



Environmental Energy Technologies Division Lawrence Berkeley National Laboratory

Deconstructing Solar PV Pricing: The Role of Market Structure, Technology, and Policy

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Presentation Outline

- Introduction
- Data
- Descriptive Evidence
- Methodology
- Results
- Conclusions and Policy Recommendations

Context and Motivation

- As the solar PV market has expanded rapidly in recent years, system prices have declined substantially
- Yet there remains remarkable heterogeneity in PV system pricing
 - 20% of systems <10 kW in 2013 sold for below \$3.9/W and 20% for above \$5.6/W
- Why?
 - System characteristics?
 - Market structure?
 - Policy incentives?
- Understanding these drivers can inform policy and industry efforts to foster further price declines

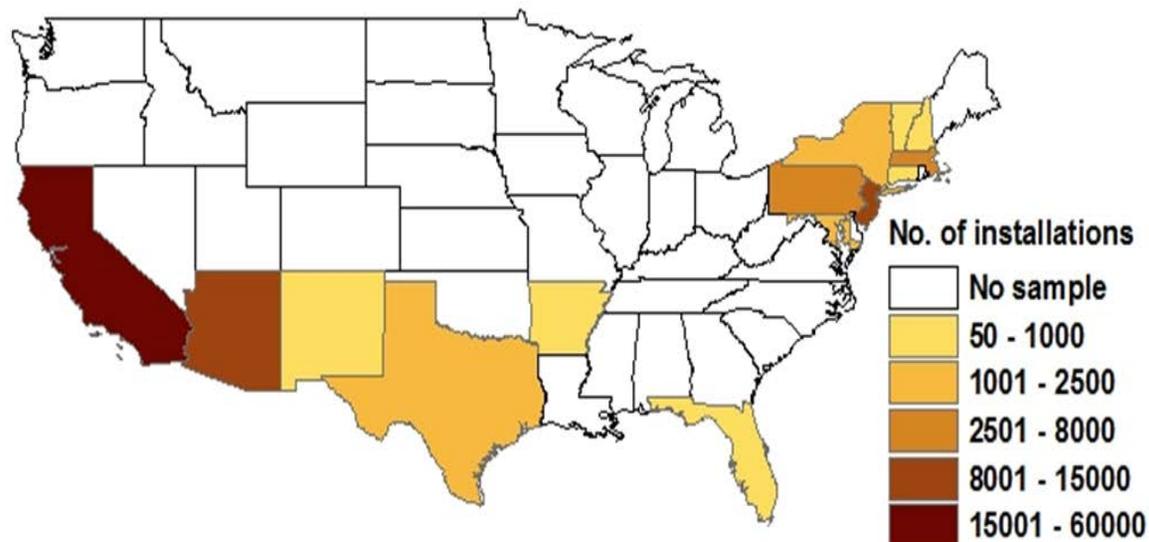
Extensive Work on Price Dispersion

- There is an extensive theoretical literature on price dispersion
 - It may be due to differentiated products with different characteristics
 - There may be search costs by consumers or firms
 - These search costs may relate to frictions in information acquisition and transmission
- Also an empirical literature on price dispersion
 - Studies have examined factors influencing equilibrium pricing in many markets:
 - Online internet markets (Baye et al. 2004, Brynjolfsson & Smith 2000, Ellison & Ellison 2009)
 - Gasoline (Barron et al. 2004, Chouinard & Perloff 2007, Shepard 1991)
 - Books (Clay et al. 2001)
 - Air travel (Borenstein & Rose 1994)
 - Market structure, firm characteristics, and policies are found to be important

Data: 2014 Tracking the Sun Report

- Draws on Berkeley Lab's *Tracking the Sun* dataset of individual PV systems
- Raw dataset includes 68% of total grid-connected residential and commercial PV in the US through 2012
- Focus only on systems 1-10 kW installed 2010-2012
- Some states dropped due to missing installer names
- Appraised-value third-party owned (TPO) systems also excluded

Geographic Distribution of Final Data Sample



99,029 systems in the final sample

Note: *This study focuses on customer-owned PV and, for TPO systems, on the sale price between installer and financier; it does not examine TPO contract pricing.*

Price Data and Key Independent Variables

- Pre-incentive prices have large standard deviation
- Market structure variables characterize county-level competitiveness
- Experience variables are motivated by the presence of learning-by-doing in solar installation
- Consumer value of solar captures how financially attractive systems might shift demand, accounting for solar insolation, rates, and incentives
- Other policy variables capture sales tax and ease of grid connection

	Mean	SD	Min	Max	Description
Pre-incentive Installed Price					
price (2012\$)	32649	14367	1903	185817	LBNL (2014)
price per watt (2012\$/W)	6.43	1.90	1.51	19.79	LBNL (2014)
Market Structure					
installer density (firms per 10,000 households)	1.36	0.90	0.00	9.64	Calculated
HHI	0.10	0.10	0.02	1.00	Calculated
Experience					
installer experience in county (000s installs)	0.09	0.16	0.00	2.03	Calculated
installer experience in state (000s installs)	0.40	0.65	0.00	5.59	Calculated
aggregate installations in county (000s installs)	1.21	1.30	0.00	6.03	Calculated
Policy-related					
consumer value of solar per watt (2012\$/W)	6.47	1.60	1.92	17.30	Calculated
% incentive SREC-based	0.07	0.14	0.00	0.69	Calculated
sales tax per watt (2012\$/W)	0.34	0.22	0.00	0.62	Tax Found. (2014)
interconnection score	12.31	3.47	-3.0	18.5	Free the Grid (2014)
Observations	99,029				

Additional Variables: Demographics and System Characteristics

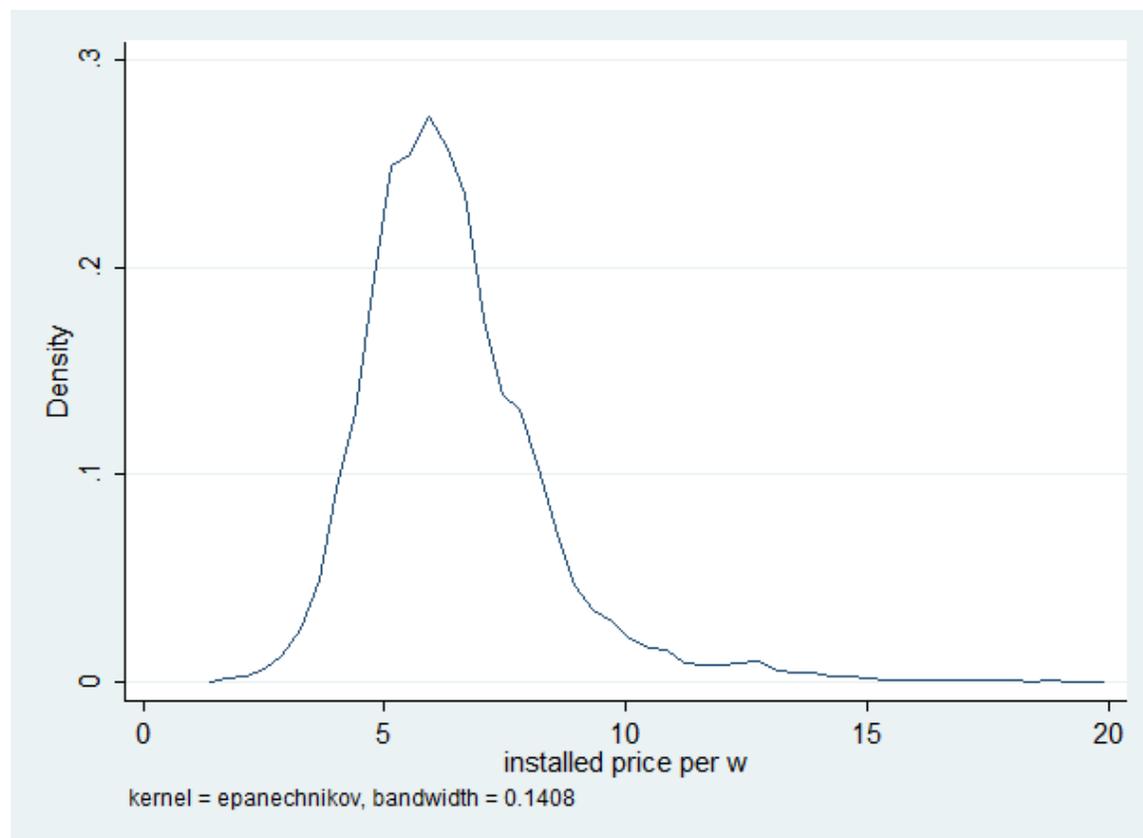
- Household socioeconomic and demographic data are at the zip code level
- Labor wage rates are at the county level, based on a weighted average of contractor, electrician, and roofing wages
- Extensive system characteristics are included (size, ownership, tracking, battery, etc.)
- Modules and inverters are globally traded; we include indices for these

	Mean	SD	Min	Max	Description
Demographics					
household density (households per 100-mi ²)	1.01	1.61	0.00	29.42	Calculated
% 9th grade to no diploma	0.06	0.04	0.00	0.39	Census (2014)
% High school graduate to Associate degree	0.51	0.14	0.00	0.85	Census (2014)
% Bachelor's degree or above	0.37	0.17	0.00	0.93	Census (2014)
% \$25,000 to \$44,999	0.16	0.06	0.00	0.59	Census (2014)
% \$45,000 to \$99,999	0.33	0.08	0.00	0.70	Census (2014)
% \$100,000 and more	0.34	0.16	0.00	0.92	Census (2014)
local labor cost (100,000 \$/year)	0.58	0.15	0.19	1.15	BLS (2014)
System Characteristics					
consumer segment (1-resid., 2-com., 3-other)	1.05	0.23	1.00	3.00	LBNL (2014)
system size (kW _{dc})	5.27	2.18	1.00	10.00	LBNL (2014)
third party-owned dummy (TPO)	0.31	0.46	0.00	1.00	LBNL (2014)
tracking installed dummy	0.00	0.05	0.00	1.00	LBNL (2014)
thin film module dummy	0.01	0.11	0.00	1.00	LBNL (2014)
building integrated system dummy (BIPV)	0.01	0.11	0.00	1.00	LBNL (2014)
new construction dummy	0.03	0.18	0.00	1.00	LBNL (2014)
battery included dummy	0.00	0.03	0.00	1.00	LBNL (2014)
self-installed system dummy	0.01	0.11	0.00	1.00	LBNL (2014)
inverter price index (2012\$/W _{ac})	0.45	0.14	0.30	0.82	GTM (2013)
module price index (2012\$/W _{dc})	1.53	0.59	0.65	2.56	GTM (2013)
Observations	99,029				

Descriptive Evidence: Major Variation in Prices

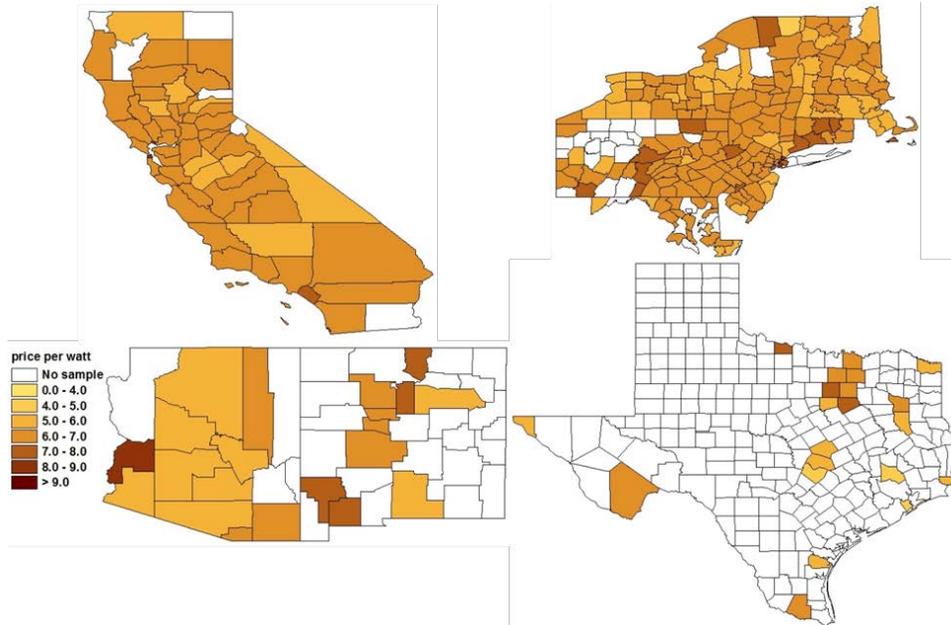
- Pre-incentive per-watt prices contain considerable variation
- Potential causes:
 - System characteristics
 - Local wages and installer experience
 - Imperfect competition
 - Information and search costs
 - Policy actions
 - Unobserved individual system-specific factors

Installed Price Distribution

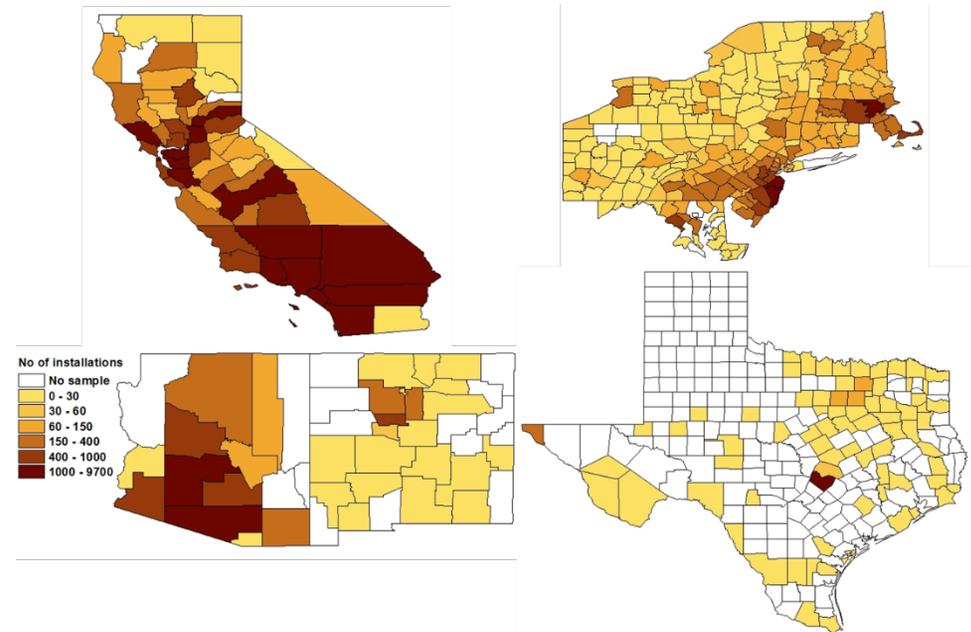


Variation Not Simply Due to Market Size

County-Level Average Prices



Number of Installations by County



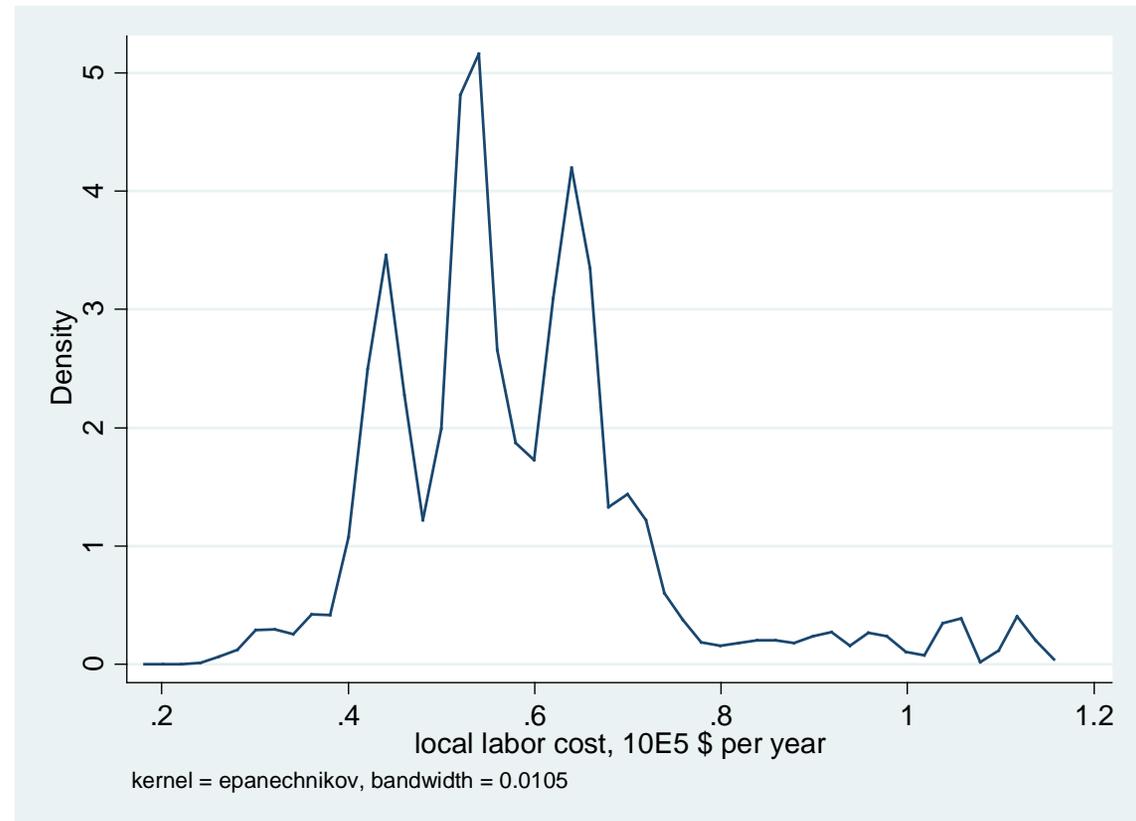
Excludes counties with <5 observations in the data sample

- California, the most mature market, has relatively homogenous prices across geography, with county-level average in \$5/W to \$7/W
- Other states exhibit greater cross-county variation
- Counties with high average prices are sometimes large markets and sometimes not; suggests that size of the market (in terms of number of installations) is not the primary driver for prices
- We can see a similar result with population

Variation in Wages

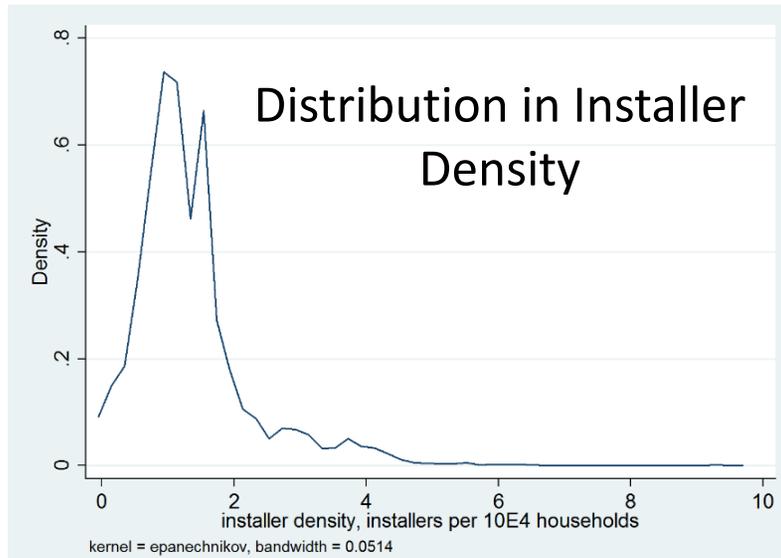
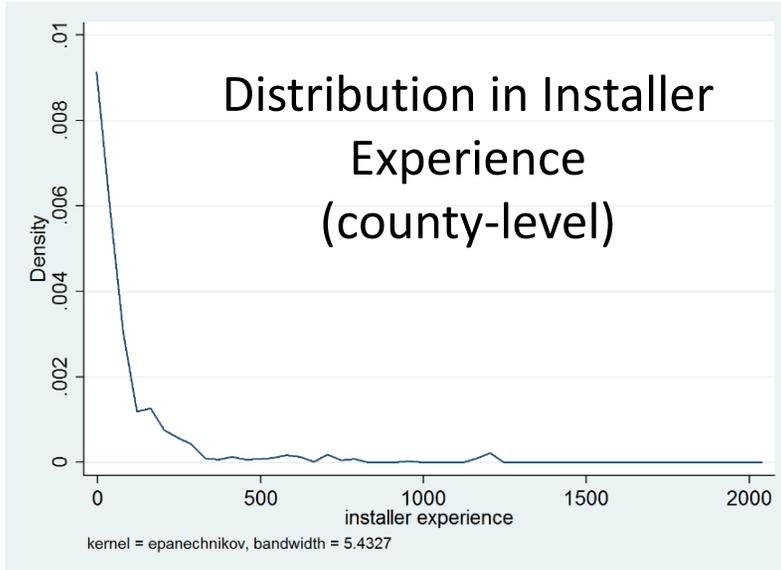
- County-level composite labor cost index derived by averaging contractor, electrician, and roofing wage data from BLS
- There is substantial variation in wages in our dataset
- One might expect higher wages to lead to higher costs, and thus higher prices, though later results do not illustrate this expected relationship

Distribution in PV-Relevant Wage Rates



Firm Experience and Installer Density

- Firm experience effects: If firms have more experience in a county, the equilibrium price might be lower
- Imperfect competition: With consumers facing search and information costs, as the number of active installers increases, equilibrium prices should decline
- Further hypotheses include
 - Price discrimination based on demand factors (e.g., “value pricing” of solar, in the presence of imperfect competition)
 - Policy actions might also influence equilibrium pricing



Methodology

$$P_{ijst} = \beta_0 + \beta_1 Mkt_{ijst} + \beta_2 Exp_{ijst} + \beta_3 Pol_{ist} + \beta_4 Dis + \beta_5 C_{ijst} + \theta_j + \eta_s + \mu_t + \varepsilon_{ijst}$$

- P_{ijst} pre-incentive price per watt
- Mkt_{ijst} market structure variables
- Exp_{ijst} experience variables*
- Pol_{ist} policy-related variables
- Dis zip-code level and county-level demographic variables
- C_{ijst} system characteristics variables
- θ_j installer fixed effects
- η_s state fixed effects
- μ_t year-month fixed effects
- Policy-related variables vary at state-level, therefore are used as alternates to state fixed effects

* Note we do not attempt to disentangle economies of scale from experience

Multiple Model Specifications

	(1)	(2)	(3)	(4)	(5)	(6)
Market Structure variables					X	X
Installer Experience variables					X	X
Policy variables		X		X		X
state dummies	X		X		X	
installer fixed effects			X	X		
Adjusted R-squared	0.37	0.36	0.34	0.33	0.38	0.37
N	99,029	99,029	99,029	99,029	99,029	99,029

- Different combinations of independent variables and fixed effects are used to explore different sources of variation
- Policy-relevant variables are sometimes used in place of state fixed effects
- Market structure and installer experience variables are sometimes used in place of installer fixed effects
- Column 6 is the preferred model
- Low adjusted R^2 value suggests much of the variation in prices remains unexplained, most likely due to highly installation-specific unobservables

Results: System Characteristics

- Commercial systems are similar to residential systems, but “other” systems (includes government and schools) are more expensive
- Tracking, thin film, BIPV, and battery all increase price
- New construction and self-installed decrease price
- Third party ownership does not have a consistent effect (note we restrict to only non-appraised value systems)
- Larger system size decreases price, but with diminishing returns to scale

	(1)	(2)	(3)	(4)	(5)	(6)
commercial system	0.067	0.063	0.028	0.176	0.077	0.086
	(0.06)	(0.06)	(0.06)	(0.10)	(0.06)	(0.06)
other system	0.453***	0.556***	0.581*	0.904***	0.480***	0.677***
	(0.13)	(0.14)	(0.29)	(0.27)	(0.13)	(0.14)
third party-owned	-0.153***	-0.052	0.022	0.245*	-0.110**	0.091*
	(0.04)	(0.04)	(0.08)	(0.11)	(0.04)	(0.04)
tracking	1.789***	1.844***	1.462***	1.444***	1.780***	1.969***
	(0.15)	(0.14)	(0.23)	(0.23)	(0.15)	(0.15)
thin film	0.333***	0.394***	0.131	0.124	0.360***	0.389***
	(0.07)	(0.07)	(0.12)	(0.13)	(0.06)	(0.07)
building-integrated	0.666***	0.609**	1.147***	1.163***	0.667***	0.605**
	(0.20)	(0.23)	(0.18)	(0.19)	(0.18)	(0.21)
new construction	-0.729***	-0.715***	-0.076	-0.289	-0.681***	-0.752***
	(0.15)	(0.15)	(0.16)	(0.17)	(0.17)	(0.17)
battery	2.500***	2.451***	2.501***	2.509***	2.534***	2.584***
	(0.30)	(0.30)	(0.36)	(0.37)	(0.30)	(0.31)
self-installed	-1.946***	-1.914***	-3.292***	-3.383***	-1.928***	-1.921***
	(0.07)	(0.07)	(0.07)	(0.08)	(0.07)	(0.07)
system size	-0.842***	-0.849***	-0.479***	-0.482***	-0.839***	-0.850***
	(0.03)	(0.04)	(0.05)	(0.05)	(0.03)	(0.04)
system size ²	0.056***	0.057***	0.031***	0.032***	0.056***	0.057***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

Results: Other Key Variables

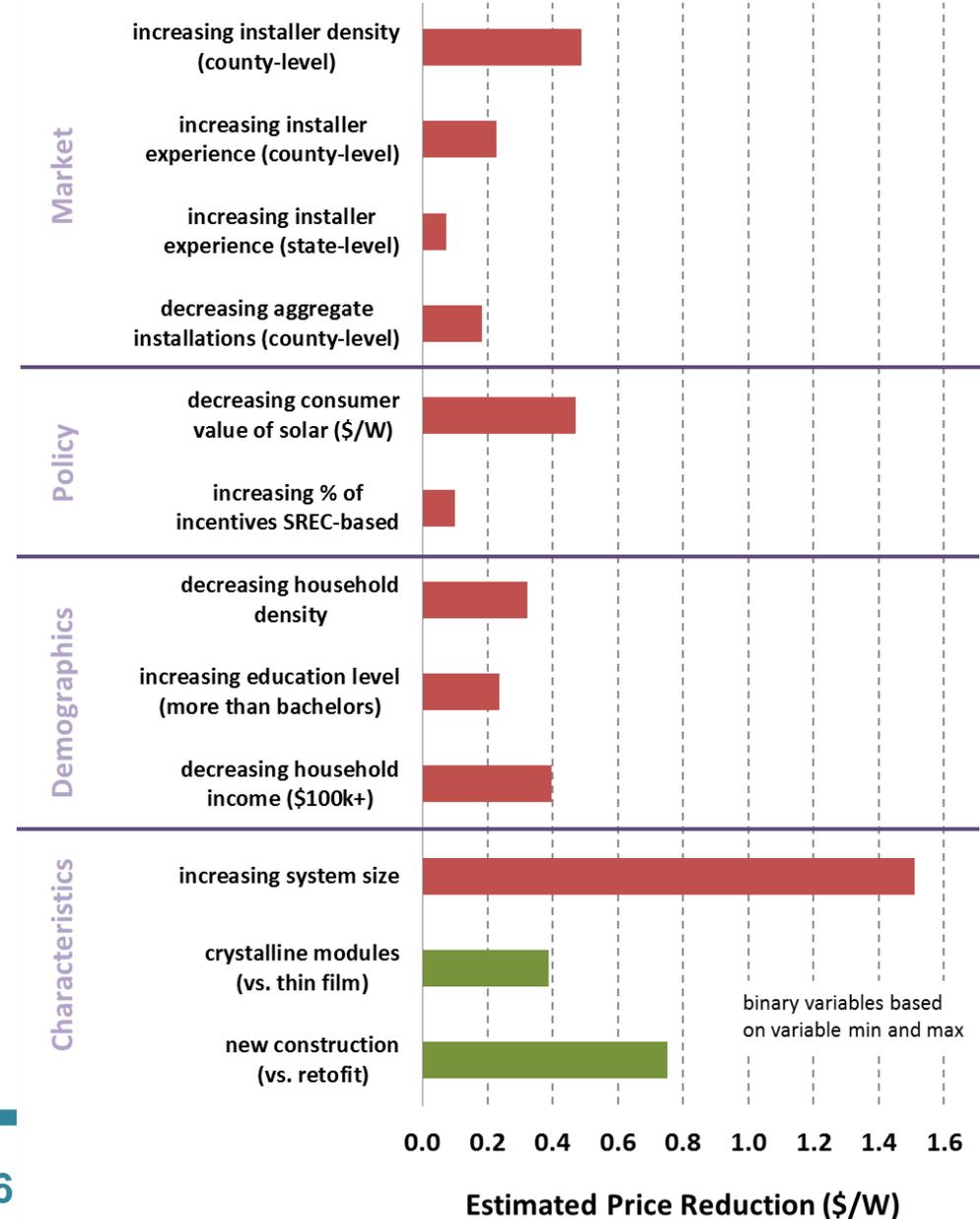
- Installer density has a strong effect, while HHI has a much smaller effect
- Installer experience lowers price, with much larger effect from county-level experience than state-level experience
- Consumer value of solar may be suggestive of “value pricing”
- Sales tax has strong positive effects
- Higher labor costs are associated with *lower* prices – possibly due to lower demand once we control for income and the value of solar

	(1)	(2)	(3)	(4)	(5)	(6)
installer density					-0.145***	-0.163***
					(0.02)	(0.02)
HHI					-0.449***	-0.248*
					(0.12)	(0.10)
installer experience county					-0.454***	-0.598***
					(0.12)	(0.13)
installer experience state					-0.070**	-0.045*
					(0.02)	(0.02)
aggregate installs in county					0.077***	0.049**
					(0.02)	(0.02)
consumer value of solar/W		0.039*		0.129***		0.095***
		(0.02)		(0.04)		(0.01)
% incentive SREC based		-0.428***		-0.538		-0.255*
		(0.12)		(0.47)		(0.11)
sales tax per watt		0.368***		-0.387		0.427***
		(0.10)		(0.39)		(0.10)
interconnection score		0.077***		0.011		0.078***
		(0.00)		(0.02)		(0.00)
household density	0.133***	0.129***	0.058***	0.072***	0.119***	0.115***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
% income group 2	0.271	-0.007	-0.045	0.037	0.186	0.006
	(0.30)	(0.31)	(0.16)	(0.14)	(0.29)	(0.31)
% income group 3	0.728***	0.444	-0.010	0.064	0.394	0.227
	(0.22)	(0.24)	(0.15)	(0.13)	(0.24)	(0.26)
% income group 4	0.809***	1.021***	-0.196	-0.115	0.529*	0.786**
	(0.20)	(0.22)	(0.19)	(0.18)	(0.22)	(0.24)
local labor cost	-0.916***	-0.681***	-0.336**	-0.331*	-1.048***	-0.814***
	(0.13)	(0.14)	(0.12)	(0.13)	(0.12)	(0.14)

Interpretation: Which Variables Contribute Most To Observed Pricing Variability?

The figure shows the price reduction associated with moving between the 5th and 95th percentile values of each variable (for a subset of variables, and the preferred model)

- Results show that a substantial portion of the pricing variability is associated with variation in system size (from 1 to 10 kW)
- Pricing variability also driven by installer density and experience, consumer value of solar, demographics, other system characteristics



Interpretation Table

A more complete version of the results presented graphically on the previous slide

The table shows the change in price associated with moving between the 5th and 95th percentile values of each variable, for all variables and across all models

	p95-p5	(1)	(2)	(3)	(4)	(5)	(6)
price per watt	5.83						
installer density	2.99					-0.43***	-0.49***
HHI	0.22					-0.10***	-0.06*
installer experience county	0.38					-0.17***	-0.23***
installer experience state	1.67					-0.12**	-0.07*
aggregate installs county	3.75					0.29***	0.18**
consumer value of solar/W	4.97		0.19*		0.64***		0.47***
% incentive SREC based	0.39		-0.17***		-0.21		-0.10*
sales tax per watt	0.62		0.23***		-0.24		0.27***
interconnection score	10.00		0.77***		0.11		0.78***
household density	2.81	0.37***	0.36***	0.16***	0.20***	0.33***	0.32***
% edu group 2	0.13	0.12*	0.20**	0.05	0.06	0.09	0.16**
% edu group 3	0.45	-0.17*	-0.10	0.01	-0.01	-0.10	-0.07
% edu group 4	0.58	-0.20	-0.28*	0.22*	0.18*	-0.13	-0.24
% income group 2	0.20	0.05	0.00	-0.01	0.01	0.04	0.00
% income group 3	0.26	0.19***	0.12	0.00	0.02	0.10	0.06
% income group 4	0.50	0.41***	0.51***	-0.10	-0.06	0.27*	0.40**
local labor cost	0.51	-0.47***	-0.35***	-0.17**	-0.17*	-0.53***	-0.41***
system size	7.16	-6.02***	-6.07***	-3.43***	-3.45***	-6.00***	-6.08***
inverter price index	0.46	0.51***	0.56***	0.06	0.05	0.51***	0.54***
module price index	1.67	1.97***	1.99***	1.25***	1.21***	2.01***	2.00***

Conclusions

- System characteristics influence price, but other factors also play a very strong role in explaining variation in prices
- Our results are consistent with imperfect competition and consumers who face search costs
 - Greater installer density leads to lower prices, consistent with a competition effect
 - Installer experience leads to lower costs, suggestive of learning-by-doing or economies of scale in installations
- Demand-side effects are important for solar PV systems
 - Regions with a higher consumer value of solar tend to face higher prices
 - This is consistent with “value pricing”
 - Higher prices at the highest income bracket
 - Again suggestive of “value pricing” due to higher income households being on a higher electricity tiered rate

Policy Recommendations

- Government efforts to foster a competitive market in solar PV have potential to bring down prices
 - E.g., by encouraging entrants and reducing information search costs
- Price reduction driven by experience should be factored in to forecasting future prices for PV systems
 - Results suggest efforts to increase deployment—whether publicly or privately funded—are likely to reduce costs
- Policy actions appear to directly influence prices
 - E.g., sales tax exemptions and changes to the magnitude of financial incentives
 - Attention may be required when designing and evaluating deployment policies aimed at achieving cost reductions, given the potential for such policies to elevate prices in the short-term

Future Research

- A deeper analysis into the factors influencing price dispersion, rather than equilibrium prices, holds promise to provide further guidance
- A targeted analysis on the lowest priced systems would be valuable to provide further policy guidance and elucidate important factors unobserved within the present research
- Given growth in third-party PV ownership, and claims that “value-based” lease and power-purchase agreement pricing is common within that segment, targeted analysis of the drivers to TPO-customer pricing would be valuable
- Such future work could lay the groundwork for more carefully designed policies, especially where the policy objectives are not only to increase deployment but also to reduce its social costs

For more information...

Download the full report, a 3-page fact-sheet, and this briefing:

<http://emp.lbl.gov/publications/>

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