Environmental Energy Technologies Division Lawrence Berkeley National Laboratory

Characteristics of Low-Priced Solar Photovoltaic Systems in the U.S.

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Presentation Outline

- Introduction
- Data
- Descriptive Evidence
- Comparisons of Means
- Predictors of Low-Priced Systems
- Conclusions and Policy Recommendations

Context and Motivation

- Though PV prices have declined worldwide, there is considerable heterogeneity within the price distribution
- Given policy interests in stimulating PV price reductions, there is a need to understand what drives low-cost PV systems. Specifically:
  - What characteristics are different about low-priced (LP) PV systems?
  - Which factors increase the likelihood of a system being LP?
  - How can these conditions be reproduced to drive down US PV system prices?
- This research helps identify practices and policies that might reduce future PV prices and further stimulate the market
- Part of a larger series of research projects under Berkeley Lab's *Academic Partners Program* that leverages large datasets and in-depth statistical analysis to address open questions about PV price and market trends (see Appendix 1 for further details)

Primary Underlying Dataset

- Draws on Berkeley Lab's *Tracking the Sun* (TTS) dataset of individual PV systems
- Focus on smaller PV systems (1-15 kW) installed in 2013
- TTS dataset includes 51% of U.S. grid-connected residential and commercial PV in 2013
- Some states dropped due to missing variables
- Appraised-value third-party owned (TPO) systems also excluded

Geographic Distribution of Final Data Sample

State	Sample size (N)	Share of total sample
CA	27,564	64.7%
AZ	4,359	10.2%
NJ	3,523	8.3%
MA	2,459	5.8%
NY	1,619	3.8%
NM	878	2.1%
CT	733	1.7%
OR	600	1.4%
ME	272	0.6%
NH	254	0.6%
NV	178	0.4%
PA	127	0.3%
CO	24	0.1%
FL	16	0.0%
DE	5	0.0%
Total	**42,611**	**100%**

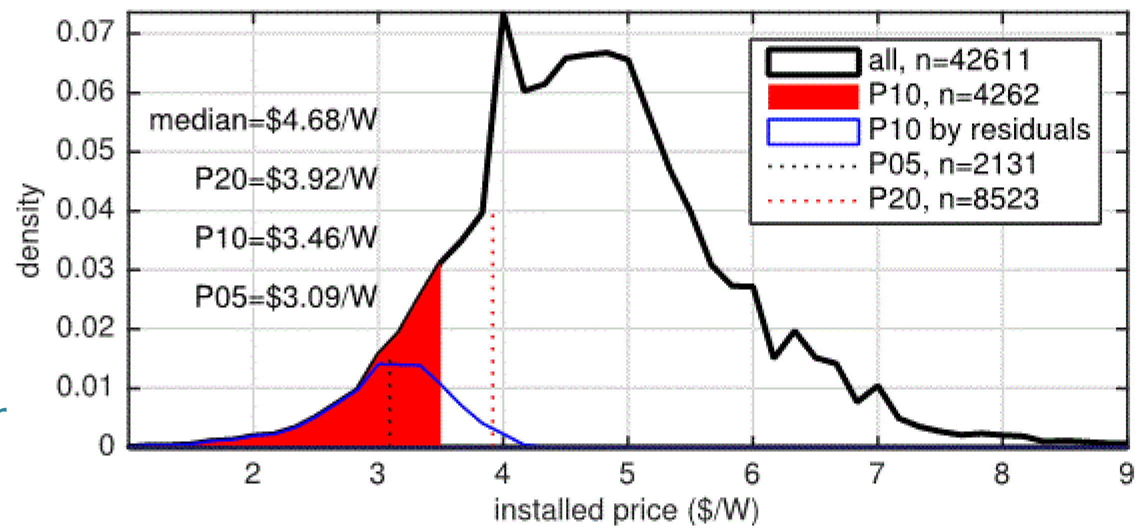
***Note:** This study focuses on customer-owned PV and, for TPO systems, on the sale price between installer and financier; it does not examine TPO contract pricing.*

Defining "Low-priced" (LP) Systems

Four definitions of LP systems:

- *P05:* ≤ 5th percentile of prices
- *P10:* ≤ 10th percentile of prices
- *P20:* ≤ 20th percentile of prices
- *P10 by residuals (P10r)*: After regressing on system size, system size², and sum of module and inverter price indices, system is LP if *residuals* are ≤ 10th percentile

Distribution of installed prices for systems installed in 2013



***Note:** Installed prices ($/W) represent the price paid by the owner of the system, prior to receipt of any incentives or subsidies.*

P10 is the principal definition used within this analysis, with other definitions used primarily as robustness checks

PV prices: Definition

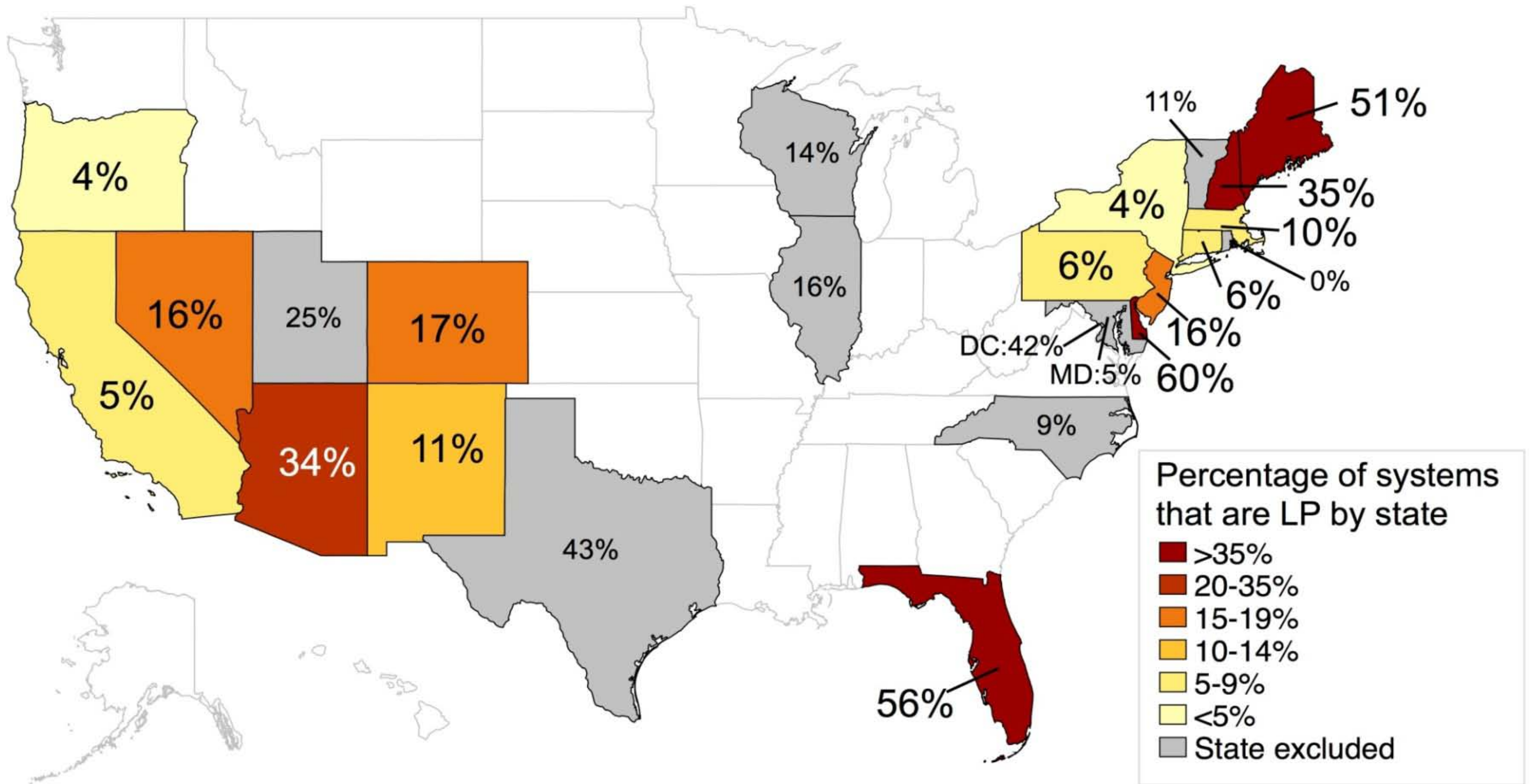
PV prices, as used in this analysis, are the reported transaction prices between the PV system owner and the installer

Included
PV modules
Inverter(s)
Wiring & meters
Racking / support structures
Labor
Permitting and administrative costs
Marketing costs
Profit / overhead

Excluded
Rebates / tax credits / subsidies
Performance based incentives
SRECs
Grid integration costs
Pollution externalities

Distribution of LP Systems Is Uneven Among States

Figure shows the share of systems in each state from the national P10 group
Values <10% imply relatively low shares of LP systems (and vice versa)



States shaded in grey have price data but are missing other key data so are dropped from subsequent analyses.

Potential Drivers for LP Systems Explored Within This Analysis

Competition
- Herfindahl-Hirschman index (HHI)
- # of active installers
- market duration

Firm
- installer experience in county
- installer experience in state
- market share
- aggregate experience by county
- installer scale by county
- installer scale by state

Market
- household density
- customer segment (res, com, other)
- third-party owned

Demographics
- educational variables
- household income variables
- local labor cost
- % democrat by county

Policies
- customer value of solar
- % of incentive SREC-based
- interconnection score

Costs
- module price index
- inverter price index

Size
- system size
- system size squared

System Characteristics
- tracking system
- building integrated PV
- new construction
- battery
- self-installed
- microinverter
- module efficiency
- China panels
- thin-film PV

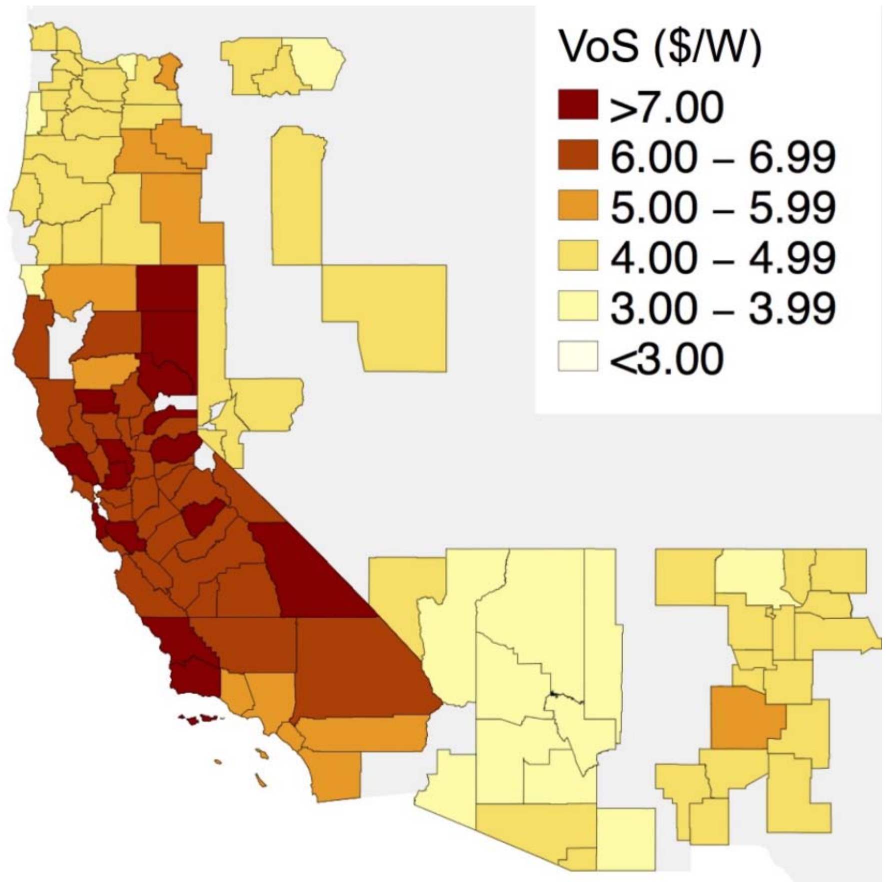
State and Time Effects
- by state
- by year-month

The Customer Value of Solar (VoS) Variable Includes Incentives + Bill Savings from PV

- The customer VoS variable encompasses all elements contributing to the economic value of PV to the customer
- Specifically, it includes:
  - Tax credits (*state*)
  - Cash rebates and incentives (*city*)
  - Performance-based incentives and feed-in tariffs (*zip*)
  - Solar renewable energy certificates payments (zip)
  - Bill savings (zip)

Note: Parentheses show geographic variation of VoS element, within the modeling

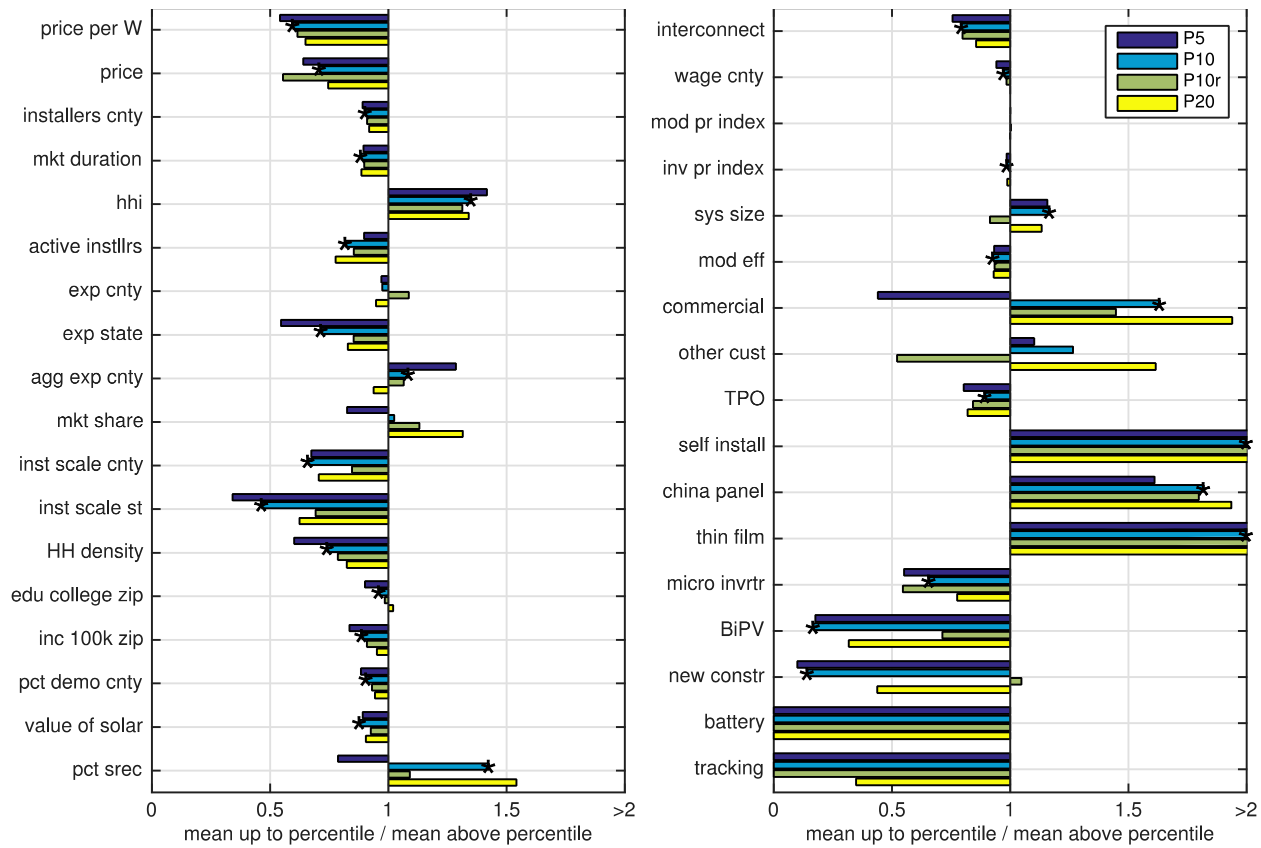
Customer VoS in Western States



Substantial Differences Emerge Comparing Variables for LP and non-LP Systems

Comparisons of means for LP systems to mean for non-LP systems

Bars pointing left (<1) indicate that mean value for LP systems is less than that of non-LP systems



Asterisks (*) indicate difference is significant with 95% confidence (t- and z-tests only for P10).

Regression Model: Predictors of LP PV Systems

$$LP_{ijst} = \beta_0 + \beta_1 COMP_{ist} + \beta_2 FIRM_{jst} + \beta_3 MKT_{ist} + \beta_4 POL_{ist} + \beta_5 SYSTEM_{ist} + \beta_6 B_i + e_{ijst}$$

Dependent variable

LP_{ijst} = binary variable: 1 if LP, 0 if non-LP

Independent variables

$COMP_{ist}$ = competition variables: concentration, # of installers

$FIRM_{jst}$ = firm variables: experience, market share, scale

MKT_{ist} = market variables: TPO, commercial, HH density, income, educ.

POL_{ist} = policy variables: value of solar, % SREC, interconnection

$SYSTEM_{ist}$ = system characteristics: size, module types, BiPV, battery, micro-inv

B_i = binary variables: state and month

i=installation, *j*=installer firm, *s*=state, *t*=month

Multiple Model Specifications

Base specification (Model 1)

- Logit regression model
- Competition variable: # of installers
- Firm characteristics: installer experience, market share
- PV system specification: exclude variables on module efficiency and whether manufactured in China

Five alternative specifications

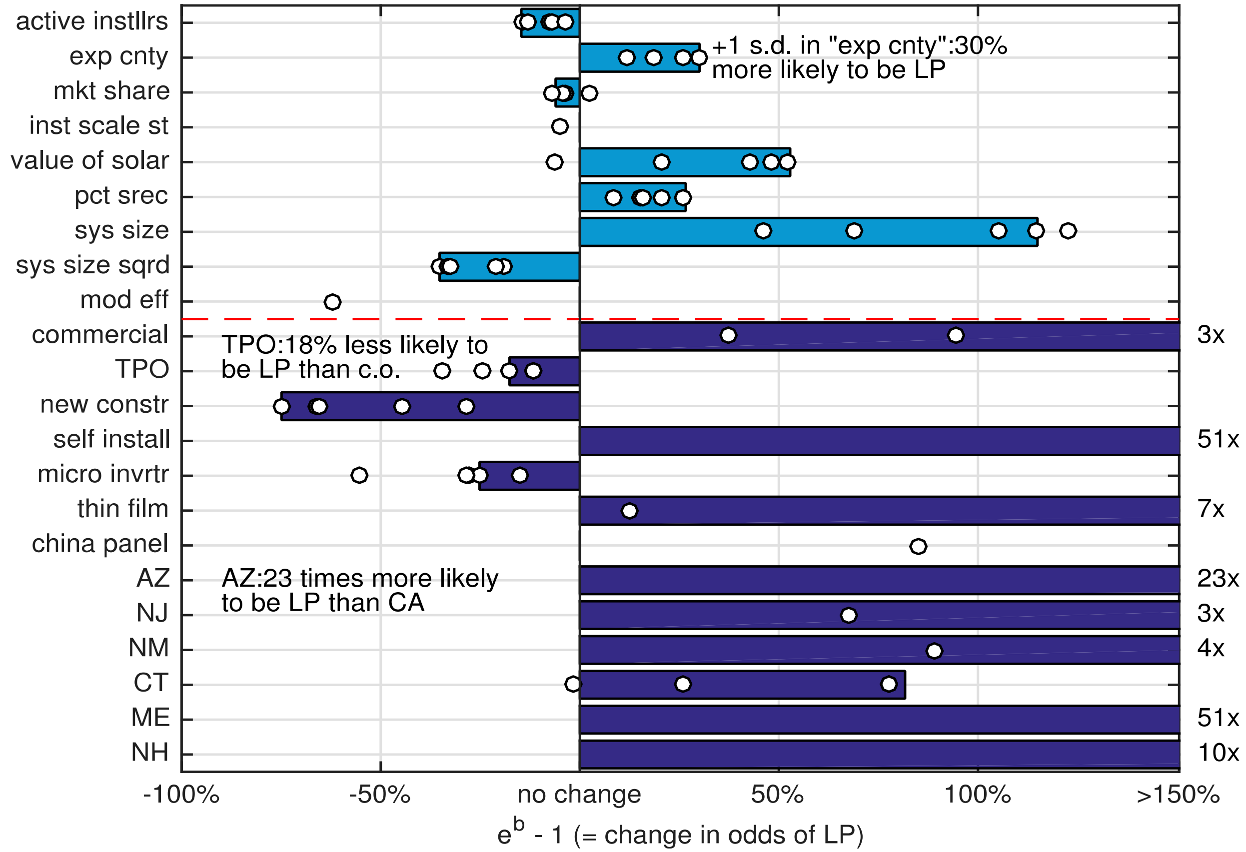
- Model 2: Fitting to probit model
- Model 3: State dummies dropped
- Model 4: Add HHI concentration index
- Model 5: Firm characteristics = installer scale only
- Model 6: Include variables for module efficiency and manufactured in China

Other robustness checks

- Alternative definitions of LP: P05, P20, P10r

Regression Results: Sizes of Significant Effects

Figure shows how increasing individual variables changes the likelihood of a system being LP



Notes: Bars refer to Model 1 in Table 1. Circle markers refer to Models 2–6. Variables above the red dashed line are ratios; those below are binary.

- Indicates the change in likelihood of a system being LP due to one standard deviation increase in that variable, compared to a system with the mean value for that variable
- Figure only includes significant variables
- Full set of regression model coefficients included in appendix

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Synthesis of Results Across Modeling Approaches

		Summary t-test logit total			Interpretation
		t-test	logit	total	*LP more likely with:*
COMP	**hhi**	+	.+	.+	concentrated (weak)
	active installers	-	-	-	few installers (weak)
	market duration	-			
FIRM	**experience county**	+	+	+	more experience
	experience state	-			
	market share	.	-	-	
	aggr experience county	+			
	installer scale county	-			
	instaler scale state	-	-	-	
MARKET	**HH density**	-	.+	.	
	commercial	+	+	+	commercial installs
	other cust type	.	.	.	
	TPO	-	-	-	customer owned
DEMOG	**inc $100k zip**	-	.+	.	
	% democrat county	-			
POLICY	**value of solar**	-	+	+	higher customer VoS
	% incentive from SRECs	.	+	+	more SRECs
	interconnect	-	.	.	

		Summary t-test logit total			Interpretation
		t-test	logit	total	*LP more likely with:*
COSTS	**module price index**	.	.-	.-	lower mod prices
	inverter price index	.	-	-	lower inverter prices
SIZE	**system size**	+	+	+	larger systems
	system size squared		-	-	… with diminishing returns
SYSTEM	**tracking**	-		-	not tracking
CHARAC.	**BIPV**	-	.-	-	not BIPV
	new construction	-	-	-	existing homes
	battery	-		-	not batteries
	self install	+	+	+	self-installs
	micro inverter	-	-	-	string inverter
	mod efficiency	-	-	-	less efficient modules
	china panel	+	+	+	Chinese panels
	thin film	+	+	+	thin films
STATE	**vs. CA**				LP: AZ, NJ, NM, CT, ME, NH

Positive: + = significant; .+ = not significant
Negative: − = significant; .− = not significant

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Summary Findings

Systems are more likely to be LP under the following conditions:

- ***Competition***: in markets with fewer installers, and somewhat in concentrated markets
- ***Firm***: installed by firms with more county-level installation experience but with less county-level market share, or by smaller firms
- ***Markets***: commercial installations and customer-owned (rather than TPO) installations
- ***Policy***: high customer VoS (although with caveats) and a higher portion of those incentives from SRECs
- ***System***: larger systems; systems without tracking, BiPV, micro-inverters, or batteries; systems installed on existing homes or self-installed; and systems using thin-film, less efficient, or made-in-China modules
- ***States***: After controlling for all of the above, Arizona, Connecticut, New Jersey, New Mexico, Maine, and New Hampshire are more likely to have LP systems. Systems in Nevada, Colorado, Florida, and Delaware—each of which had fewer than 200 systems in the analyzed data sample—are also more likely to be LP. The base state, California has about half as many LP systems compared to its overall share of U.S. systems.

Interpretation of Findings

Competition and firm variables:

- Results consistent with learning by doing (lower prices for more-experienced firms)
- High proportion of LP by small firms in relatively concentrated markets suggests pricing for market entry; reputation and risk

Market and state variables:

- Standardized pricing for TPO systems (narrower price distribution) leads to lower likelihood of LP systems than among customer owned systems
- Strong state effects: California much less likely to be LP, consistent with higher mean pricing in the state (as other studies have shown)

System characteristics:

- Results consistent with expectations related to economies of scale in system sizing, and known cost differences among technology and system designs
- Higher likelihood of LP for existing construction vs. new construction contrasts with lower average pricing for new construction (as other studies have shown); may reflect standardized pricing for new construction systems

Interpreting the Results for the Customer VoS Variable

This analysis found that increasing customer VoS associated with higher likelihood of LP

- Seemingly contrasts with previous studies of mean prices (Gillingham et al. 2014), which show higher incentives lead to higher average prices

Some possible explanations for the (apparent) discrepancy:

1. More recent data (2013) vs previous studies (2010-12)
2. Customer VoS picking up effects of some other factor
   - Effect is insignificant once state dummies added
   - Effect is strongest in northern California (with high VoS and relatively high %LP); something particular about NorCal?
3. Customer VoS affects left-tail of price distribution differently than it does the mean
   - Subsidies raise prices but also generate some very inexpensive ones

Policy Implications and Future Research

- Today's LP systems are the mean-priced systems of the future
- Distinct determinants of LP (vs. mean) systems suggest policy-makers should look closely at drivers for LP systems
- Some factors may be amenable to policy intervention while others are exogenous
  - For example, our results suggest that solar subsidies might be positively influencing the generation of LP systems in some areas (despite potentially higher average prices, as other work has shown)
- Further research needed to refine and extend findings on LP drivers
  - Expand data sample: systems without incentives, more-recent systems
  - Expand/refine explanatory variables: e.g., roof characteristics, measures of system quality, more-specific data on location and installer characteristics
  - Extend analysis to evaluate TPO contract pricing and to evaluate trends and drivers for price dispersion

For more information…

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

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

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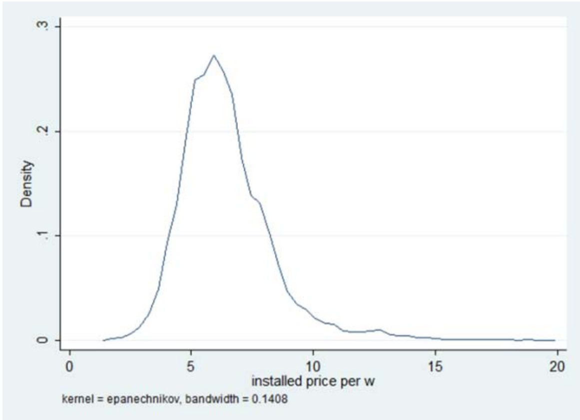
APPENDIX 1
Berkeley Lab's Academic Partners Program

Data Analytics / Academic Partners Program: Overview

OBJECTIVE: Leverage ***large datasets*** and ***academic partners*** to conduct in-depth, innovative, rigorous and impactful ***statistical*** analysis that addresses open questions about PV price and market trends.

Multiple research efforts over last three years (see following slides), more to come over the next three years, focused on understanding pricing and market trends and heterogeneity in the United States

Kenneth Gillingham, Yale University	CG Dong, UT Austin (NREL)
Greg Nemet, Univ. of Wisconsin	Eric O'Shaugnessy, Univ. of Wisconsin (NREL)
Varun Rai, UT Austin	Ryan Wiser, Berkeley Lab
Hao Deng, Yale University	Galen Barbose, Berkeley Lab
Jesse Burkhardt, Yale University	Naim Darghouth, Berkeley Lab

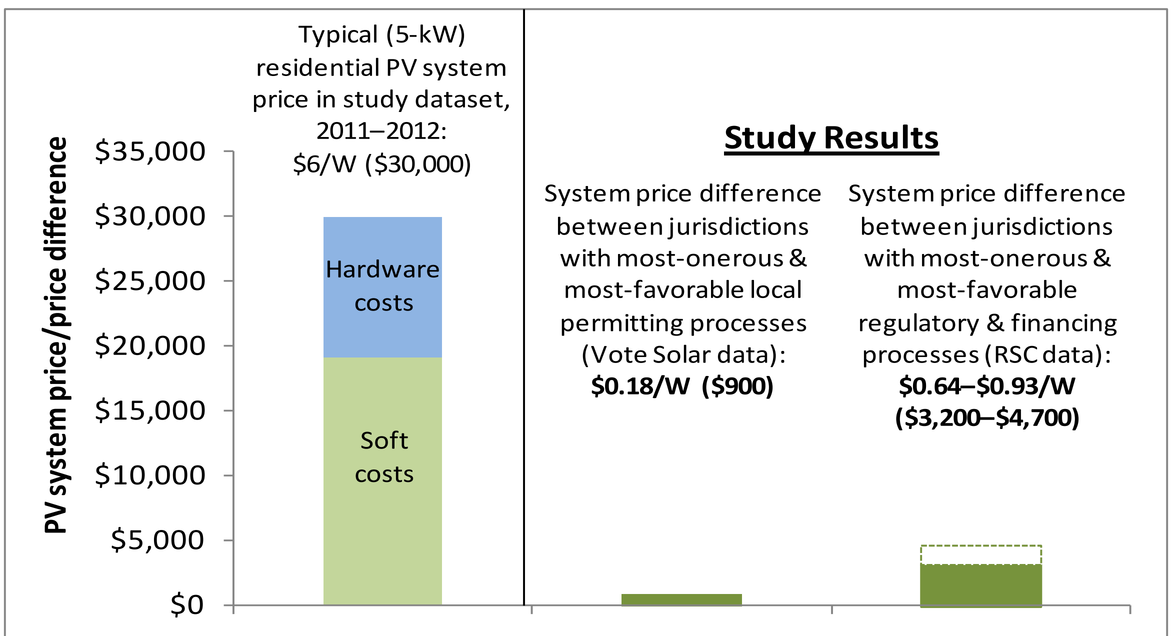


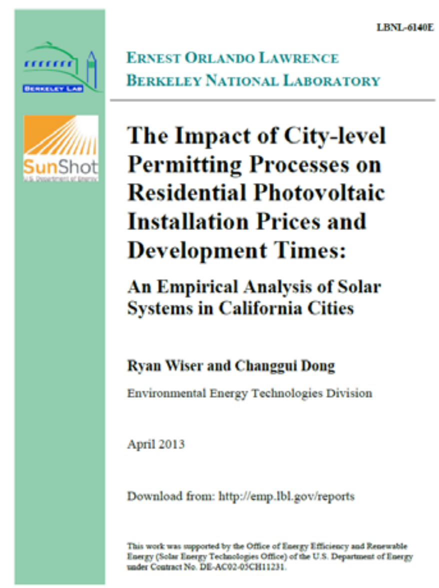
Collaborate with NREL staff where appropriate, depending on project

Academic Partners Program: Impact of Permitting and Local Regulations

OBJECTIVE: Assessed impact of permitting (Vote Solar scores) and local regulations (RSC scores) on PV prices, with two distinct research efforts, highlighting magnitude of cost reduction that might be expected from streamlining regulatory regimes

PROJECT LEAD: Yale University; University of Texas, Austin




LBNL-6140E

Ernest Orlando Lawrence Berkeley National Laboratory

The Impact of City-level Permitting Processes on Residential Photovoltaic Installation Prices and Development Times:

An Empirical Analysis of Solar Systems in California Cities

Ryan Wiser and Changgui Dong

Environmental Energy Technologies Division

April 2013

Download from: http://emp.lbl.gov/reports

This work was supported by the Office of Energy Efficiency and Renewable Energy (Solar Energy Technologies Office) of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

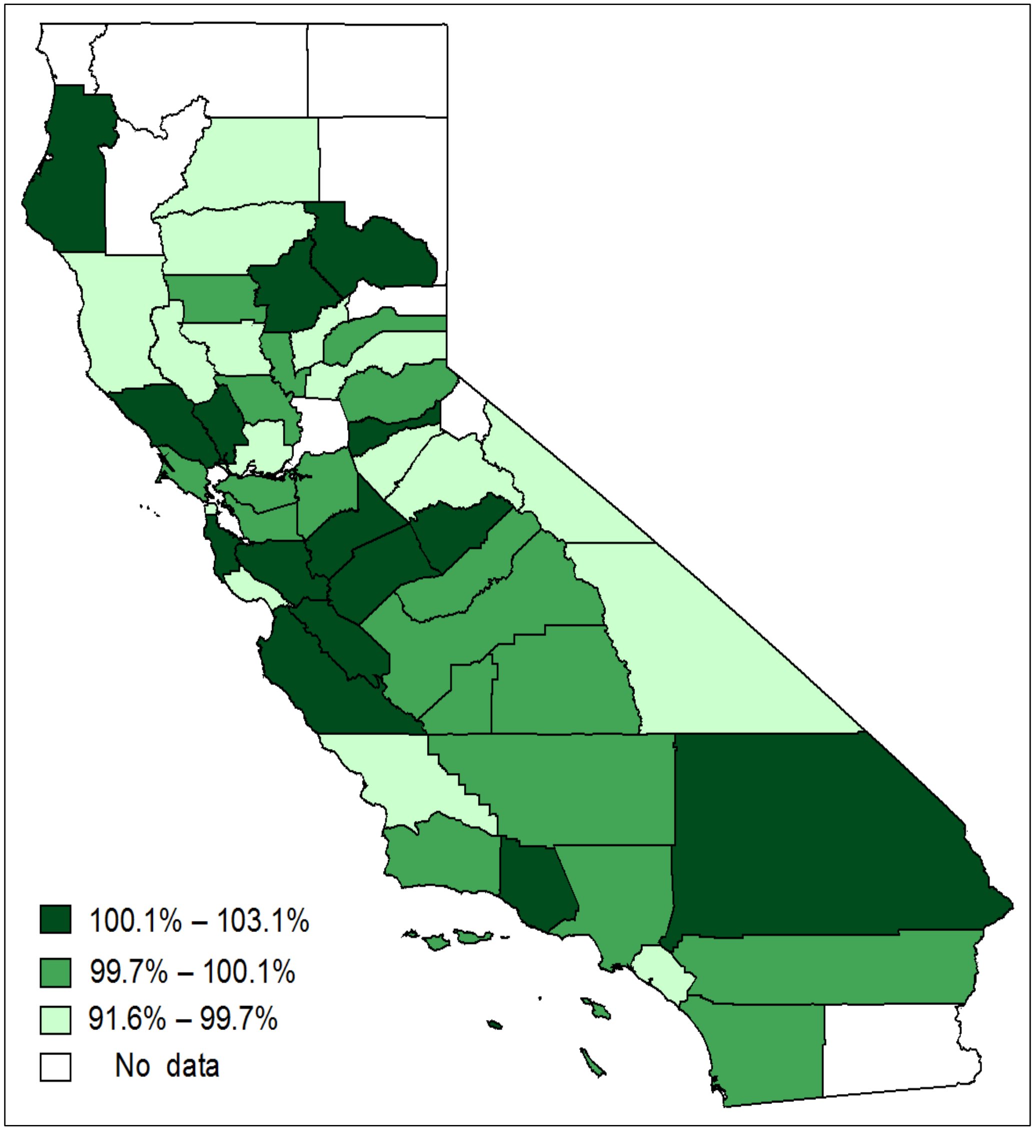
See https://emp.lbl.gov/publications/exploring-impact-permitting-and-local

Academic Partners Program: Incentive Pass-Through

OBJECTIVE: Assessed degree of incentive pass-through historically in California residential PV market

KEY FINDING: High (nearly 100%) incentive pass-through to customers under CSI

PROJECT LEAD: University of Texas, Austin



See https://emp.lbl.gov/publications/incentive-pass-through-residential

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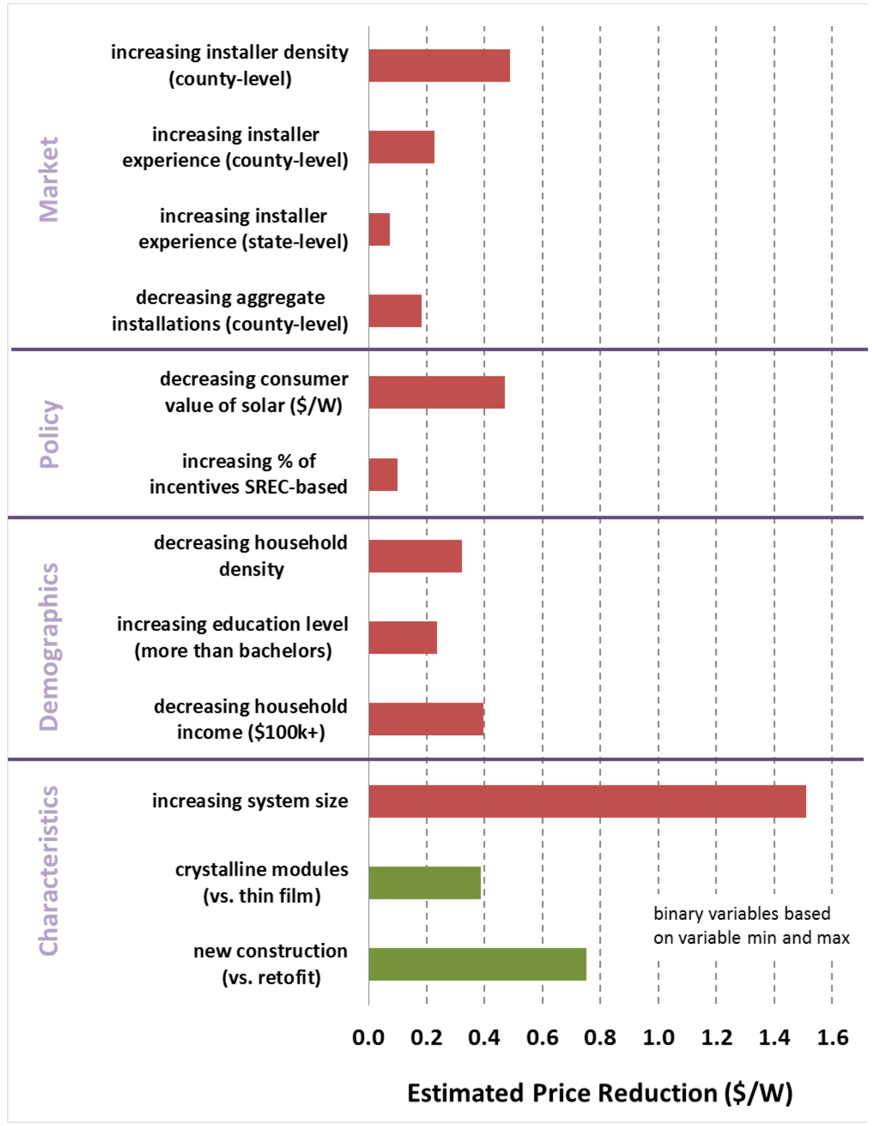
Academic Partners Program: Understanding Pricing Heterogeneity

OBJECTIVE: Quantified diversity of drivers for differences in residential PV prices across projects: system characteristics, value-based pricing, market competition, installer experience, etc.

KEY FINDING: Figure shows the price reduction associated with moving between the 5th and 95th percentile values of each variable

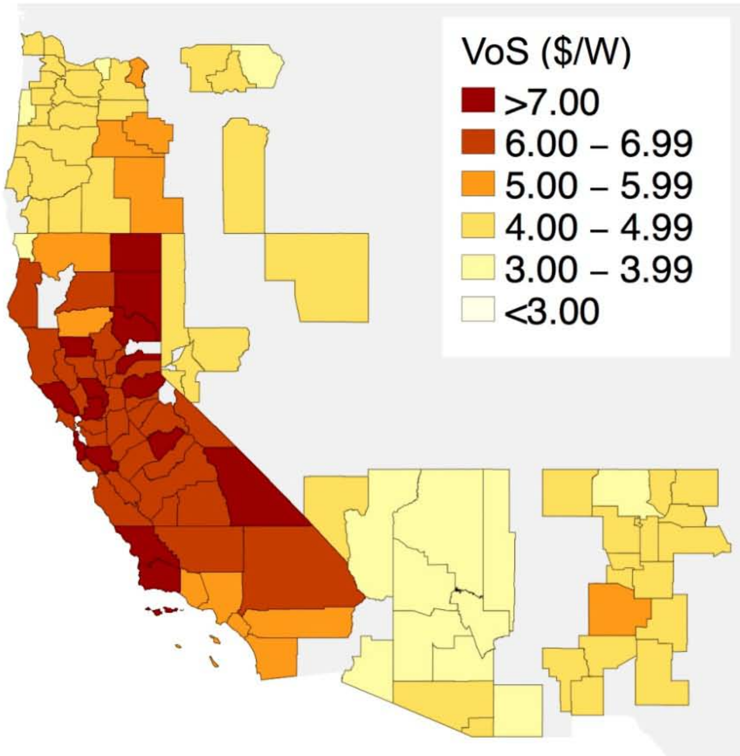
PROJECT LEAD: Yale University

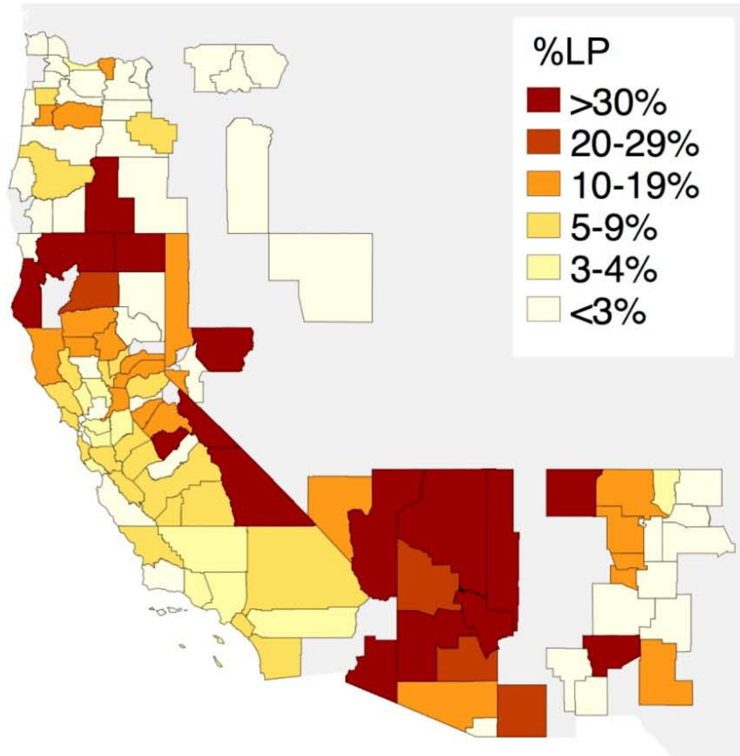


See https://emp.lbl.gov/publications/deconstructing-solar-photovoltaic

APPENDIX 2
Additional Slides

Variation in Customer VoS by County Compared to Variation in Percent of Systems that are LP



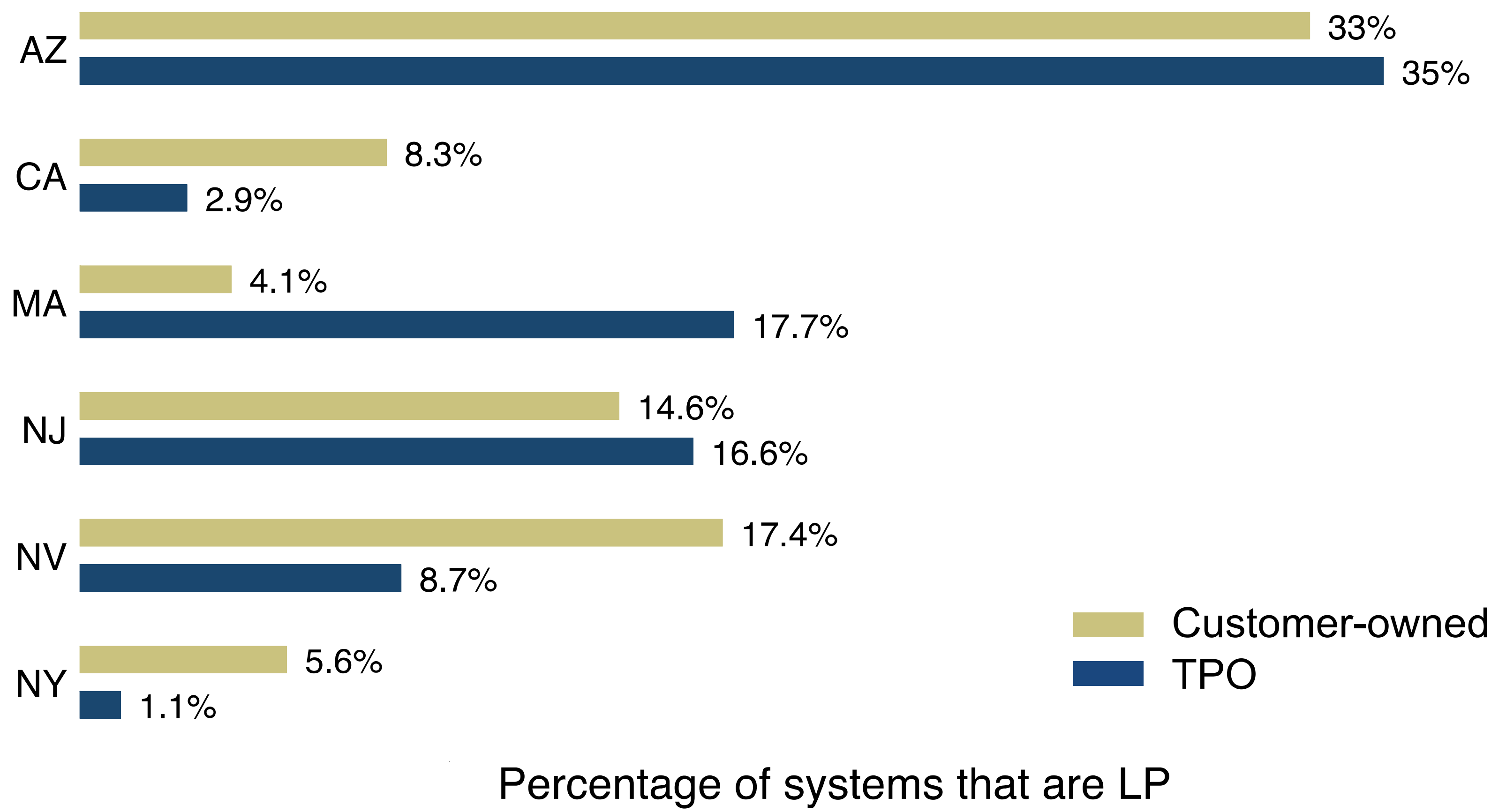


Value of solar in dollars per watt (left) and percent of systems that are LP (right), by county for California, Arizona, New Mexico, and Nevada.

Distribution of LP Systems by State

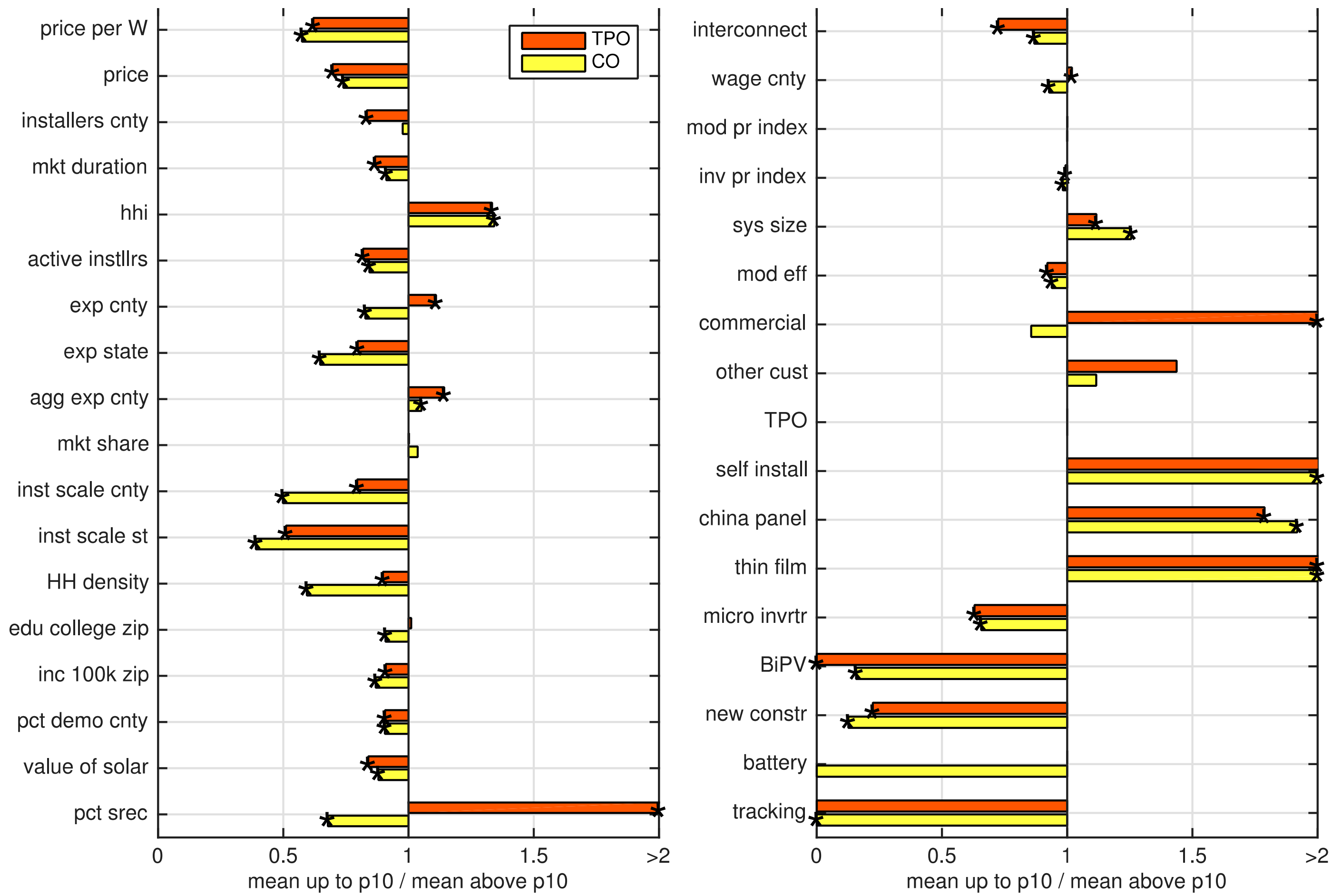
	All systems		p10 systems		Diff.
	n	%	n	%	% pt.
1 CA	27,564	65	1,443	34	-31
2 AZ	4,359	10	1,503	35	25
3 NJ	3,523	8	577	14	5
4 MA	2,459	6	234	5	-0
5 NY	1,619	4	63	1	-2
6 NM	878	2	94	2	0
7 CT	733	2	44	1	-1
8 OR	600	1	24	1	-1
9 ME	272	1	138	3	3
10 NH	254	1	90	2	2
11 NV	178	0	29	1	0
12 PA	127	0	7	0	-0
13 CO	24	0	4	0	0
14 FL	16	0	9	0	0
15 DE	5	0	3	0	0

Percentage of Customer-Owned and TPO Systems That Are LP by State



Includes only states with TPO systems constituting greater than 10% of all systems in data sample, in 2013

Ratio of Variable Mean Value for LP Systems to Mean for Other Systems



Orange bars for TPO systems, yellow bars for customer owned. Asterisks indicate difference is significant with 95% confidence.

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Regression Results (1)

Coefficient estimates from logit regressions of Y = P10 on Xs for 2013 installations.

	(1) base	(2) probit	(3) no states	(4) comp2	(5) firm2	(6) module
Y=1 if P10						
active instllrs	-0.159***	-0.0798***	-0.0675*	-0.154***	-0.0398	-0.141***
hhi				0.0436		
exp cnty	0.263***	0.114***	0.230***	0.263***		0.169***
mkt share	-0.0622**	-0.0376**	-0.0459*	-0.0706**		0.0245
inst scale st					-0.0477*	
HH density	0.00549	0.00654	-0.119***	0.00114	0.00973	0.0462*
commercial	1.230***	0.665***	0.303***	1.229***	1.168***	1.407***
other cust	0.219	0.207	-0.0674	0.213	0.146	-0.0862
TPO	-0.193**	-0.122***	-0.431***	-0.195***	-0.120*	-0.280***
inc 100k zip	0.00648	0.00152	-0.0688***	0.00923	0.00902	0.00206
value of solar	0.425***	0.188***	-0.0607	0.421***	0.395***	0.358***
pct srec	0.237*	0.139*	0.156***	0.234*	0.188	0.0824
interconnect	0.0746	0.0161	-0.701***	0.0893	0.0963	0.0539
mod pr index	-0.0342	-0.0248*	-0.165***	-0.0319	-0.0488*	-0.0386
inv pr index	-0.196***	-0.111***	-0.373***	-0.182***	-0.197***	-0.235***
sys size	0.765***	0.377***	0.529***	0.765***	0.719***	0.799***
sys size sqrd	-0.435***	-0.208***	-0.238**	-0.435***	-0.402***	-0.397***
BiPV	-0.661	-0.337	-0.618	-0.676	-0.902	-2.850**
new constr	-1.382***	-0.595***	-1.072***	-1.375***	-1.058***	-0.333
self install	3.929***	2.213***	4.165***	3.926***	2.911***	3.820***
micro invrtr	-0.290***	-0.166***	-0.324***	-0.292***	-0.339***	-0.806***
thin film	1.935***	0.980***	1.845***	1.937***	2.233***	0.116
china panel						0.615***
mod eff						-0.970***
N	42582	42582	42582	42582	42244	32503
ll	-11051	-11052	-11671	-11049	-10920	-6868
r2_p	0.202	0.202	0.157	0.202	0.174	0.273

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Regression Results (2)

Coefficient estimates from logit regressions of Y = P10 on Xs for 2013 installations.

	(1) base	(2) probit	(3) no states	(4) comp2	(5) firm2	(6) module
Y=1 if P10						
2 AZ	3.125***	1.547***		3.108***	3.127***	3.190***
3 NJ	1.240***	0.518**		1.252***	1.370***	1.171**
4 MA	-0.410	-0.359		-0.395	-0.274	0.0228
5 NY	-0.0928	-0.112		-0.119	-0.131	-0.551**
6 NM	1.403***	0.639***		1.329***	1.344***	1.154*
7 CT	0.593**	0.227*		0.568**	0.569**	-0.0199
8 OR	0.438	0.132		0.420	0.422	
9 ME	3.930***	2.063***		3.790***	3.726***	
10 NH	2.294***	1.089***		2.283***	2.336***	2.099***
11 NV	1.715***	0.800***		1.730***	1.721***	1.348***
12 PA	0.396	0.0588		0.373	0.509	0.259
13 CO	1.690**	0.769*		1.635**	1.600*	1.961*
14 FL	3.680***	1.917***		3.624***	3.647***	2.966**
15 DE	2.894***	1.554**		2.798***	2.979***	
N	42582	42582	42582	42582	42244	32503
ll	-11051	-11052	-11671	-11049	-10920	-6868
r2_p	0.202	0.202	0.157	0.202	0.174	0.273

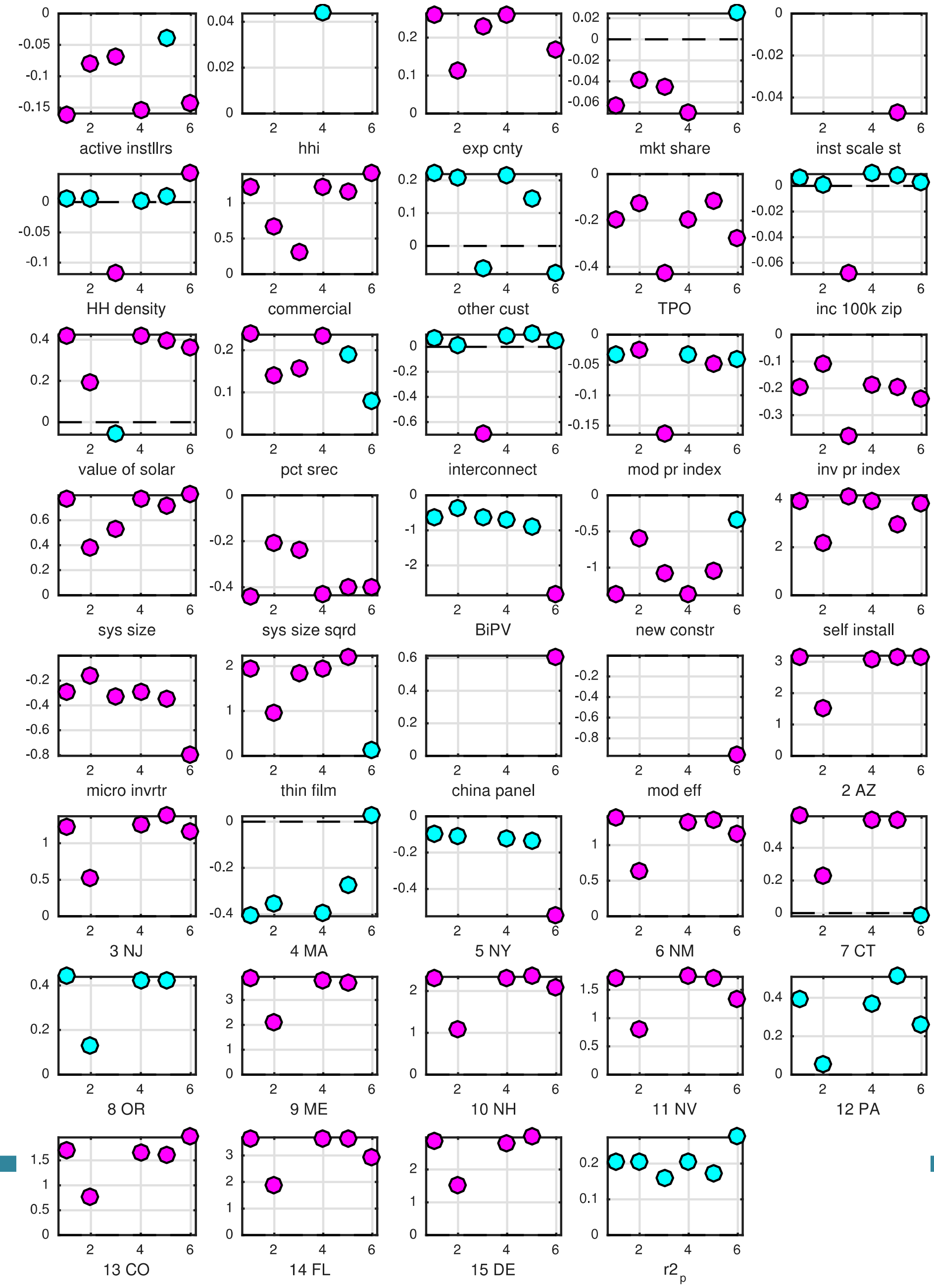
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Comparisons of Coefficients Across Models

Each chart compares coefficient value for a given variable across model specifications

X-axis is the model number

Fuchsia color indicates variable is significant at a level of at least $p < 0.05$ (or better; see previous tables for more detail on significance level)



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