Letting the Sun Shine on Solar Costs:

An Empirical Investigation of Photovoltaic Cost Trends in California

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January 2006

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Overview of Report

Objective: Evaluate trends in solar photovoltaic (PV) installed costs in California's market for residential and commercial grid-connected PV, focusing on the state's two largest rebate programs.

Report Structure

- Introduction
- The California Solar Market in Context
- Data and Methodology
- Analysis Results: CEC Systems Under 30 kW in Size
- Analysis Results: CPUC Systems 30 kW and Above in Size
- Comparing the CEC and CPUC Programs
- Conclusions and Recommendations

Report Seeks to Answer the Following Questions…

MAJOR QUESTIONS

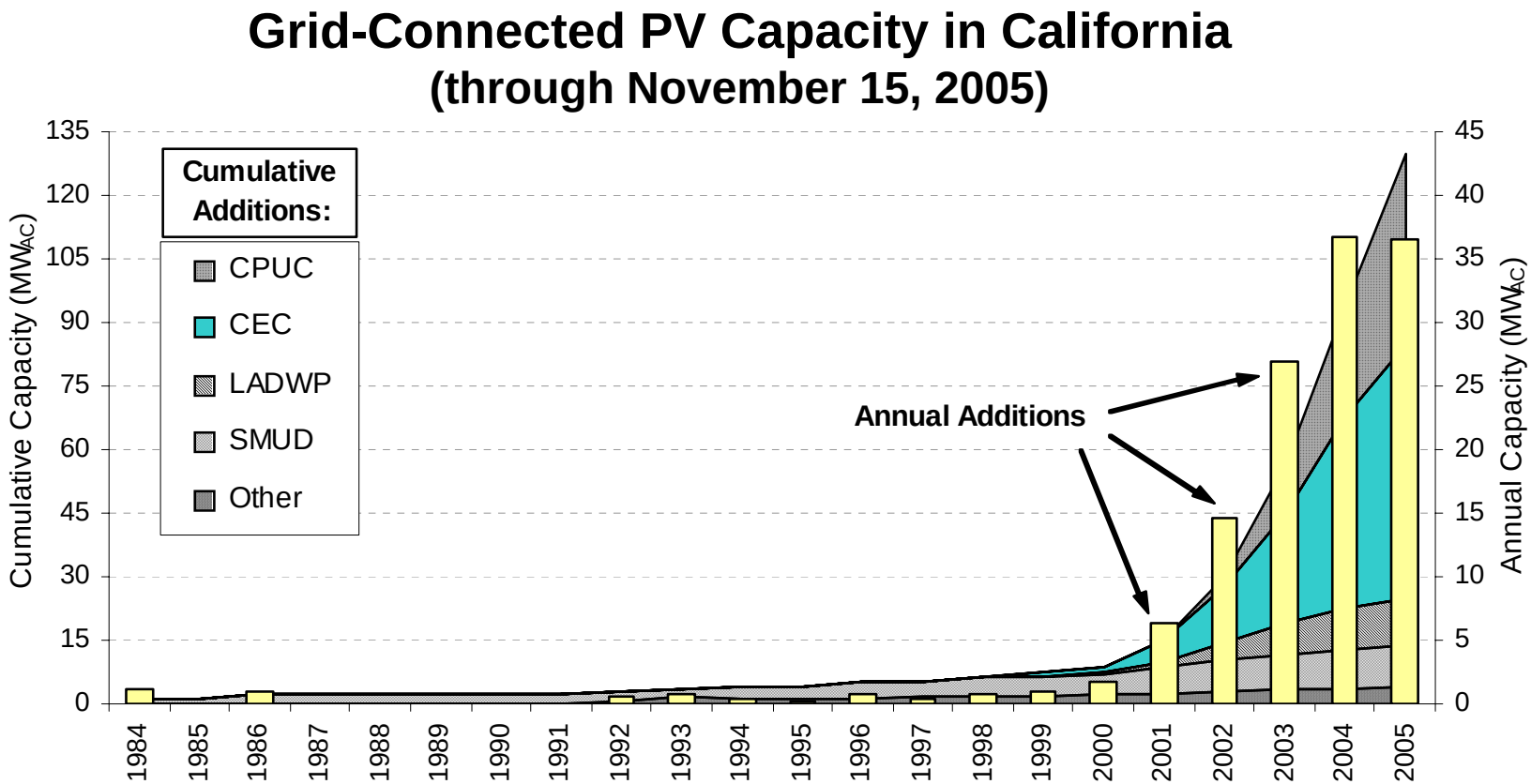
- How have installed PV costs changed over time, on average?
- To what extent have costs declined with system size?
- Has the size and design of rebates offered in California impacted pre-rebate installed PV costs?
- Have changes in state tax incentives and retail rates affected installed costs?
- Are there significant variations in average cost between systems installed as residential retrofits, as part of new home construction, in affordable housing, or on schools?

SUPPLEMENTAL QUESTIONS

- Have more-experienced installers charged more, or less, for their systems, on average?
- Have thin-film systems come in at lower or higher costs than crystalline silicon, on average?
- Has system location impacted average installed costs?

California Solar Market Overview

California is the dominant market for PV in the U.S., and the third largest PV market in the world (well behind Germany and Japan).

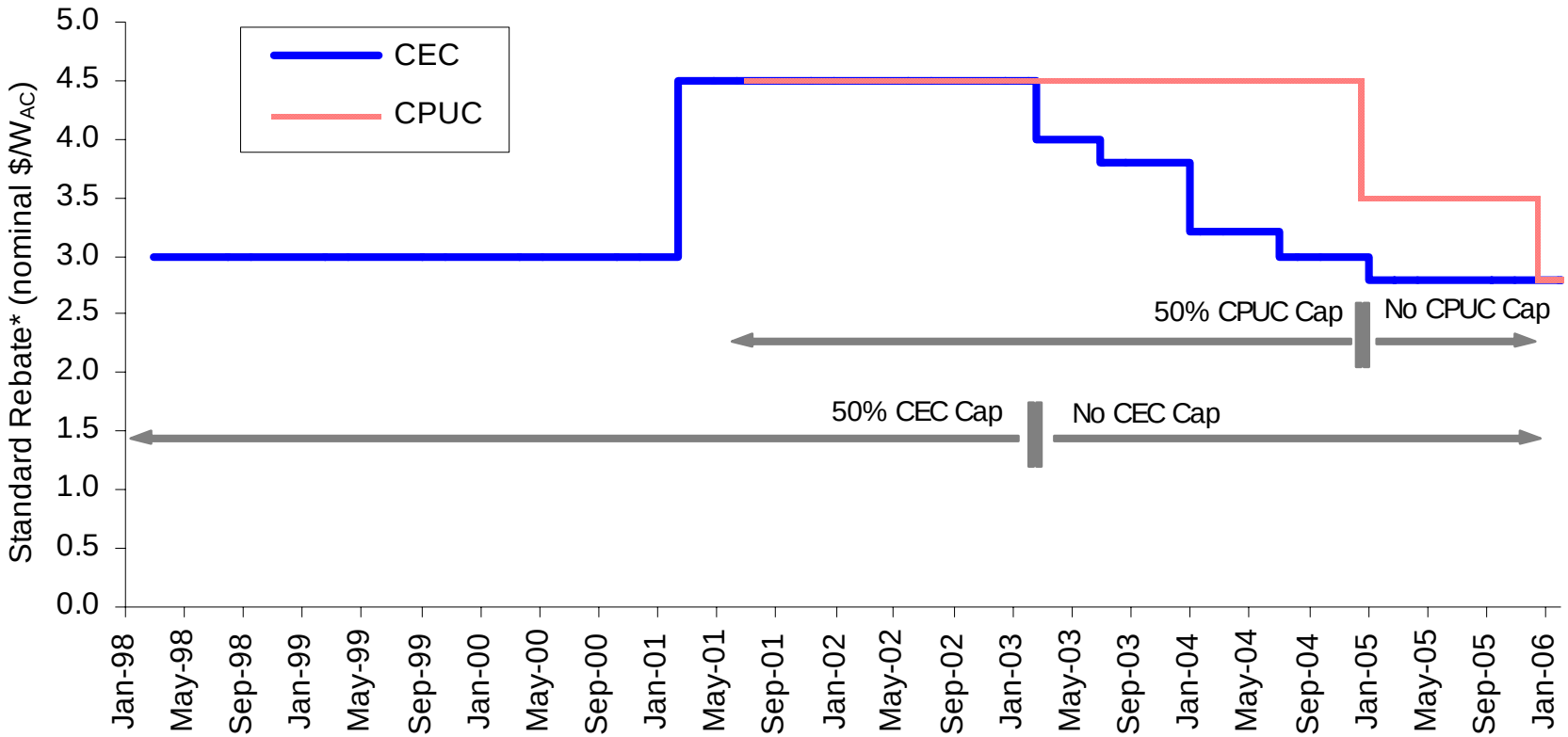


California Solar Programs

- The most prominent PV incentives in California – and those that are the focus of this study – are capital cost rebates offered by:
  - **California Energy Commission (CEC):** Operated since March 1998, focusing primarily on systems under 30 kW in size
  - **California Public Utilities Commission (CPUC):** Operated since July 2001, focusing on systems 30 kW and above
- In aggregate, these two programs have paid ~$400 million in incentive applications to currently operating PV projects in the state
- January 2006 order by CPUC will create a more sizable (~$3.2 billion) and stable (11-year) solar incentive program for the state, cementing California as a major player in the worldwide solar market
- Other supportive policies for PV in California have included rebate programs offered by publicly owned utilities, net metering, exemptions from certain utility fees and property tax, and state income tax credits

The CEC and CPUC Rebates Have Changed Over Time

Rebate levels are currently the same between the two programs, but the CPUC program offered richer incentives from 2003 through 2005.



Data and Methodology

- Data came from program databases of the CEC and CPUC programs, updated through May and June 2005, respectively
- Analysis results include data on 18,942 completed, approved, and waitlisted PV systems, totaling 254 MW_{AC} of PV capacity *(analysis also conducted just on completed systems – not shown here)*
- Data are restricted to system costs of \$4-30/W_{AC}, and CEC data to systems under 30 kW_{AC} in size
- All cost data are expressed in real 2004\$, and all size data are expressed in W_{AC}; note that many other programs use W_{DC}, making program comparisons somewhat more difficult
- Dependent variable is actual (for completed) or projected (for approved/waitlisted) installed costs of individual PV systems, in real 2004\$/W_{AC}
- Analysis is based on numerous multivariate regression models of each dataset separately, and of both datasets combined

Summary Information on Final Datasets

	CEC	CPUC
System Size Range	0.024 kW – 30 kW*	25 kW** – 1,063 kW
System Cost Restriction	$4/$W_{AC}$ – $30/$W_{AC}$	$4/$W_{AC}$ – $30/$W_{AC}$
Systems Eliminated Due to Cost Restriction	85 (0.5 MW)	4 (1.3 MW)
System Status for Those Included in Final Dataset		
Completed	12,856 (48.5 MW)	327 (35.7 MW)
Approved	5,033 (24.3 MW)	464 (73.4 MW)
Waitlisted	0 (00.0 MW)	262 (71.7 MW)
TOTAL	17,889 (72.8 MW)	1,053 (180.8 MW)
Application Date Range	03/20/98 – 04/15/05	07/23/01 – 04/15/05
Completion Date Range	04/08/98 – 04/07/05	06/18/02 – 05/17/05

* The CEC program initially funded systems over 30 kW in size, but ceased providing funding to such systems in March 2003. We exclude these larger systems from our analysis (a total of 66 systems, and 9.1 MW of capacity) to ensure that a limited number of outliers do not unduly affect our analysis results.

** Although the CPUC program rules state that only systems of at least 30 kW in size are eligible, the CPUC database does contain a few systems less than 30 kW (and as low as 25 kW).

Average cost in CEC dataset = $9.6/$W_{AC}$ ($8.0/$W_{DC\text{-}STC}$)
Average cost in CPUC dataset = $8.8/$W_{AC}$ ($7.4/$W_{DC\text{-}STC}$)

Independent Variables Included in Each Separate Dataset

CEC

- Date of application
- System size
- Rebate level
- Rebate percentage cap
- State tax credit level
- Applicable retail rate
- Installation status (completed vs. approved)
- System location (by utility territory)
- Installation type (retrofit; large new home development; single/cluster new home; affordable housing; schools)
- Installer and retailer experience; contractor- vs. owner-installed
- Population density
- Module type (thin-film vs. crystalline silicon)
- Module cost index

CPUC

- Date of application
- System size
- State tax credit level
- Applicable retail rate
- Additive other incentives
- Installation status (completed vs. approved vs. waitlisted)
- System location (by utility territory)
- Installer experience; systems installed by California Construction Authority
- Module type (thin-film vs. crystalline silicon)
- Module cost index

Regression Analysis

Four regression models were applied to each dataset independently:

- **Model 1** includes many of the independent variables listed earlier, but excludes the module cost index and rebate level variables. This model, as well as models 2 and 4, also excludes the rebate percentage cap, state tax credit, and retail rate variables.
- **Model 2** is equivalent to Model 1, but includes the module cost index and rebate level variables.
- **Model 3** is equivalent to Model 2, but adds three additional variables that experience some colinearity among themselves and with other independent variables: rebate percentage cap, state tax credit, and retail rate variables.
- **Model 4** contains the same independent variables as Model 2, but includes a large number of crossed terms to determine whether the coefficients of certain variables included in other models are affected by time or by system size.

Combined regressions of both CEC and CPUC datasets together also conducted

Regression models uniformly had low R^2 values (~0.3), but a large number of the independent variables were found to have statistically and substantively significant effects; **this means that analysis uncovered important trends in PV costs, but that much of the variation in costs across systems remains unexplained**

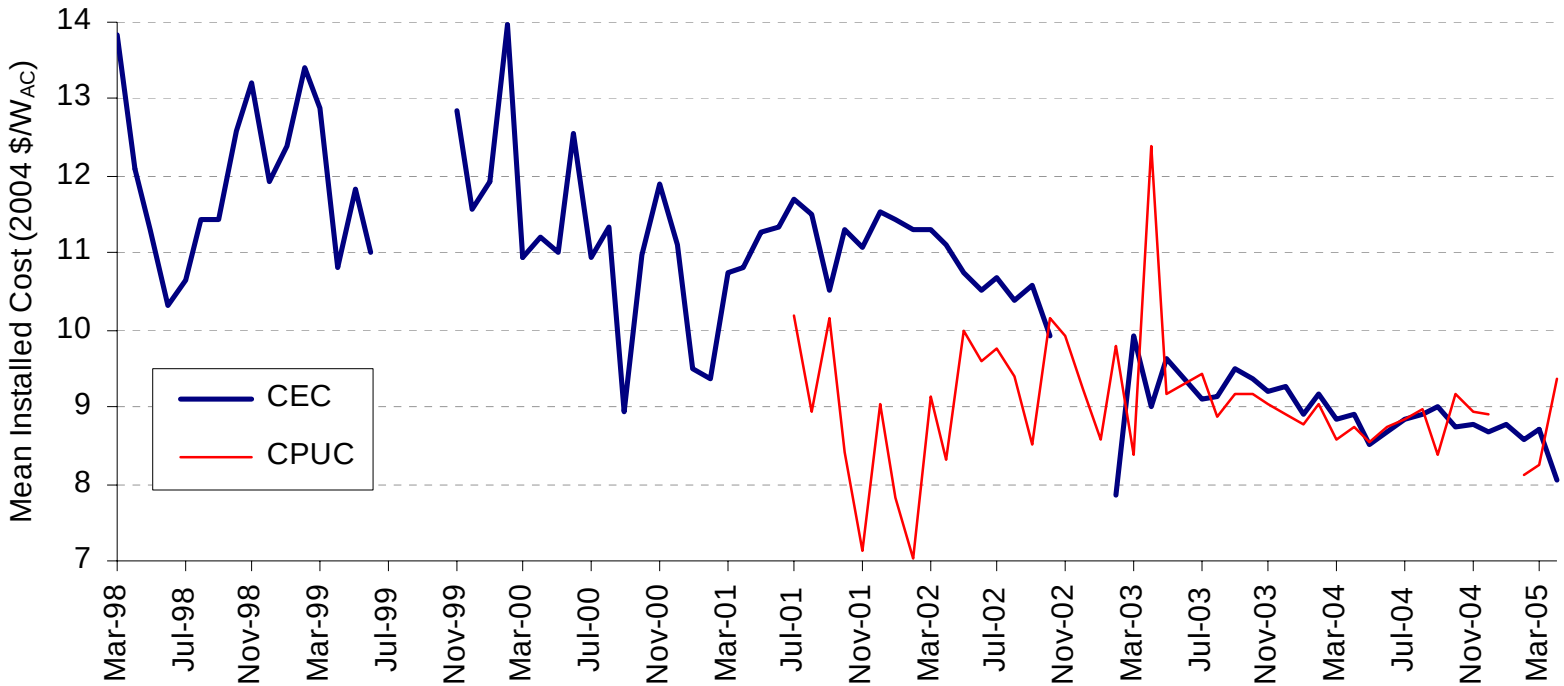
Key Findings

1. Solar costs have declined substantially over time, but less so under the CPUC's program
2. Policy incentives have impacted pre-rebate installed costs, and some cost inflation is apparent
3. Economies of scale drive down costs as system size increases
4. Systems installed in new home developments and in affordable housing projects experience much lower costs
5. Installer experience and type, module type, and system location all affect costs, but the effects differ by program

Regression Analysis Shows that Costs Have Declined Over Time

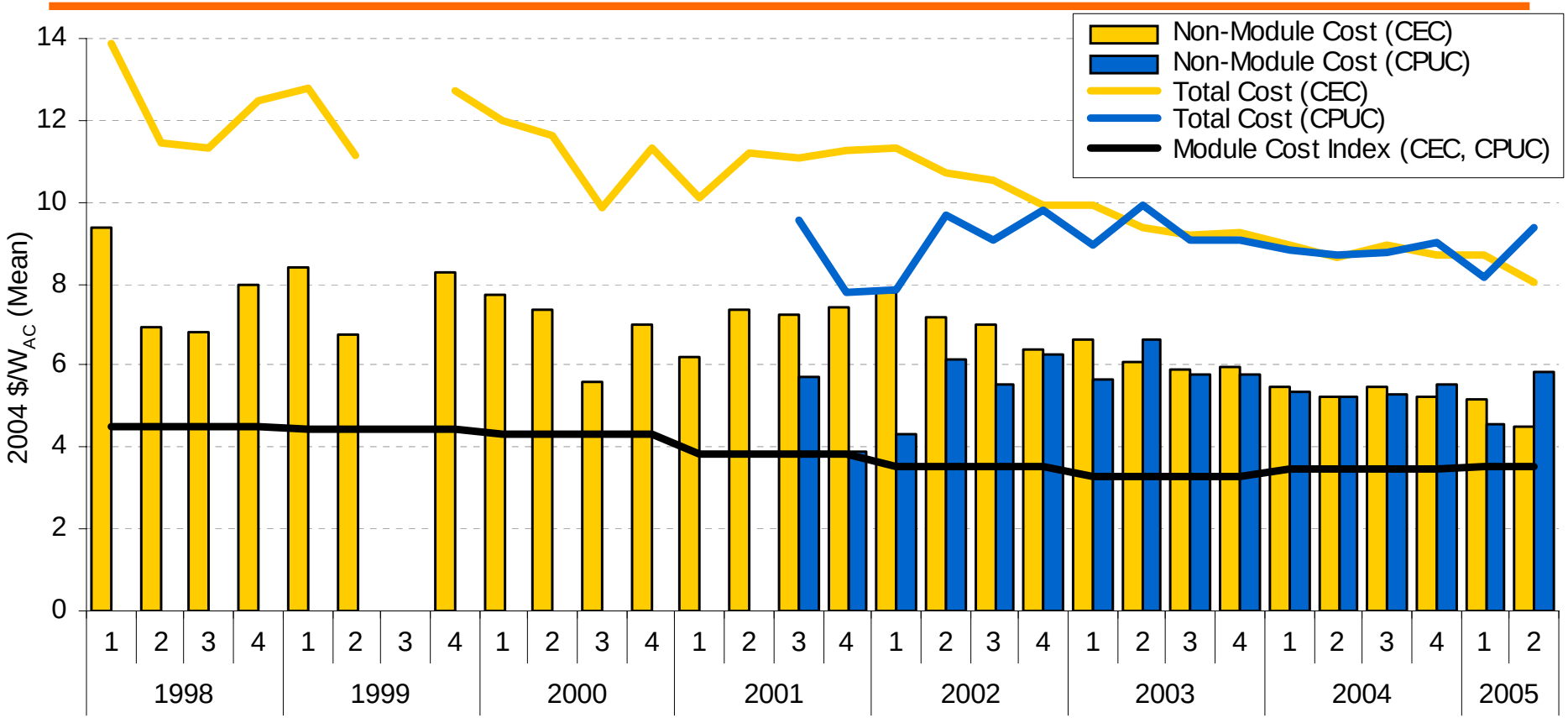
CEC: Average annual reduction of **$0.70/W$_{AC}$** (7.3%/yr)

CPUC: Average annual reduction of **$0.36/W$_{AC}$** (4.1%/yr)



Cost reductions for smaller systems are outpacing those for larger systems, especially under the CEC program, but the reasons for the slower cost reductions under the CPUC program remain somewhat unclear.

Reductions in Module and Non-Module Costs Have Both Been Important



Significant reductions in non-module costs, especially under the CEC program, are encouraging because module costs are set in a worldwide market: non-module costs are what state programs can affect!

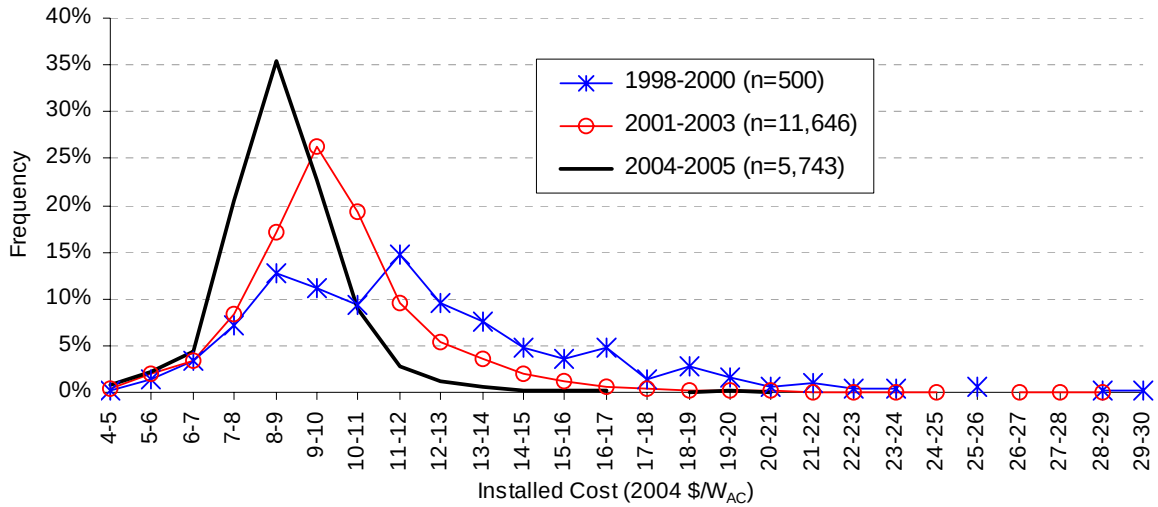
(Note: our analysis is unable to prove that the non-module cost reductions in CA have been caused by the state's incentive programs, though some causality seems likely)

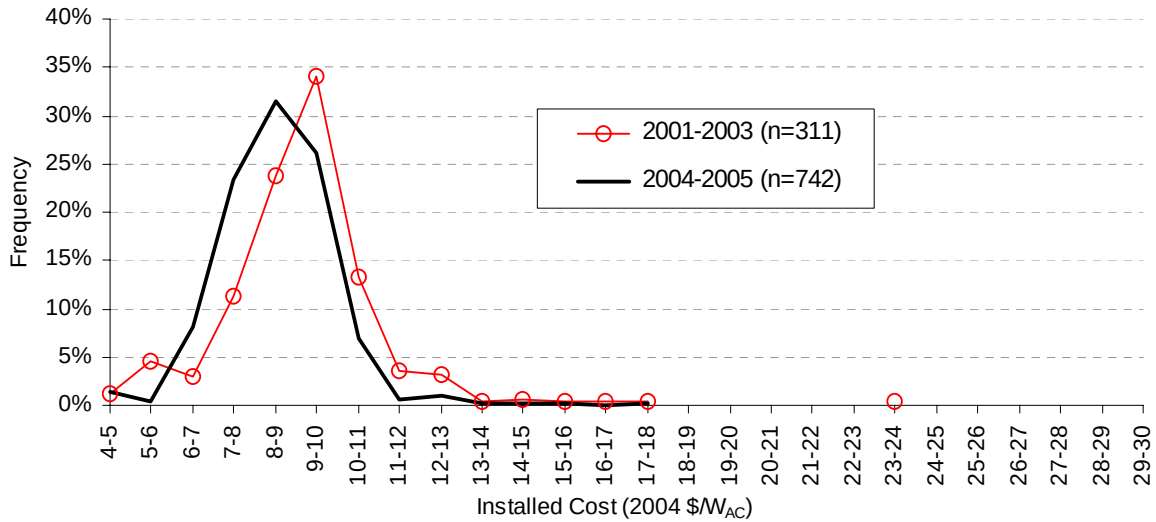
Cost Distributions Are Narrowing and Shifting With Time

Costs declining due to:

- **Shifting:** Overall shift of the cost distributions for the CEC and CPUC toward lower costs
- **Narrowing:** For the CEC, a significant reduction in high-cost outliers, demonstrating a maturing market in which price competition is becoming more robust

Top graph shows CEC and bottom graph CPUC cost distributions over time





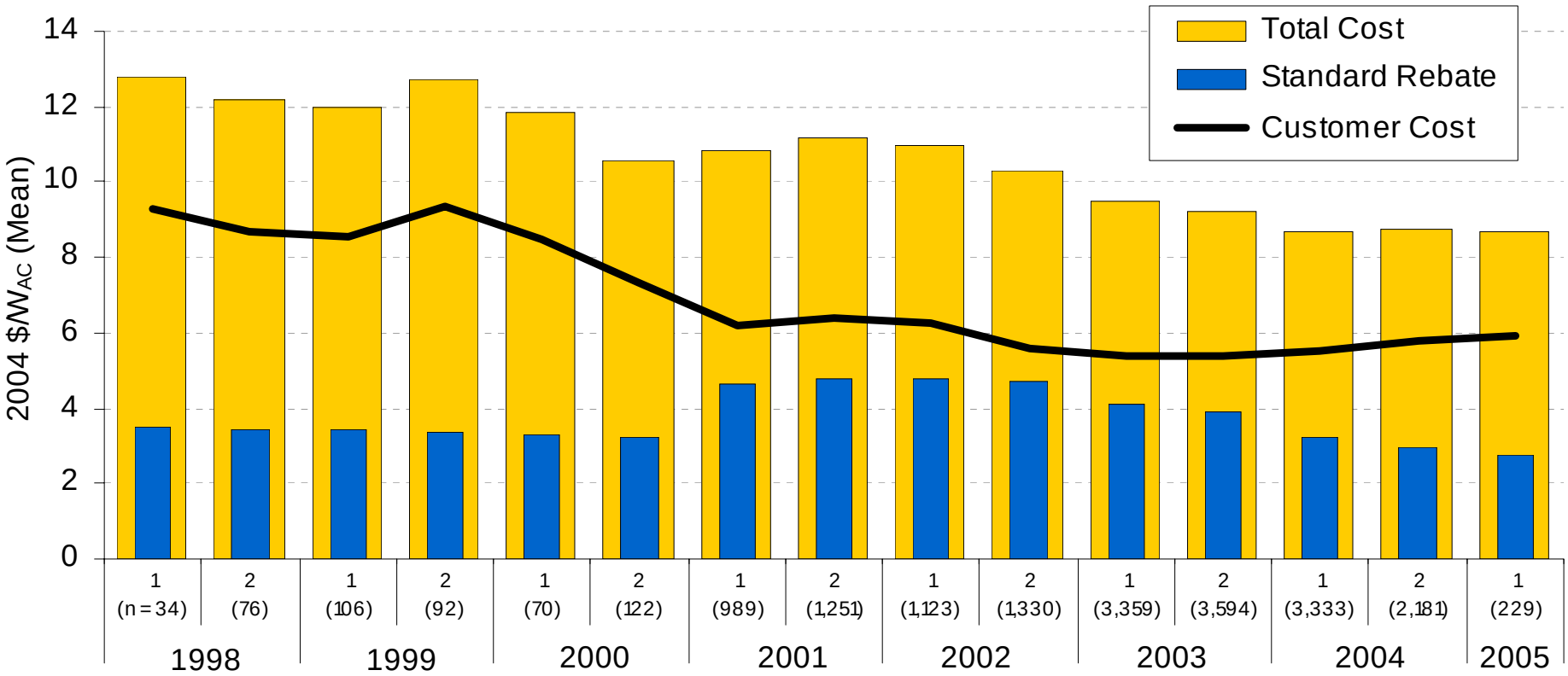
Policy Incentives and Rebate Levels Have Affected Pre-Rebate Costs

Analysis shows that heavy subsidies can dampen the motivation of installers to provide, and/or customers to seek, lower costs

CEC Rebate Levels Have Affected the Cost of CEC-Funded PV Systems

- Pre-rebate installed costs of CEC-funded systems have been linked to the rebate levels: each \$1/W_{AC} change in incentive level has (on average) yielded an 0.55-0.80/W_{AC} change in pre-rebate installed costs
- In other words, when the rebate level increased by \$1.5/W_{AC} (from \$3/W_{AC} to \$4.5/W_{AC}) in early 2001, system purchasers only realized \$0.3-\$0.7/W of that increase, on average, with the remaining \$0.8-\$1.2/W being "captured" by system retailers or installers through correspondingly higher prices
- By the same token, regression results suggest that as the CEC gradually reduced its rebate levels since early 2003, system retailers have absorbed some of the decrease by reducing prices

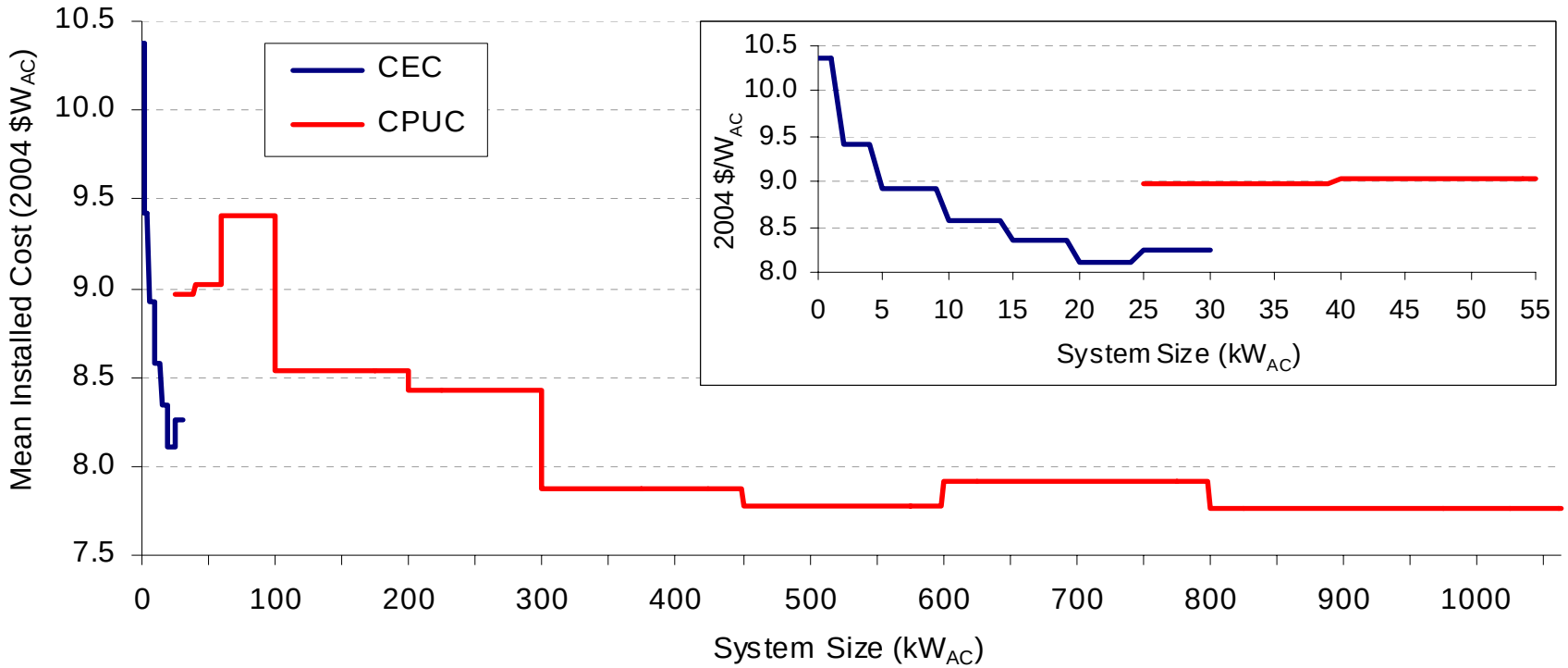
Installed Costs Under the CEC Program Have Been Linked to the Size of the Rebate



CPUC's Historically Richer Incentives Have Yielded Higher Costs than for Similar-Sized CEC Systems

The CPUC's historically richer incentives appear to have yielded higher cost PV systems than similar-sized systems funded by the CEC

The cost difference is found to be at least $0.60/WAC (on average)



Applications received from July 1, 2001 to April 15, 2005

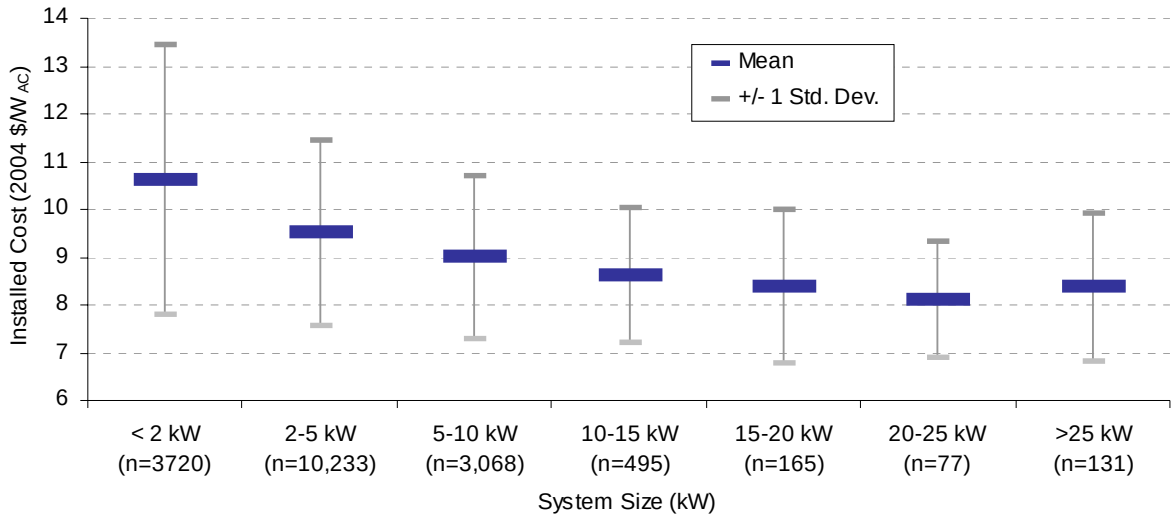
Other Evidence Supports View that Incentive Levels Have Affected Pre-Rebate Costs

- Systems funded by the CPUC that received sizable *additional* incentives (beyond those provided by the CPUC) are found to have had higher average costs of $\$0.60/W_{AC}$
- Existence of rebate percentage caps for CEC and CPUC appears to have resulted in cost inflation when those caps were in place
  - **CEC:** Regression analysis suggests $\$0.20/W_{AC}$ cost inflation
  - **CPUC:** Number of systems in price range $\$8.75$-$\$9.25/W_{AC}$: 30% when percentage cap was in place; 5% when percentage cap was eliminated
- Tax incentives appear to have increased installed costs to some degree
  - **CEC:** Regression analysis suggests $\$0.25/W_{AC}$ increase under 15% state income tax credit compared to no credit
  - **CPUC:** Regression analysis suggests $\$0.45/W_{AC}$ increase under 15% state income tax credit compared to no credit
- Retail rates are not found to have impacted pre-rebate costs, but the retail rate variable used is blunt and imperfect

Economies of Scale Have Driven Down Costs as System Size Increases

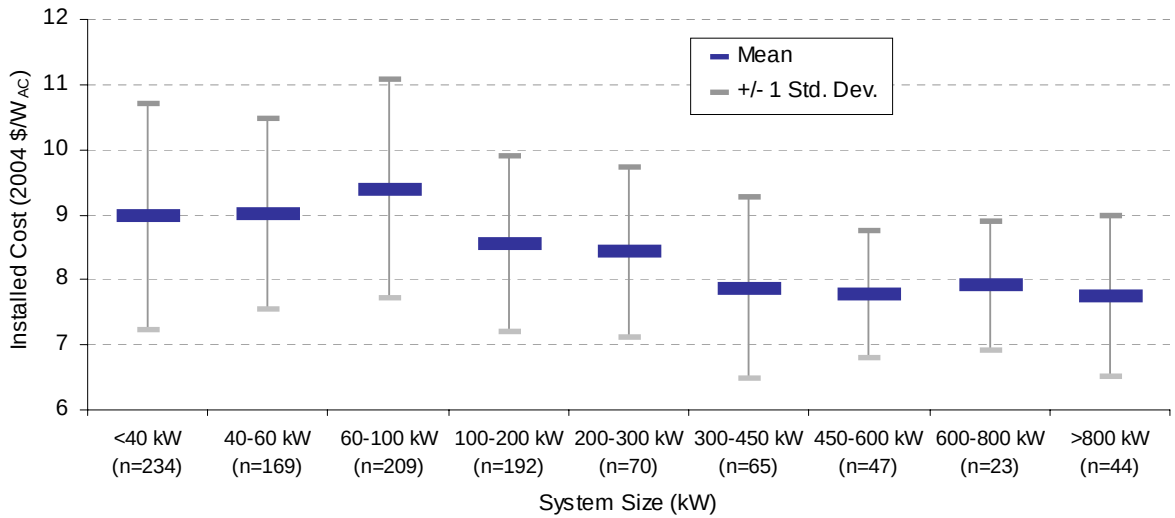
CEC

Largest systems are ~$2.5/$W_{AC}$ cheaper, on average, than 1 kW installations



CPUC

Largest systems are ~$1.5/$W_{AC}$ cheaper, on average, than smaller installations funded by the CPUC



Systems Installed in Bulk in New Construction Have Had Substantially Lower Costs

Compared to the general retrofit market, certain applications demonstrate higher, or lower, average installed costs

Application Type	Number	Relative Cost
Large new residential developments	1,946	↓ $1.2/$W_{AC}$
Single new homes or small clusters	771	↑ $0.18/$W_{AC}$
Affordable housing projects	340	↓ $1.9/$W_{AC}$
Schools	60	No Impact

A Variety of Other Factors Impact Costs, but Often in Inconsistent Ways Across the Two Programs

Application Type	CEC	CPUC
Experienced Installers	↑ $0.29/$W_{AC}$	↓ $0.70/$W_{AC}$
Experienced Retailers	↑ $0.17/$W_{AC}$	n/a
Owner-Installers	↓ $1.8/$W_{AC}$	↓ $4.0/$W_{AC}$ [CA Const. Author.]
Thin-Film Modules	↓ $0.70/$W_{AC}$	↑ $0.20/$W_{AC}$
Utility Service Territory	↓ costs outside of PG&E	↑ costs outside of PG&E
Population Density	↑ costs in densely populated areas	n/a

Policy Recommendations

Reducing non-module costs should be a primary goal of local PV programs

- Unlike module costs (which are set in a worldwide market, and passed through one-for-one to customers), non-module costs may be affected by local programs
- State policymakers should consider programmatic activities aimed specifically at improving the PV installation infrastructure and driving down non-module costs

Sustained, long-term programs may enable more significant cost reductions

- Though PV cost reductions in California are significant, experience from Japan demonstrates that a sustained, long-term program may yield greater reductions
- In 2004, the average cost of a residential PV system in Japan was reportedly \$1.4/W_{AC} lower than in California, and annual average cost declines from 1999 through 2004 were greater in Japan (8.9%) than in California (5.2%) for similar-sized residential systems
- The CPUC's newly announced program of incentives that will decline at ~10% a year will require continued system cost reductions

Policy Recommendations

The structure and size of PV incentives should encourage cost reduction, not cost inflation

- California's historical experience shows that rich incentives can result in increased installed costs
- Though rich incentives may initially be required to jump-start the market, over time those incentives should decline
- Rebate percentage caps have resulted in cost inflation, and should be considered for elimination in other states

Targeted incentives that account for the relative economics of different systems may be appropriate

- Significant cost variations by system size, application type, and installer type suggest that a further targeting of incentives may be appropriate
- This may be especially true with EPAct 2005, which offers federal investment tax credits whose benefits are highly variable by system size and customer type

For More Information...

Download the full report from:

http://eetd.lbl.gov/ea/ems/re-pubs.html

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