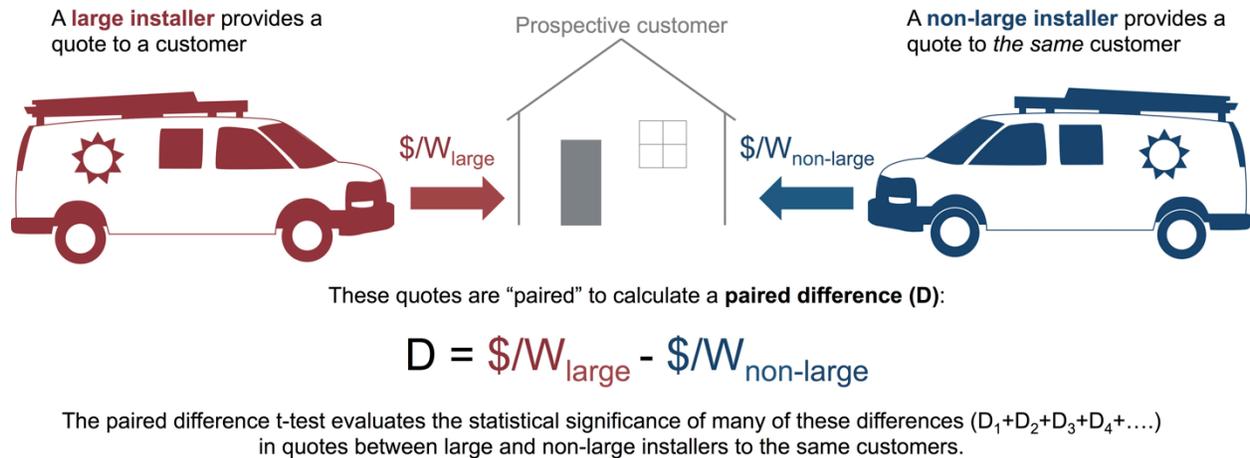


Figure 2. Paired difference test methodology

2.3 Paired Data

Of the full data set described in Table 2, 142 customers received at least one quote from both a large and a non-large installer, providing 707 possible pairings available for the paired difference analysis. In general, paired difference testing is applied to paired data for which each observation in a set is matched to a single observation in a second set. We take two approaches to address customers with multiple quote pairs:

- **Quote differences:** Measures the difference of every possible pairing of large and non-large installer quotes (made to the same customer) and treats each pair as an observation ($n = 707$).
- **Customer average differences:** Treats each customer as a single observation, using the *average* of differences for every possible pairing of large and non-large installer quotes made to that customer ($n = 142$).

The *quote differences* metric is our preferred specification. All figures are based on the quote differences metric. We present results for the *customer average differences* metric as a robustness check.

Where s_D is the standard deviation in paired quote differences.

For example, suppose a customer receives three quotes. Quotes 1 and 2 from non-large installers are \$3.30/W and \$3.70/W respectively. Quote 3 from a large installer is \$3.50/W. The customer has two possible pairings of large and non-large installer quotes: quote 3 (the large installer quote) with quote 1, and quote 3 with quote 2. Therefore, two quote differences are calculated:

$$\text{quote difference (quote 3 - quote 1)} = 3.50 - 3.30 = \$0.20/W$$

$$\text{quote difference (quote 3 - quote 2)} = 3.50 - 3.70 = -\$0.20/W$$

Under the customer average approach, the average values of large and non-large quotes are compared. In this example, the average value of non-large quotes is the average value of quotes 1 and 2, while the average value of large installer quotes is simply the value of quote 3. Therefore, the customer average difference is:

$$\text{customer average difference} = 3.50 - \frac{3.30 + 3.70}{2} = 3.50 - 3.50 = \$0.00/W$$

3 Results

Results are presented in three sections. Section 3.1 provides descriptive statistics for the full data set to give context to the paired difference results. Section 3.2 presents paired difference test results based on raw quote prices. Finally, Section 3.3 presents more robust results that control for systematic differences between large and non-large installer quotes.

3.1 Descriptive Statistics

Table 3 presents descriptive statistics for the full data set described in Table 2.

Table 3. Descriptive Statistics, Full Data Set

	All Installers	Large Installers	Non-Large Installers
Number of quotes	1,588	176	1,412
Mean price (\$/W)	3.66	3.99	3.62
Price standard deviation	0.60	0.67	0.58
10 th percentile price	3.02	3.37	3.00
90 th percentile price	4.35	4.98	4.25

Large installer quotes are, on average, about \$0.37/W higher than non-large installer quotes in the full data set (Figure 3). Large installer quotes also exhibit greater price variation, with a span of \$1.61/W between the 10th and 90th percentile of large installer prices, compared with a span of \$1.25/W for non-large installer prices.

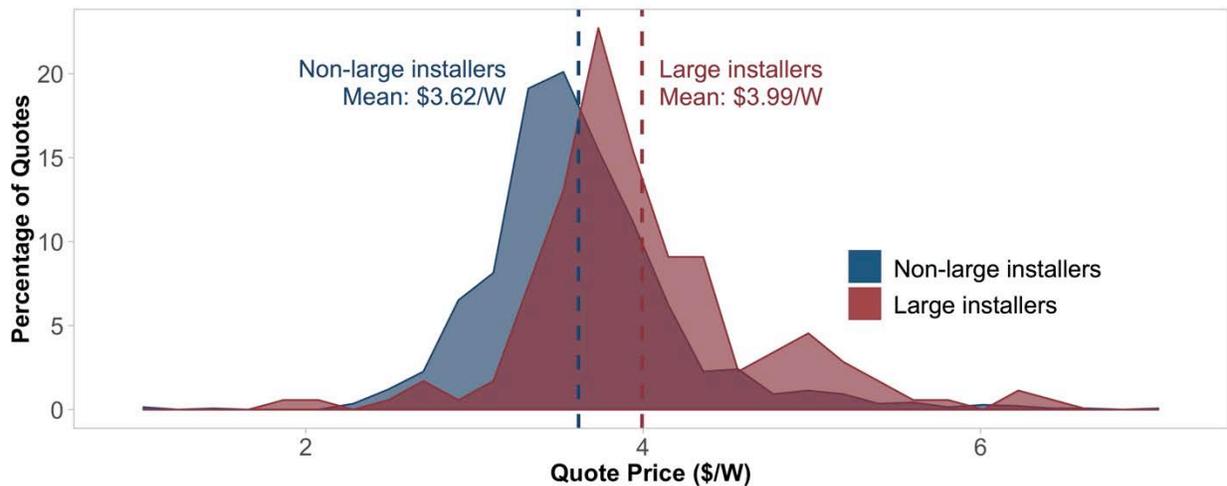


Figure 3. Quote price (\$/W) distributions for large and non-large installers, full data set

3.2 Paired Difference Test Results: Raw Quote Price Approach

Our paired data set provides 707 unique pairings of large and non-large installer quotes made to 142 customers. Large installer quotes are about \$0.33/W higher than the corresponding non-large installer quotes, on average, for the 707 pairs (Figure 4). The large installer quote is higher than the corresponding non-large installer quote in about 70% of pairings. The large installer quote is more than \$0.30/W higher than the non-large installer quote for about half of pairings.

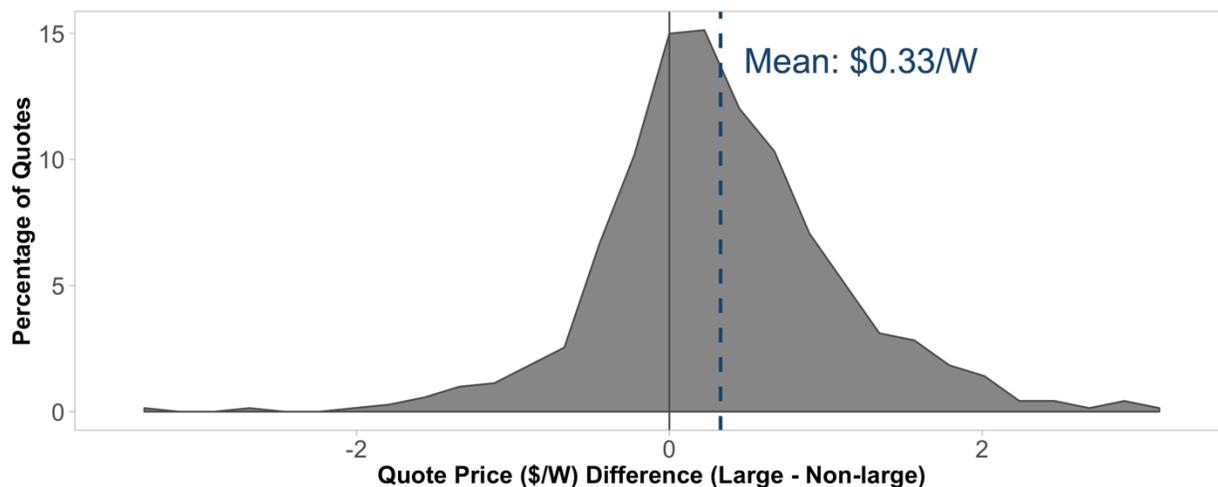


Figure 4. Paired difference distribution

The paired quote price difference is statistically significant under both paired difference test approaches defined in Section 2.3 (the two-sided t-tests are statistically significant for $t > 1.96$) (Table 4).

Table 4. Paired Difference Test Results (Raw Quote Price Approach)

Approach	Mean Difference (\$/W)	Paired T Statistic
Quotes (n = 707)	0.33	11.6 ^a
Customer average (n = 142)	0.34	5.6 ^a

^a Statistically significant at $p < 0.01$.

3.3 Paired Difference Test Results: Quote Prices with Controls for Systematic Variations between Groups

The results in Section 3.2 suggest that large installer quotes are generally higher than non-large installer quotes. However, large installer quotes may vary systematically in ways that affect quote prices independently of the effects of the installer's size. On average, large installer quotes are associated with smaller system sizes and earlier quote dates, and they are more likely to be external to the EnergySage platform compared with non-large installer quotes (Table 5). Large installers are more likely to use micro-inverters than are non-large installers, but non-large

installers are more likely to use optimizers.⁶ All of these factors could influence the quote differences shown in Section 3.2.

Table 5. Mean Values of Quote Characteristics for Large and Non-Large Installers, Full Data Set

	Large Installers	Non-large Installers
Price (\$/W)	3.99	3.62
System size (kW)	6.9	7.8
Quote date	4/2/2016	4/17/2016
% external	62%	14%
Module efficiency (%) ⁷	16.1%	16.1%
% using micro-inverters	38%	33%
% using optimizers	10%	46%

To control for these potentially confounding factors, we develop the following model:

$$Q_i = \beta_0 + \beta_1 size_i + \beta_2 size_i^2 + \beta_3 date_i + \beta_4 eff_i + \beta_5 micro_i + \beta_6 optim_i + \beta_7 ext_i + \epsilon_i$$

Where Q_i is the quote price for quote i , $size_i$ and $size_i^2$ are the system size and system size squared,⁸ $date_i$ is the quote date, eff_i is the efficiency of the installed module (used as a proxy for equipment quality), $micro_i$ is a dummy variable for whether the system used a micro-inverter, $optim_i$ is a dummy variable for whether the system used an optimizer, ext_i is a dummy variable for whether the quote is internal ($ext = 0$) or external ($ext = 1$), ϵ_i is a residual term for quote i , and the terms β are the coefficients in the model.

The residual term ϵ is the variation in the quote price that remains after controlling for the other factors in the model. A high residual value indicates the quote is relatively expensive after controlling for these factors, and a low residual value indicates the quote is relatively inexpensive. We use the residual term to create a difference metric that controls for potentially confounding factors:

$$D_i^\epsilon = large\ installer\ \epsilon_i - non\ large\ installer\ \epsilon_i$$

⁶ Installers in the EnergySage installer network must meet certain equipment-quality criteria. Although EnergySage does not require optimizers, many installers include the technology in quotes to ensure compliance with the quality standards. This might account for the higher use of optimizers among non-large installers, who provided mostly internal (EnergySage) quotes, in contrast to the predominantly external quotes provided by large installers.

⁷ Module efficiency is based on data from *Tracking the Sun* (Barbose and Darghouth 2016). Module data were only available for a subsample of 1,351 quotes; some external quotes did not specify a module brand and are dropped from analyses using module efficiency inputs.

⁸ Previous work has identified a quadratic relationship between system size and prices (Gillingham et al. 2016; Nemet et al. 2017) (i.e., larger systems tend to be installed with lower prices, but the effect is weaker for increasingly larger systems).

The test statistic with the residuals has the same structure as the basic test statistic described in Section 2.2:

$$t_D^\epsilon = \frac{\overline{D^\epsilon}}{SE(\overline{D^\epsilon})}$$

This modified test statistic provides a more robust measurement of quote differences between large and non-large installers. The statistic measures the significance of quote price differences after controlling for differences in system sizes, quote dates, equipment, and how the quote was made (internal/external).

Table 6 displays the results of the model. Module and inverter information was not available for all external quotes; we therefore ran the model with and without controlling for system hardware.

Table 6. Model Results

Y = quote price (\$/W)

Variable	(1) Without Hardware	(2) With Hardware
<i>size</i>	-0.04 (8.4) ^a	-0.04 (9.2) ^a
<i>size</i> ²	2.0e ⁻⁴ (5.3) ^a	2.0e ⁻⁴ (6.0) ^a
<i>date</i>	-8.1e ⁻⁴ (7.3) ^a	-1.3e ⁻³ (11.8) ^a
<i>eff</i>		24.0 (18.8) ^a
<i>micro</i>		0.08 (2.2) ^b
<i>optim</i>		0.14 (3.7) ^a
<i>ext</i>	0.25 (6.9) ^a	0.15 (3.9) ^a
R ²	0.11	0.30
n	1,588	1,351

^a Statistically significant at p < 0.01, ^b p < 0.05

The values in Table 6 refer to the effect of each variable on the expected system price. The model results suggest that quote prices are negatively correlated with system size (due to economies of scale), negatively correlated with the quote date (due to falling prices over time), positively correlated with module efficiency (due to the higher costs of higher-efficiency modules), and higher on average for external quotes. Large installer quotes are associated with smaller system sizes, earlier quote dates, and they are more likely to be external (see Table 5). The model results also suggest premiums of about \$0.08/W and \$0.14/W for micro-inverters and optimizers, respectively. An interesting corollary result from the model results in Table 6 is that internal quotes are lower, on average, than external quotes. This effect is explored more in Section 4.

The residual approach controls for differences in system/quote characteristics and time that could confound the results. The association between large installers and higher quotes is robust after controlling for these factors. On average, large installer quotes are \$0.19/W higher than predicted by the model ($\epsilon = 0.19$), while non-large installer quote prices are \$0.02/W lower than predicted by the model ($\epsilon = -0.02$) (Figure 5).⁹ The average difference in residual values between paired large and non-large installer quotes is about \$0.17/W (Figure 6), or about \$0.21/W when controlling for hardware (Figure 7). This difference is statistically significant under both paired difference test approaches, with and without controls for hardware (Table 7).

Table 7. Paired Difference Test Results (Residual Approach)

Approach	Mean Difference (\$/W)	Paired T Statistic
Without control for hardware		
Quotes (n = 707)	0.17	6.3 ^a
Customer average (n = 142)	0.17	2.9 ^a
With control for hardware		
Quotes (n = 346)	0.21	6.9 ^a
Customer average (n = 75)	0.29	5.7 ^a

^a Statistically significant at $p < 0.01$.

⁹ This is based on residuals without controls for hardware. Results are similar with controls for hardware: the large installer average residual is 0.32, and the non-large installer average residual is -0.02.

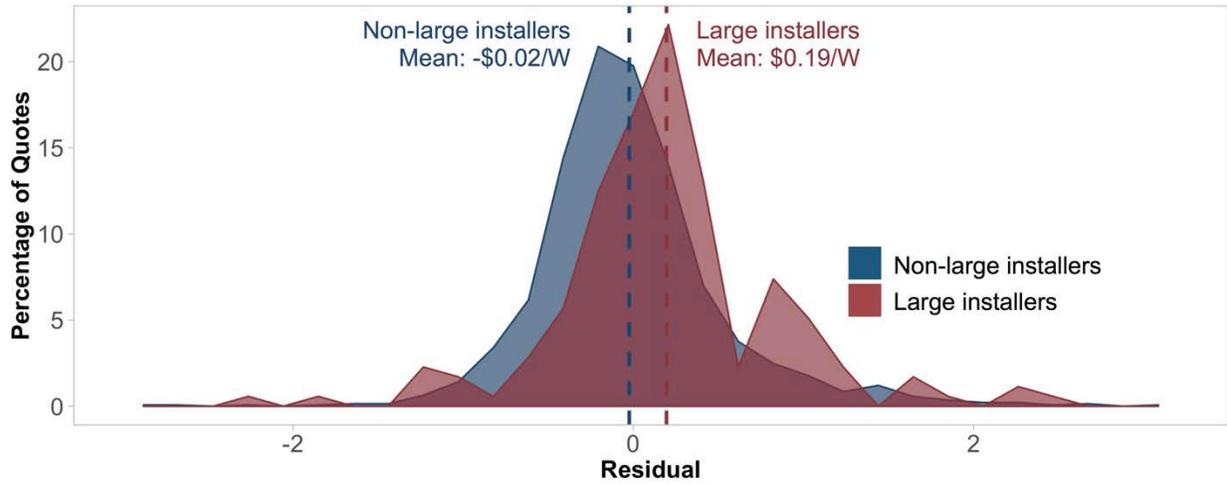


Figure 5. Residual distributions for large and non-large installers

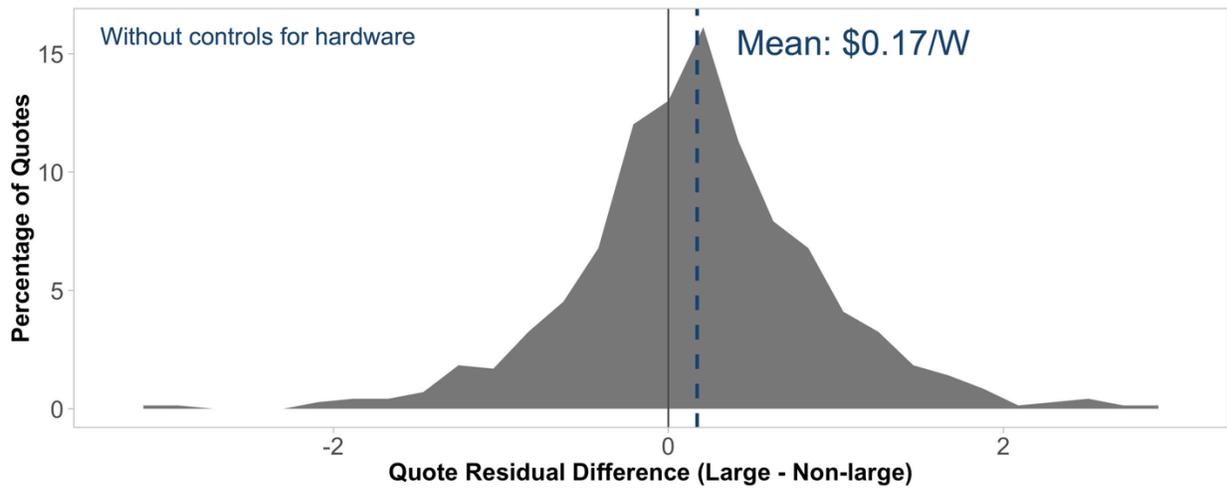


Figure 6. Paired difference distribution of residuals (without controls for hardware)

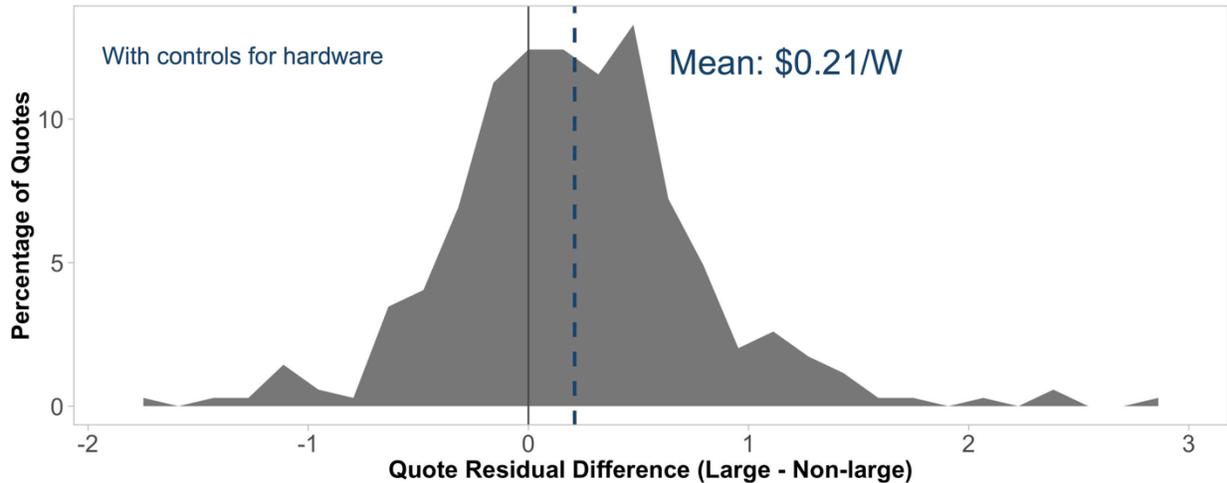


Figure 7. Paired difference distribution of residuals (with controls for hardware)

Most large installer quotes are external, so some of the large installer price difference may be attributable to a difference between external and internal quotes. The change in paired differences from the raw quote price approach (\$0.33/W) to the residual approach (\$0.21/W) partially reflects the elimination of an external/internal effect due to the control variable *ext* in the model. As an additional sensitivity analysis, we repeated the paired difference analyses while excluding all external quotes. The results are robust, with statistically significant paired differences for all specifications (Table 8). The robustness of the results is particularly striking given that relatively few large installer quotes remain after eliminating external quotes.

Table 8. Sensitivity Analysis: Paired Differences for only Internal Quotes

Approach	Mean Difference (\$/W)	Paired T Statistic
Raw quote price approach		
Quotes (n = 252)	0.12	4.0 ^a
Customer average (n = 66)	0.15	3.4 ^a
Residual approach (with control for hardware)		
Quotes (n = 193)	0.14	4.3 ^a
Customer average (n = 51)	0.19	3.7 ^a

^a Statistically significant at $p < 0.01$.

4 Discussion and Conclusion

Previous research on the effects of installer size on PV system pricing has produced conflicting results, in part because PV price research generally relies on installed system price data, making comparisons across customers more difficult. This study uses quote data from a third-party quote provider rather than installed system price data to compare large and non-large installer pricing behavior for quotes made to the same customer. Through a paired difference approach, we effectively control for customer-level characteristics that were unaccounted for in previous analyses.

In our paired data set, large installer quotes are \$0.33/W (about 10%) higher than non-large installer quotes made to the same customer, on average. Large installers offered a higher quote than corresponding non-large installers in about 70% of pairings. The difference falls to \$0.21/W when controlling for differences in system size, quote date, module efficiency, inverter type, and whether the quote was internal or external, but it remains statistically significant. Our findings suggest that large installers are associated with higher quote prices.

The result that non-large installers offer lower prices is consistent with findings that smaller installers are more likely to install low-priced systems (Nemet et al. 2017). The results seem to conflict with previous findings that more experienced installers offer lower prices (Gillingham et al. 2016; Nemet et al. 2017; Pless et al. 2017). However, because non-large installers in the EnergySage network must have at least 3 years of experience and be certified by the North American Board of Certified Energy Practitioners, they are relatively experienced even though they are not large by our definition. Further, the relationship between installer experience and pricing identified in previous studies might not be entirely linear. Installers might initially reduce costs through experience and pass lower costs through to customers up to a certain installer size. Then, our results suggest, the correlation between installer size and pricing could become positive for very large installer firms.

As a corollary result, we find that installers offered lower prices for internal than external quotes (see Table 6). This difference, on average, is about \$0.30/W (Figure 8), and is robust for both large and non-large installers. Lower quotes in EnergySage's installer network may reflect the value of increased competition in the PV industry. Installers that provide quotes through EnergySage know that customers have access to other competitive quotes, reducing the probability that an installer could successfully win a high-price bid. The potential for increased competition and price transparency to further reduce PV prices is as an area of ongoing research.

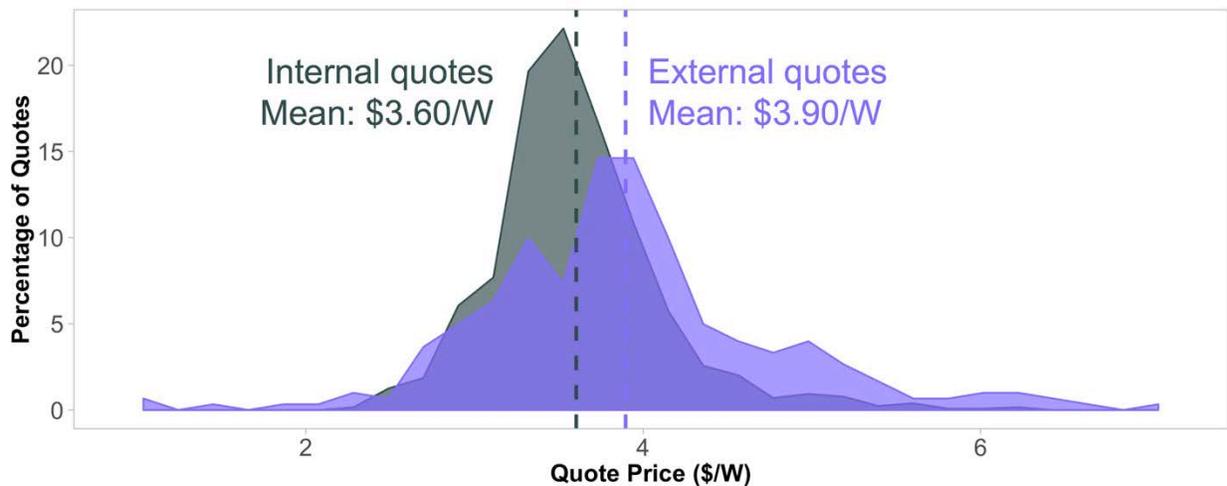


Figure 8. Price (\$/W) distributions for internal and external quotes, full data set

Our results support a market power hypothesis for large installer price behavior. Large installers may bid higher prices due to imperfect competition in the PV quote collection process. Large installers may also have a customer acquisition advantage that allows them to bid higher prices. Large installers may use customer acquisition to proactively generate more leads and provide bids to more prospective customers than non-large installers. Some customers may accept large installer quotes without additional search under the assumption that their search costs would offset any potential price reductions. Other prospective PV customers may accept higher quotes due to the perceived advantages of working with large installers.

4.1 Limitations

We note three limitations in this analysis. First, we controlled for various factors such as system size, time, and equipment type that could produce a spurious correlation between large installers and differential pricing behavior. However large installers may offer products differentiated in dimensions that we have not controlled for. For example, large installers may offer superior warranties and inverter replacement terms. Second, our market power hypothesis is based on an assumption that large installers have equal or lower costs than non-large installers. However it is possible that large installers experience diseconomies of scale and that higher prices reflect higher production costs rather than market power. Last, our results apply only to quotes for customer-owned systems. Large installers have developed and implemented innovative alternative ownership structures in the United States such as leases and power purchase agreements (Feldman et al. 2013). It is possible that large installer bid behavior varies in these alternative products.

4.2 Key Takeaways

Our results imply that low prices were not the primary value proposition of large installer systems, at least for quoted customer-owned systems during 2014–2016 in 27 states and Washington, DC. Rather, the success of large installers, in terms of significant market shares, may be attributable to a host of other factors such as product innovation (e.g., third-party ownership), customer acquisition, and the perceived values of working with large installers.

From a policy perspective, the results corroborate previous findings that market structure affects PV prices (Gillingham et al. 2016; Nemet et al. 2017; Pless et al. 2017). Prospective PV customers may benefit from increased competition and access to a larger pool of potential installers. Increased price transparency and more competition may promote future price reductions. Third-party quote platforms that connect customers with more installers could create competitive pressure for lower quotes from all installers.

From a customer perspective, the fact that large installers successfully bid higher prices may indicate that some customers are willing to accept higher prices, possibly even if lower priced options are available. Customers may attribute various reputational values to large installers and be willing to pay a premium for large installer services. Further, working with large installers may reduce customer transaction costs if obtaining a quote from a large installer is easier than obtaining a quote from smaller installers. Some customers may be willing to accept higher prices from large installers if doing so allows them to save time and effort in obtaining additional quotes. Still, our results suggest that customers could benefit from obtaining more quotes before making a decision, and all customers could benefit from increased competition.

There are a number of future research directions that could be pursued related to understanding *why* large installer pricing might differ from non-large installer pricing. For example, research could explore *if* and *how* large installers provide differentiated services from non-large installers. Future research could also explore *if* and *how* customers perceive differences between large installers and non-large installers and how those perceptions might influence pricing behavior. Lastly, research could examine how the customer quote collection process has evolved over time and thus explore if increased competition has resulted in reduced differentials in pricing across installer types.

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