COST TRENDS AND GOVERNMENT INCENTIVES IN THE CALIFORNIA PHOTOVOLTAICS MARKET, 2007-2008

by

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ABSTRACT

The focus of this thesis is to analyze cost trends and government incentives in the California PV market during 2007-2008. The data show that pre-rebate system costs increased in California during this time period and that this was driven by a surge in worldwide module cost. Systems employing thin film technology did not exhibit a downward impact on cost, which contradicts historical and technological expectations. Furthermore, the introduction of the California Solar Initiative's declining rebate structure had a limited effect on reducing system costs. Additional research is necessary to understand installer pricing behaviors, which seemed to negatively affect commercial buyers, and how to best capitalize on the strong effect of economies of scale that was present in the data. This may lead to improved mechanisms of cost reduction that can aid policymakers.

Thesis Supervisor: Richard K. Lester
Title: Professor of Nuclear Science and Engineering

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List of Acronyms

CEC	California Energy Commission
CPI	Consumer Price Index
CPUC	California Public Utilities Commission
CSI	California Solar Initiative
EIA	Energy Information Administration
EPBB	Expected Performance Based Buydown
ERP	Emerging Renewables Program
PBI	Performance Based Incentive
PG&E	Pacific Gas and Electric Company
PTC	Performance Test Conditions
PV	Photovoltaic
SCE	Southern California Edition
SDGE	San Diego Gas and Electric
SGIP	Self-Generation Incentive Program
STC	Standard Test Conditions
ZCTA	Zip Code Tabulation Area

1. Introduction

From 1979 to 2006, installed solar electric generating capacity increased from 5MW to more than 2,000MW. During that same period of time, the wholesale cost of photovoltaic (PV) modules has decreased roughly 50% per decade (Pernick 2007). Using estimates more conservative than industry forecasts, the United States Department of Energy's goal is that by 2015, installed system cost will be reduced by a further 50% (U.S. DOE 2008). However, the growth of PV around the world would not have been possible without substantial incentives from government entities. Even with the dramatic cost reductions of the past three decades, solar power is still not competitive with conventional utility-supplied electricity on a cost basis and can be three to five times more expensive than wind, nuclear, or geothermal energy (Henderson 2007). These high costs help to explain why solar energy still accounts for less than 0.1% of global electricity output (Wiser et al. 2006).

Around the world, local governments have utilized rebates and other incentives to subsidize the costs of PV system installations in an effort to reach grid parity. In the United States, the state of California has offered rebates on PV systems since March 1998 under the California Energy Commission's (CEC) Emerging Renewables Program (ERP), which focused on systems under 30kW in size, and since July 2001 under the California Public Utilities Commission's (CPUC) Self-Generation Incentive Program (SGIP), which focused on systems larger than 30kW in size. In their 2006 paper, Wiser et al. studied cost trends in California's PV market from 1998-2005 under these two programs in an effort to aid energy policymakers and stakeholders to revise their solar incentive programs (Wiser et al. 2006).

The framework for the California Solar Initiative (CSI) program through 2016 was announced by the CPUC in January 2006 and replaced the ERP and SGIP. The CSI included two incentive programs for consumers. Under the Expected Performance Based Buydown (EPBB), buyers are paid a lump sum rebate based on system characteristics including size and the program is targeted towards residential and small business customers. Under the Performance Based Initiative (PBI), buyers are paid a monthly rebate based on the system's actual output and the program is targeted towards large commercial, government, and non-profit customers.

The focus of this thesis is to analyze cost trends and government incentives in the California PV market during 2007-2008 and to extend the work done by Wiser et al. (2006). The effects of time, learning, economies of scale, and other variables on pre-rebate system costs are analyzed under the EPBB and PBI programs. Although only two years of data are studied, the total grid-connected solar photovoltaic installed capacity more than doubled during this time period. The actual number of systems in the 2007-2008 data is comparable to the number found in Wiser et al. (2006) from 1998-2005. The results of this study can help explain the driving factors behind PV costs and also aid policymakers in making decision on how to modify solar incentives in the future.

Section 2 begins by reviewing the California Solar Initiative and presenting hypotheses about how costs should behave. Section 3 presents the data and models used in the multivariate regression analysis. Sections 4 and 5 present the results for PV systems in the EPBB and PBI programs, respectively. Section 6 compares the results of the two programs. Finally, Section 7 presents conclusions and recommendations.

2. Photovoltaic Systems in California

2.1 The California Solar Initiative

The state of California has offered rebates on PV systems since March 1998 under the ERP, which focused on systems under 30kW in size, and since July 2001 under the SGIP, which focused on systems larger than 30kW in size. By providing these incentives to lower the cost to consumers, the intention was to increase the demand for PV systems, which in turn was expected to lead to increased manufacturing efficiencies due to more production. The expectation is that over time the rebates can be eliminated as the price of photovoltaic systems decline due to learning curve effects.

Since the end of the Emerging Renewables Program and Self Generation Incentive Program in 2006, California's PV capacity has more than doubled to 440MW from 198MW[1]. Figure 1 shows the cumulative installed capacity in California from 1980 to 2008. Capacity has grown at roughly 40% per year over this period of time.

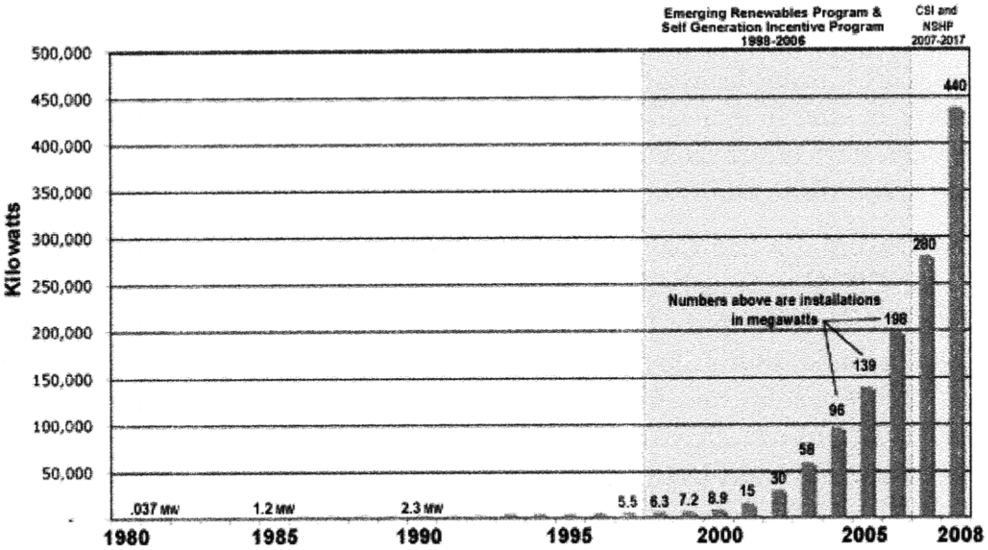

Figure 1: Cumulative Grid-Connected Photovoltaic Installed Capacity in California (Source: California Solar Energy & Statistics)

Beginning in 2007, the CPUC began administering two new incentive programs under the California Solar Initiative. These programs support facilities in investor-owned utility territories (PG&E, SCE, SDGE), which include the majority of new PV systems.

- **Expected Performance-Based Buydown:** "[Systems] smaller than 50kW in capacity can receive a one-time, up-front incentive based on expected performance, and calculated

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[1] In the data presented in Section 3, the total installed capacity from 2007-2008 totals 371MW, which is greater than the increase of 242MW shown in Figure 1 during that same time period. In Wiser et al. (2006), their data's cumulative capacity totals 253MW from 1998-2005, but Figure 1 only shows 139MW of capacity in 2005. This may be because some installed systems are not connected to the grid, which would not be included in Figure 1 above.

by equipment ratings and installation factors (geographic location, tilt and shading). EPBB payments are provided on a $ per watt basis. EPBB is available for systems under 30 KW after 2010. Systems eligible for EPBB can choose to opt-in to the PBI system described below" ("The California Solar Initiative").

- **Performance Based Incentive:** "As of January 1, 2008, all systems over 50 kW must take the PBI, and by 2010 all system over 30 kW must be on PBI. Any sized system can elect to take PBI. The PBI pays out an incentive, based on actual kWh production, over a period of five years. PBI payments are provided on a $ per kilowatt-hour basis" ("The California Solar Initiative").

The central feature of the incentive in both programs is a declining rebate over time. Rebates within each program vary depending on the system size, customer class (residential, commercial, or government), and system step, which is the cumulative capacity installed in a service area. Once the total number of megawatts of capacity is reached within a customer class and service area, the lower rebate at the next step is offered. This produces a declining rebate level over time and because service areas are differentiated, higher demand in one area does not decrease rebates in another. At any particular step, non-residential incentives are greater than residential incentives. California policymakers may have chosen this structure because non-residential systems tend to be larger and thus have a larger impact on the effort to drive down PV costs through more production. Table 1 summarizes the rebate structure of the EPBB and PBI programs.

Table 1: EPBB and PBI rebates.
(Source: California Solar Initiative)

		EPBB Payments (per Watt)			PBI Payments (per kWh)		
Step	**Statewide MW in Step**	**Residential**	**Commercial**	**Government/ Non-Profit**	**Residential**	**Commercial**	**Government/ Non-Profit**
Step 1	50	0	0	0	0	0	0
Step 2	70	$2.50	$2.50	$3.25	$0.39	$0.39	$0.50
Step 3	100	$2.20	$2.20	$2.95	$0.34	$0.34	$0.46
Step 4	130	$1.90	$1.90	$2.65	$0.26	$0.26	$0.37
Step 5	160	$1.55	$1.55	$2.30	$0.22	$0.22	$0.32
Step 6	190	$1.10	$1.10	$1.85	$0.15	$0.15	$0.26
Step 7	215	$0.65	$0.65	$1.40	$0.09	$0.09	$0.19
Step 8	250	$0.35	$0.35	$1.10	$0.05	$0.05	$0.15
Step 9	285	$0.25	$0.25	$0.90	$0.03	$0.03	$0.12
Step 10	350	$0.20	$0.20	$0.70	$0.03	$0.03	$0.10

2.2 Hypotheses

Cost reduction is important to the long term success of the solar industry and its ability to compete with other sources of electricity generation. Right now, growing energy demands and excitement over renewable energy are increasing the expectation that solar power will provide a cheap source of clean energy in the future. However, we should be careful or risk finding ourselves in the same position as in the late 1970s when high expectations failed to materialize in the following decade. If solar costs increase or fail to decrease fast enough in the near future, interest in solar may decrease, slowing down industry progress. To better understand which mechanisms are driving the changes in the cost of PV systems in California, six potentially important variables are analyzed. Hypotheses for the effects of each variable on system cost are presented below.

- **Time:** Over time, system cost is expected to decrease.
- **System size:** Larger systems are expected to cost less than smaller systems due to economies of scale.
- **Thin film technology:** Thin film technology is often cheaper on a dollars per watt basis so we expect that systems employing these types of modules are cheaper than systems with regular crystalline modules.
- **Buyer type:** The default buyer type is residential and we expect that there is no difference in system cost for government or commercial buyers.
- **Rebate:** Ideally, rebates have no effect on system cost and consumers reap all the benefits.
- **Cumulative capacity:** As cumulative capacity increases, system cost is expected to decrease because of manufacturing efficiencies derived from production volume.

3. Analysis Overview

3.1 Data & Methodology

Data for this study primarily comes from the California Solar Energy Statistics & Data website, which provides a spreadsheet on CSI-funded PV systems from January 1, 2007 to early 2009. These data include systems funded both by the EPBB program (n = 19,270) and the PBI program (n = 1,298). Only data from January 1, 2007 to December 31, 2008 are used in the regressions presented here. Table 2 summarizes the content of each program's dataset after cleaning and elimination of missing entries.

Negative or zero system costs were removed from the data. This cost restriction resulted in the removal of 552 observations in the EPBB dataset and 143 observations in the PBI data. Rather than set an arbitrary range of unrestricted system size or system cost values[2], an observation was removed if its Cook's D fell more than three standard deviations away from the dataset's mean Cook's D. This resulted in the removal of 4 observations from the EPBB dataset and 3 observations from the PBI dataset. This was consistent with elimination resulting from visual inspection. Appendix A summarizes other data cleaning procedures.

Table 2: Summary Information on Final EPBB and PBI Datasets

	EPBB	**PBI**
System Size Range[3] (kW)	0.194 - 770.723	1.342 - 1115.575
System Cost Restriction ($/W$_{AC}$)	> $0/W$_{AC}$	> $0/W$_{AC}$
Systems Restricted due to Cost Restriction	552	143
Systems Eliminated due to Outlier (Cook's D) Restriction	4	3
Total Capacity (MW)	98.7	272.7
Date Range	2007-2008	2007-2008
Observations (n)	17,072	885

EPBB and PBI datasets were analyzed separately because each program has unique rebate characteristics that can affect PV system costs. To study the effect of the independent variables on the dependent variable, pre-rebate system cost, Ordinary Least Squares regressions were performed under various models. Robust standard errors were used to account for the presence of heteroskedasticity in the data. Furthermore, variance inflation factors were calculated for each model to prevent multicollinearity issues. This thesis focuses on four models for each of the EPBB and PBI datasets. In Model 1, only certain control variables are regressed against system cost. In Model 2, other variables are introduced into the regression. In Model 3, cumulative capacity replaces time. Model 4 examines the interaction effects of thin film technology and time.

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[2] Wiser et al. (2006) restricted system cost to $4-30/W$_{AC}$.

[3] Although systems eligible for the EPBB program are supposed to be under 50kW in size and systems eligible for the PBI program are supposed to be greater than 50kW in size, both datasets contain systems that fall outside of these ranges. According to a CSI representative, program administrators can choose to allow systems outside of the specified criteria into a program at their discretion.

Three models (Models W1, W2, and W3) analogous to Models 1, 2, and 3 are found in Wiser et al. (2006), and are included in Appendix C. The fourth model was not included after finding insignificant results due to multicollinearity when including many interaction variables.

3.2 Variables

The dependent variable for all the models is the pre-rebate system cost, which is measured in $\$/W_{AC}$. All dollar values in the analysis are converted to January 2007 dollars using the monthly Consumer Price Index (CPI). The independent variables used in the models are described below and modeled after Wiser et al. (2006). Table 2 lists the independent variables used in each model and Table 3 contains their summary statistics.

- **Date of Application**: Both datasets include a variable for Reservation Request Review Date, which is used as the TIME_MONTH variable after being converted into months (1, 2, 3... 24).
- **System Size:** The system size variable is represented by CEC PTC rating (in kW) in both datasets[4]. In the models, LN_SYSTEM_SIZE is the natural log of the CEC PTC rating in watts. This transformation was used to ensure a linear relationship with the dependent variable.
- **Cumulative Capacity:** CUMUL_CAPACITY measures the total new installed capacity (in kW) in California beginning January 1, 2007 under the EPBB and PBI programs, respectively. It is used in models without the TIME_MONTH variable to prevent collinearity issues. This variable was constructed by numbering each system within a dataset chronologically and then calculating the cumulative capacity at that time.
- **Rebate Variables:** The EPBB_REBATE and PBI_REBATE variables are in $/W and $/kWh, respectively, and are based on the CSI rebate structure steps. The EPBB program rebate is a lump sum payment based on the expected maximum system output. It is more difficult to interpret the results of rebates in the PBI program because it is a monthly payment based on the actual system output, which is impossible for us to forecast.
- **Thin Film**: The binary THIN_FILM variable is equal to 1 if a PV system uses thin film modules instead of crystalline silicon technology.
- **Buyer Type:** Dummy variables are included for commercial and government systems to observe any potential differences compared to residential system costs.

The following variables are controls.

- **System Location, Population Density**: Dummy variables are used to study if systems installed in the SCE or SDGE areas are different from systems located in the PG&E area. We do not hypothesize whether the effects are positive or negative in each case. In case differences do exist, a population density variable (SQRT_POP_DENSITY in units of square root of residents per square mile) is included in the model.

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[4] The CEC PTC rating is defined as the inverter efficiency multiplied by the module PTC rating. The module PTC rating is always less than the module STC rating, which is the number used when people refer to system size by kW_p or W_{DC}.

- **Retail Rates**: The effect of average monthly retail electricity rates (cents/kWh) in California, obtained from the EIA, is also observed in the models ("Electric Power Annual Data Tables"). There are different rates for residential, commercial, and government users.
- **Installation Status:** Dummy variables are included for approved (EPBB & PBI) and waitlisted (EPBB only) systems to observe any potential differences compared to completed system costs.
- **Installer Experience**: The installer experience is a dummy variable which is 1 if the installer is among the top 5% of system installers in the dataset as measured by total number of systems installed. There may be other ways to measure installer experience but this was the method used by Wiser et al. (2006). It is possible that experienced installers may be able to set lower costs depending on knowledge they have acquired that can reduce their own costs.
- **Module Cost Index**: The monthly solar module index from Solarbuzz (www.solarbuzz.com) is included to determine how system cost varies with the module cost. Module costs can account for more than 50% of the system cost (Henderson 2007).

Table 3: Summary of Independent Variables

Variable Name	Units	EPBB	PBI	Definition
TIME_MONTH	1, 2, 3… 24	X	X	Month of application reservation request review date; January 2007 is month 1, February 2007 is month 2, etc.
LN_SYSTEM_SIZE	$\ln(W_{AC})$	X	X	The natural log of system size in watts as given by the CEC-PTC rating.
CUMUL_CAPACITY	MW	X	X	The cumulative capacity in each program at a certain point/new system in time.
PBI_REBATE	$/kWh		X	The monthly payment for system in the PBI program based on system output.
EPBB_REBATE	$/W	X		The lump sum payment for systems in the EPBB program.
COMMERCIAL	Binary	X	X	1 if commercial buyer, 0 otherwise.
GOVERNMENT	Binary	X	X	1 if government buyers 0 otherwise.
THIN_FILM	Binary	X	X	1 if system uses thin film technology, 0 otherwise.
RETAIL_RATES	cents/kWh	X	X	Average monthly retail electricity rate in California, which depends on buyer type.
APPROVED	Binary	X	X	1 if system is approved and not completed, 0 otherwise.
WAITLISTED	Binary	X		1 if system is waitlisted and not completed, 0 otherwise.
SCE	Binary	X	X	1 if system is in SCE's service area, 0 otherwise.
SDGE	Binary	X	X	1 if system is in SDGE's service area, 0 otherwise.
INSTALLER_EXPERIENCE	Binary	X	X	1 if the installer is among the top 5% of system installers in the dataset as measured by total number of systems installed, 0 otherwise.
SQRT_POP_DENSITY	persons/mi^2	X	X	Square root of the population density by ZCTA or zip code.
MODULE_COST_INDEX	$/W	X	X	Monthly solar module index from Solarbuzz

Table 4: Summary Statistics of Variables

		EPBB (n = 17,072)				PBI (n = 885)			
Continuous Variables	**Units**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Mean**	**Std. Dev.**	**Min**	**Max**
SYSTEM_COST	$\$/W_{AC}$	10.18	4.01	0.84	324.72	9.06	2.19	0.18	32.52
TIME_MONTH	1,2,3...24	14.65	6.45	1.00	24.00	10.91	6.98	1.00	24.00
LN_SYSTEM_SIZE	$\ln(W_{AC})$	8.34	0.61	5.27	13.56	11.35	1.78	7.20	13.92
CUMUL_CAPACITY	MW	52,049	27,845	31	98,714	141,387	79,504	1,001	272,686
EPBB_REBATE	$/W	2.19	0.30	1.10	5.57	N/A			
PBI_REBATE	$/kWh	N/A				0.31	0.07	0.16	0.76
RETAIL_RATES	cents/kWh	14.91	0.95	11.48	16.44	13.33	1.64	11.48	16.44
SQRT_POP_DENSITY	persons/mi^2	32.53	26.95	1.30	166.02	31.74	23.09	0.00	145.45
MODULE_COST_INDEX	$/W	5.05	0.09	4.88	5.21	5.01	0.10	4.88	5.21
Dummy Variables		**Mean**	**Std. Dev.**	**Count**	**%**	**Mean**	**Std. Dev.**	**Count**	**%**
COMMERCIAL	Binary	0.07	0.26	1260	7%	0.65	0.48	576	65%
GOVERNMENT	Binary	0.01	0.11	227	1%	0.11	0.32	101	11%
THIN_FILM	Binary	0.08	0.27	1362	8%	0.11	0.31	94	11%
APPROVED	Binary	0.30	0.46	5154	30%	0.77	0.42	679	77%
WAITLISTED	Binary	0.02	0.13	316	2%	N/A			
SCE	Binary	0.24	0.43	4094	24%	0.40	0.49	353	40%
SDGE	Binary	0.09	0.28	1516	9%	0.15	0.36	136	15%
INSTALLER_EXPERIENCE	Binary	0.69	0.46	11855	69%	0.52	0.50	461	52%

4. Analysis Results: EPBB Systems

4.1 Summary Statistics

Figure 2 shows the mean installed cost in the EPBB program and module cost index over time. There is a noticeable increase in the system cost over this time period, which includes 17,072 systems and 98.7MW of capacity. In the last quarter of 2008, costs begin to decline. The behavior of system cost seems closely related to the module cost index during this period. In Wiser et al. (2006), there is a similar but weaker finding for the effect of module cost index on system cost in the CEC program (under 30kW in size). However, they find that costs decrease during the 1998-2005 period on average. In 2007-2008, the cost of PV systems in the EPBB seems to be rising. This suggests a strong relationship between module cost and system cost.

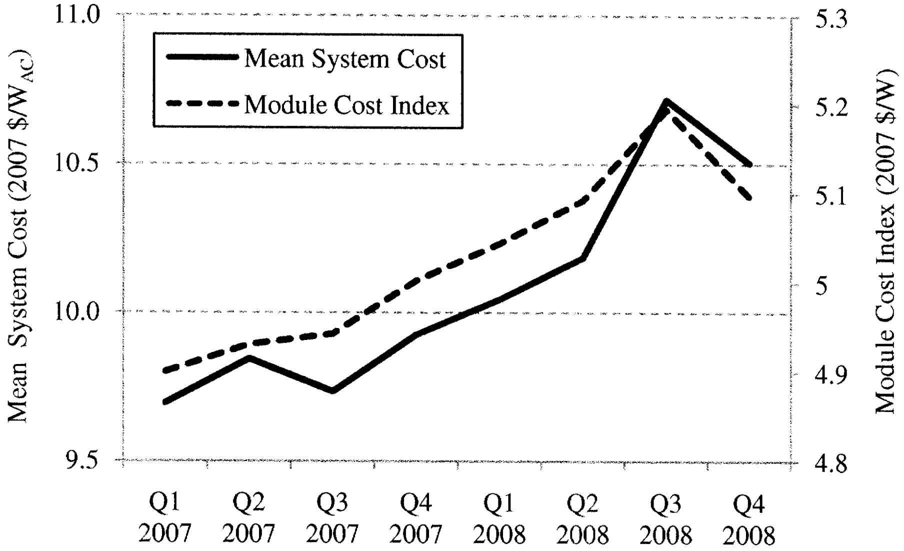

Figure 2: Mean system cost and module cost index over time (EPBB).

From 2007-2008, larger systems are less expensive on a per watt basis, suggesting that there are economies of scale present in PV systems installed under the EPBB program. Figure 3 shows the mean pre-rebate system cost of PV systems in the EPBB program bucketed by system size. Error bars represent one standard deviation in the data. It appears that as the system size increases, the mean cost of the system (measured in $/W$_{AC}$) decreases. This is similar to the finding by Wiser et al. (2006) for systems under 30kW in size in the CEC program. These economies of scale are present possibly because the cost of installation, inverters, and other non-module costs may represent a larger proportion of the costs of smaller systems.

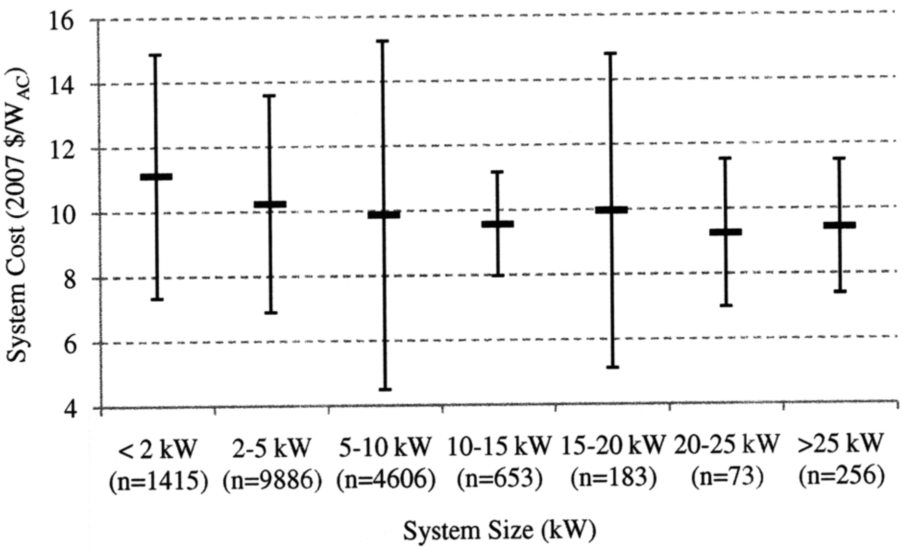

Figure 3: Mean system cost by system size, 2007-2008 (EPBB).

Figure 4 shows that thin film systems are more expensive than crystalline systems in the EPBB dataset. Thin film systems have a mean cost of $\$10.42/W_{AC}$, which is greater than the $\$10.16/W_{AC}$ for crystalline systems. This difference is surprising, but consistent with the behavior found in small systems (< 10 kW) installed in 2006-2007 by Wiser et al. (2009)[5]. In our data, the mean system cost for thin film systems less than 10 kW in size (n = 1260) is $\$10.44/W_{AC}$, which is also greater than the cost for crystalline systems.

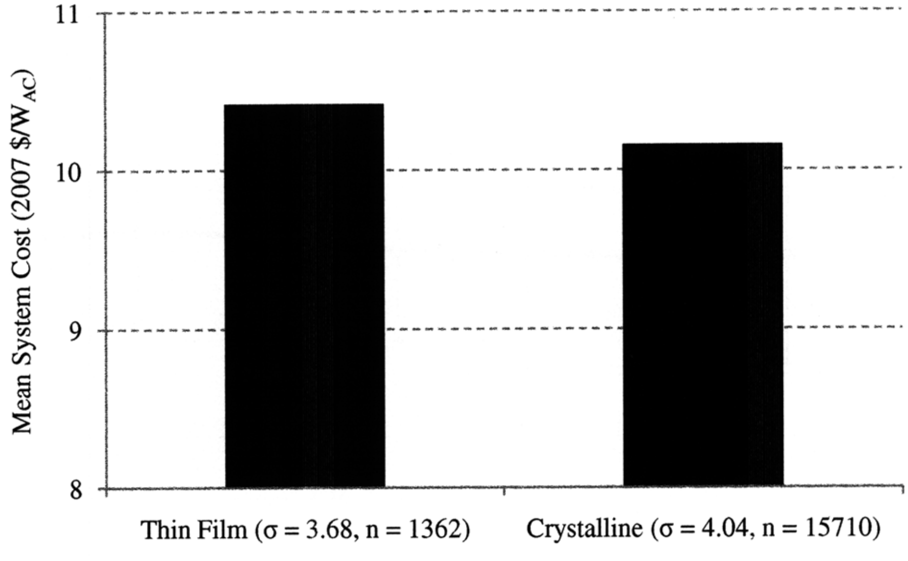

Figure 4: Mean system cost by system technology, 2007-2008 (EPBB).

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[5] Wiser et al.'s 2009 findings are based on a survey of installed costs in nine states including California. Although California represents over 80% of the installed capacity in their data, the behavior of solar costs in other states may prevent any significant conclusions from direct comparison with our regression results.

Figure 5 shows the mean system cost by buyer type. Residential buyers (\$10.09/W_{AC}) and government buyers (\$10.07/W_{AC}) pay approximately the same system cost while commercial buyers must pay significantly more (\$11.24/W_{AC}).

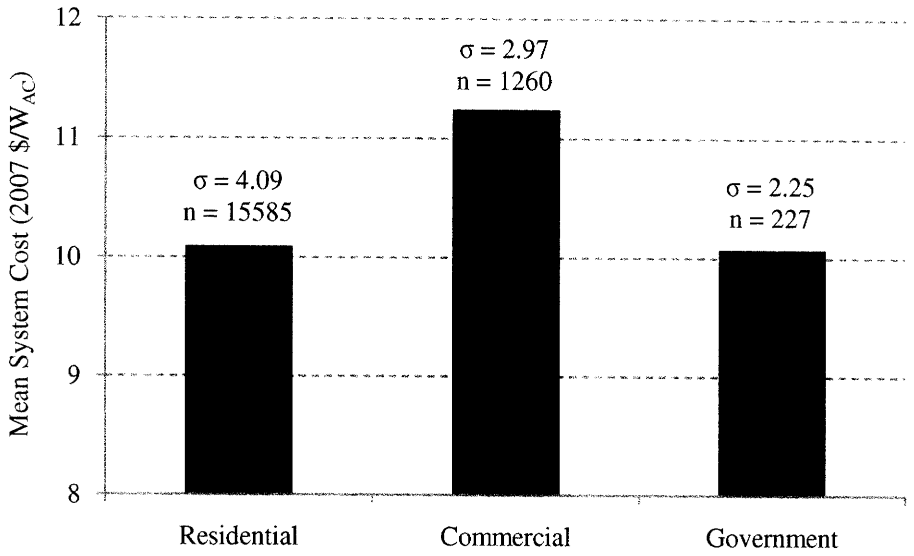

Figure 5: Mean system cost by buyer type, 2007-2008 (EPBB).

Figure 6 shows the mean system cost within a given range of cumulative capacity. It appears that as more systems were installed from 2007-2008 and capacity increased, the mean system cost slightly increased. Error bars represent one standard deviation in the data.

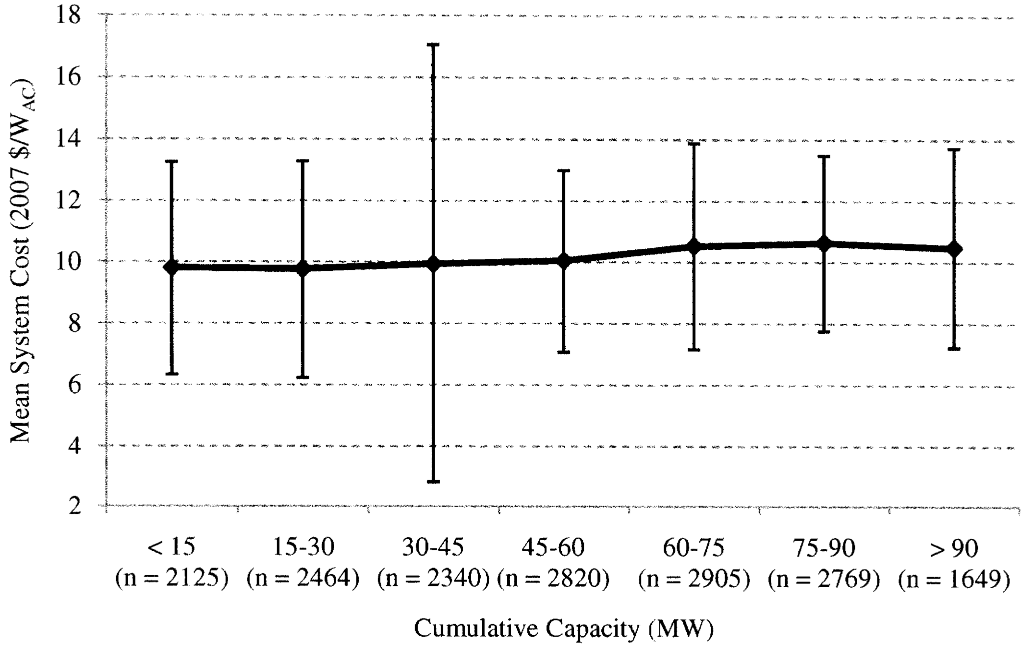

Figure 6: Mean system cost by MW of cumulative capacity, 2007-2008 (EPBB).

4.2 Regression Results

Table 5 summarizes the regression results for Models 1-4. Except for Model 1, which only tests control variables, the R^2 values of the models are very small, ranging from 0.025 to 0.027. This is because we placed a weaker restriction on what we considered an outlier by using Cook's D (see Section 3.1). If we had removed the 13 observations in the EPBB dataset that had systems costs greater than $\$50/W_{AC}$, the R^2 would be approximately 0.116 for Model 2a (same as Model 2 but with system costs < $\$50/W_{AC}$). However, the coefficients and p-values are essentially the same in both cases so Model 2 is chosen. Appendix B compares the results of Model 2 with Model 2a. Appendix C presents results from Models W1, W2, and W3, which are analogous to the models found in Wiser et al. (2006).

Table 5: Regression results for EPBB dataset (Models 1, 2, 3, and 4).

Variable	Model 1		Model 2		Model 3		Model 4	
	coef.	*p*	*coef.*	*p*	*coef.*	*p*	*coef.*	*p*
Intercept	-6.516	< 0.01	0.735	0.764	0.663	0.776	0.707	0.769
TIME_MONTH			0.020	0.022			0.020	0.017
LN_SYSTEM_SIZE			-0.702	< 0.01	-0.700	< 0.01	-0.702	< 0.01
CUMUL_CAPACITY					0.000	0.010		
EPBB_REBATE			0.728	< 0.01	0.737	< 0.01	0.730	< 0.01
COMMERCIAL			1.446	< 0.01	1.451	< 0.01	1.447	< 0.01
GOVERNMENT			0.467	< 0.01	0.460	< 0.01	0.467	< 0.01
THIN_FILM			0.332	< 0.01	0.332	< 0.01	0.256	0.210
RETAIL_RATES	-0.091	< 0.01	0.008	0.798	0.010	0.738	0.008	0.791
APPROVED	0.217	< 0.01	0.257	< 0.01	0.246	< 0.01	0.258	< 0.01
WAITLISTED	-0.467	< 0.01	-0.313	0.059	-0.318	0.055	-0.314	0.058
SCE	0.053	0.319	-0.060	0.284	-0.068	0.235	-0.061	0.283
SDGE	-0.168	< 0.01	-0.314	< 0.01	-0.318	< 0.01	-0.315	< 0.01
INSTALLER_EXPERIENCE	0.064	0.320	0.022	0.739	0.023	0.728	0.022	0.737
SQRT_POP_DENSITY	0.008	< 0.01	0.004	< 0.01	0.004	< 0.01	0.004	< 0.01
MODULE_COST_INDEX	3.505	< 0.01	2.567	< 0.01	2.577	< 0.01	2.573	< 0.01
THIN_FILM x TIME_MONTH							0.005	0.748
R-SQUARED	0.012		0.027		0.027		0.027	
OBSERVATIONS (n)	17,072		17,072		17,072		17,072	

4.2.1 The Effect of Time

Models 2 and 4 suggest that the average monthly pre-rebate system cost has increased by $\$0.02/W_{AC}$ per month from 2007-2008, which is equivalent to an annual increase of $\$0.24/W_{AC}$. At the mean system cost of $\$10.18/W_{AC}$, this represents a 2.36% annual increase (real rate) in pre-rebate system cost.

Average module costs have a significant effect on the pre-rebate cost of PV systems. The coefficient for MODULE_COST_INDEX in Models 2, 3, and 4 is approximately 2.57 and statistically significant in all cases. An interpretation of the coefficient is that if the module cost increased by $0.10/W, sellers of PV systems would increase the pre-rebate system cost by $0.26/W. This reflects the fact that sellers must make a certain margin on the PV systems to be profitable. It is important to note that the module cost index only varied by \$0.33/W during 2007-2008.

Wiser et al. (2009) found that installed costs were relatively stable in 2006 and 2007 following a decline from 1998-2005. Our data and models show that pre-rebate system costs increased from 2007-2008 with the sharpest increase in Q3 of 2008. Figure 3 shows that system cost declined in Q4 of 2008, which may have been due to a decrease in module costs.

4.2.2 The Effect of System Size

Larger systems are less expensive than smaller systems as shown in Models 2, 3, and 4. The coefficients in each of these models for LN_SYSTEM_SIZE are nearly identical and statistically significant. However, it is difficult to directly interpret the meaning of this coefficient without taking the anti-log of the coefficient. Figure 7 shows the predicted system cost under Model 2 in untransformed space as system size is varied and the mean value is used for all other variables[6].

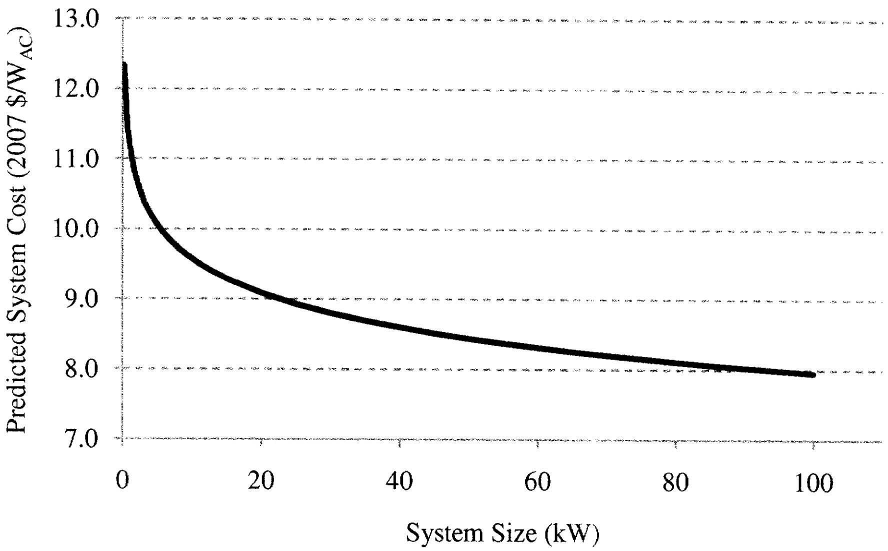

Figure 7: Predicted system cost as a function of system size (EPBB).

Economies of scale are clearly present in the data which drives the behavior of the curve shown in Figure 7. Systems smaller than 20kW are substantially more expensive than larger systems. The mean system cost of \$10.18/W_{AC} corresponds to a system size of 4.2kW in the EPBB data.

4.2.3 The Effect of Thin Film Technology

Systems employing thin film technology are more expensive than crystalline systems in the EPBB dataset. Models 2 and 3 suggest that thin film systems cost \$0.332/W_{AC} more than

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[6] There were only 6 systems in the EPBB dataset ranging from 100-770.723kW in size. The predicted values were not plotted for this range due to low confidence in the sparse data.

crystalline systems of the same size. Wiser et al.'s 2009 paper also found some evidence that thin film technology increased the cost of small systems (< 10kW) in 2007. They explain that it is possible that "lower efficiency of thin-film modules leads to higher balance of system costs..." This explanation begs the question – shouldn't installers know that using thin film technology will lead to higher balance of system costs? One possibility is that installers make errors when predicting the final system cost. Another explanation is that installers do know that thin film systems are more expensive but customers do not care due to some reason not captured in the data.

This result is a mystery considering that thin film systems in the CEC program (< 30kW) were approximately $\$0.73/W_{AC}$ cheaper than crystalline systems from 1998-2005 (Wiser et al. 2006). Further research is necessary to determine why the effect of thin film technology changed after 2005.

4.2.4 The Effect of Buyer Type

Models 2, 3, and 4 shows that commercial and government customers had to pay more than residential customers for PV systems. The statistically significant coefficients suggest that government customers paid approximately $\$0.47/W_{AC}$ more and commercial buyers paid approximately $\$1.45/W_{AC}$ more. Figure 5 showed that the actual differences among the mean system costs faced by these buyers were present but less pronounced than the model suggests.

One possible explanation is that commercial buyers derive a tax benefit from the depreciation of their PV system and a 30% federal tax credit. Sellers could potentially take advantage of this knowledge by charging a higher price to commercial buyers who are willing to pay the higher upfront cost because it will be compensated by tax benefits later. Residential buyers could also receive a 30% tax benefit but it was capped at $2000. This law changed starting in 2009. It is unclear why government buyers faced a higher cost.

4.2.5 The Effect of the EPBB Rebate

The coefficient for the EPBB_REBATE variable in Models 2, 3, and 4 is approximately 0.73 and statistically significant. This suggests that retailers lower their prices slower than the rate of the decline in the rebate. In the case of the declining EPBB rebate structure, the result suggests that when the rebate decreases by $\$1/W_{AC}$, the retailer decreases his price by $\$0.73/W_{AC}$. This can be due to the inability or reluctance to lower prices quickly. So while lowering rebates in the CSI may help to reduce prices in the long run, the effect is slower than desired.

This result is consistent with the finding among systems in the CEC program (< 30kW) by Wiser et al. (2006). In fact, the rebate coefficient is also 0.73 in their Model 2. However, the CEC rebate sometimes increased over time so another interpretation was that when the rebate increased by $\$1/W_{AC}$, the retailer increased his price by $\$0.73/W_{AC}$. Thus, the consumer only received $\$0.27/W_{AC}$ in savings while the retailer captured $\$0.73/W_{AC}$. This suggested that consumers do not benefit from the full amount of an increase in the rebate because it is partially captured by the retailer. Although we cannot observe any increase in the rebate over time in the EPBB data, it seems that the same phenomenon would be true.

4.2.6 The Effect of Cumulative Capacity

The statistically significant coefficient of 0.000 for CUMUL_CAPACITY in Model 3 suggests that cumulative capacity has no effect on system cost. Qualitative examination of Figure 6 shows that any effect might be to increase rather than decrease system cost. This result is unintuitive because we expect that manufacturing efficiencies derived from learning and production volume will decrease system costs. Our finding may have risen from the construction of the cumulative capacity variable, which measures capacity across PV systems in all of California. A better variable could calculate cumulative capacity by region (service area or zip code) or by retailer/installer. In the latter case, we would expect that retailers/installers with more experience could charge lower prices based on cost-cutting measures they have learned. However, all four models have a positive coefficient for INSTALLER_EXPERIENCE (though not statistically significant). It is possible that more reputable companies find that consumers are willing to pay more for their expertise or reputation.

4.2.7 Service Area, Population Density, Retail Rates, and System Status

Compared to the base service area of PG&E, systems installed in the SDGE and SCE areas have lower system costs. Systems located in SDGE's service area are approximately \$0.32/W_{AC} cheaper. We find that systems located in the SCE service area are marginally cheaper (by 6-7 cents/W_{AC}), but the result is not statistically significant. Both findings are consistent in with Wiser et al. (2006) but it is interesting that our SCE variable is not significant. However, nothing present in the data allows us to explain the system cost differences in these service areas.

The coefficient for SQRT_POP_DENSITY is slightly positive and statistically significant. Wiser et al. (2006) find a similar result in CEC program systems (< 30kW) and suggest that "population density may be a proxy for the cost of living, and therefore labor costs. One would expect smaller systems to generally be more sensitive to labor costs than larger systems, because small systems likely require a greater proportional amount of installation labor."

Retail rates do not have a statistically significant effect on system cost. The positive coefficient can imply that as retail rates for electricity increases, people may be more willing to buy PV systems, which would allow sellers to increase their prices. Wiser et al. (2006) find a similar, non-significant result.

Relative to completed systems, approved systems cost approximately \$0.26/W_{AC} more and waitlisted systems cost approximately \$0.31/W_{AC} less. Whether or not this is of interest to the consumer is dependent on when the final cost is determined and paid for. If the price of the PV system is only an estimate while it is waitlisted or approved (but incomplete) then the differences can be attributed to unknown external factors that affect system cost over time.

5. Analysis Results: PBI Systems

5.1 Summary Statistics

Figure 8 shows the mean installed cost in the PBI program and module cost index over time. There is a volatile increase in the system cost over this time period, which includes 885 systems and 272.7MW of capacity.

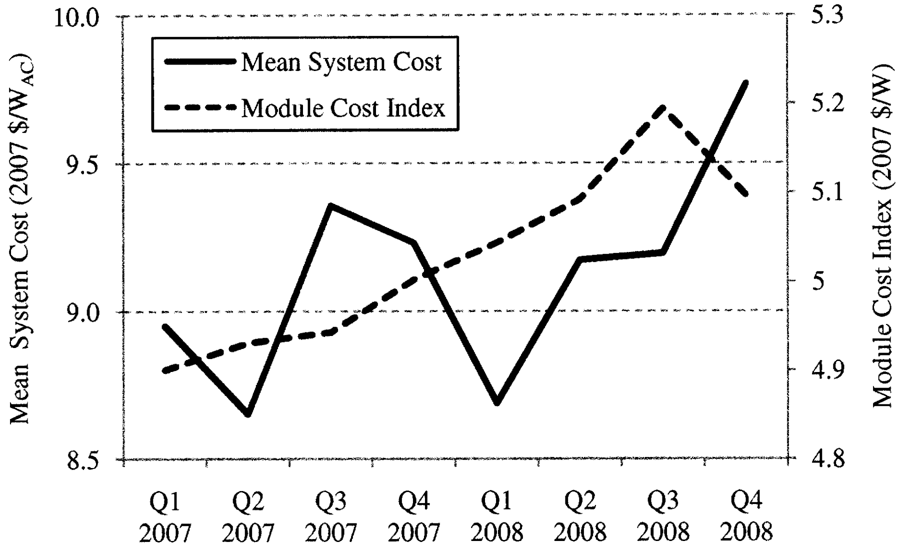

Figure 8: Mean system cost and module cost index over time (PBI).

From 2007-2008, there appears to be economies of scale present in PV systems installed under the PBI program. Figure 9 shows the mean pre-rebate system cost of PV systems in the PBI program bucketed by system size. Error bars represent one standard deviation in the data. It appears that as the system size increases, the mean cost of the system (measured in $/W$_{AC}$) decreases. This is similar to the finding by Wiser et al. (2006) for larger systems in the CPUC program.

Fundamental differences exist between system cost in the PBI and EPBB programs. Figure 10 shows the mean pre-rebate system cost of PV systems in the PBI and EPBB programs for different system sizes. Economies of scale exist with larger systems being cheaper than smaller systems. On average, the systems in the PBI program are cheaper than systems in the EPBB program. However, this is not always the case when considering similar size systems (see graph inset). In this case, EPBB systems from 5-50kW in size seem to be cheaper than comparable PBI systems. This result is surprisingly similar to the findings by Wiser et al. (2006) concerning the CEC and CPUC programs.

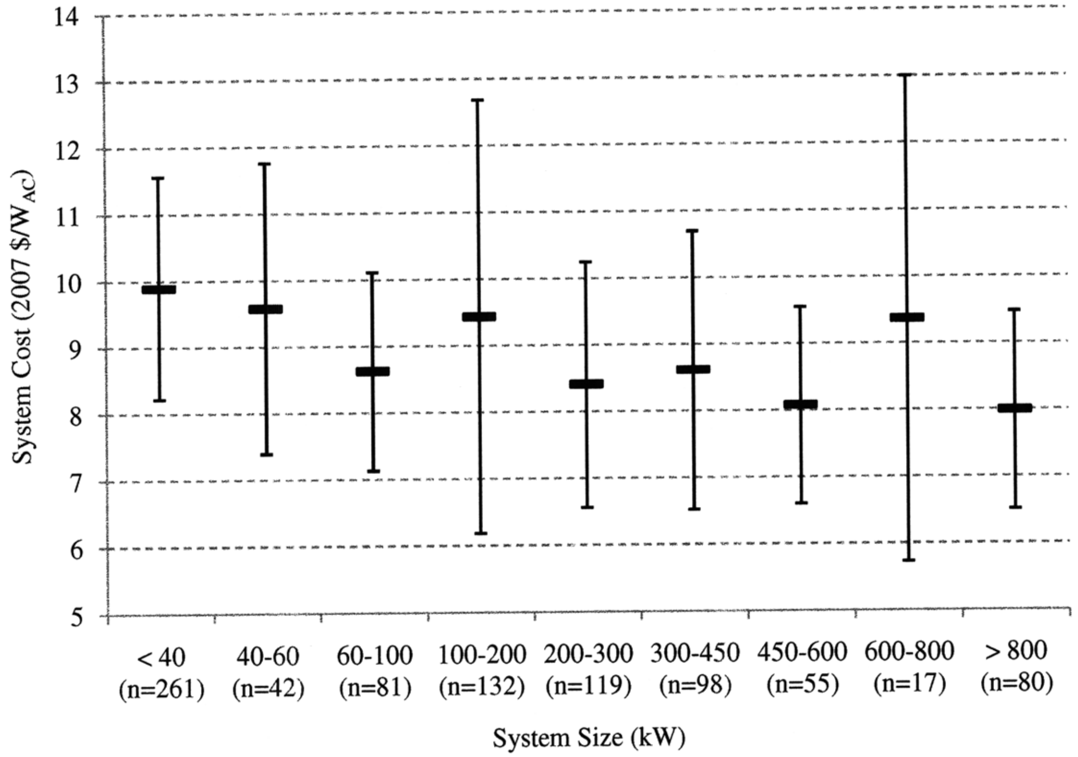

Figure 9: Mean system cost by system size, 2007-2008 (PBI).

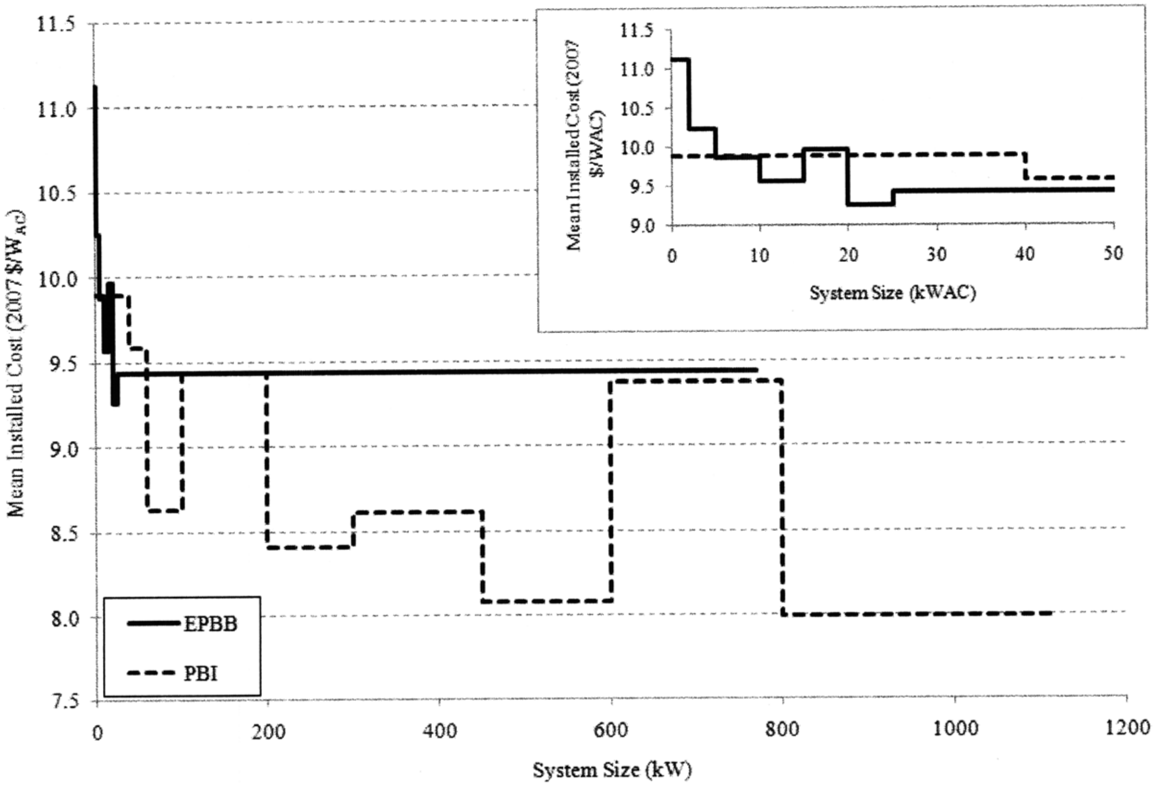

Figure 10: Mean system cost by size (EPBB & PBI).

Figure 11 shows that thin film systems cost less than crystalline systems in the PBI dataset. Thin film systems have a mean cost of \$8.74/W_{AC}, which is less than the \$9.09/W_{AC} for crystalline systems. This difference is inconsistent with the behavior found in systems greater than 10kW in size installed during 2006-2007 by Wiser et al. (2009). They find that costs are marginally greater for thin film systems.

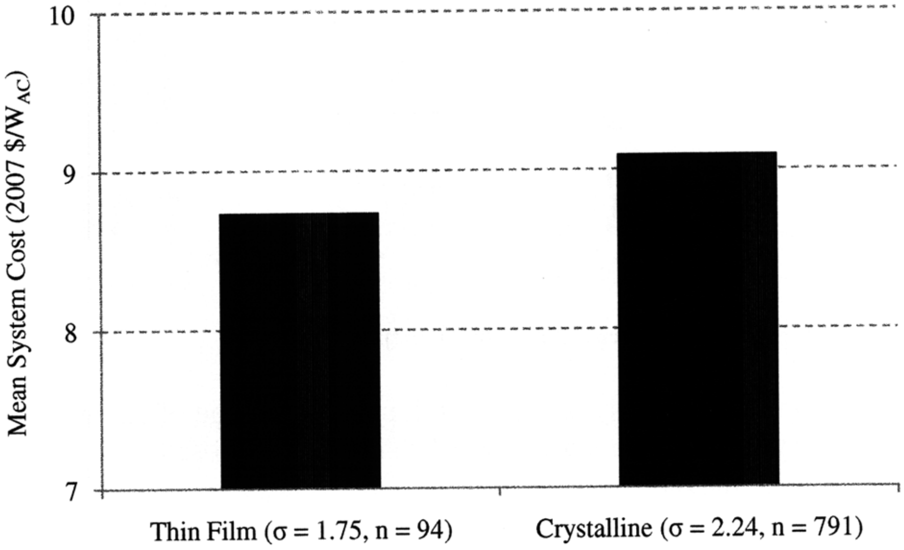

Figure 11: Mean system cost by system technology, 2007-2008 (PBI).

Figure 12 shows the mean system cost by buyer type. Residential buyers (\$10.06/W_{AC}) face higher costs than government buyers (\$9.58/W_{AC}) and significantly greater costs than commercial buyers (\$8.60/W_{AC}). For EPBB systems, we considered the possibility that commercial buyers' tax benefits could lead to sellers charging higher prices, but that is clearly not plausible in this situation.

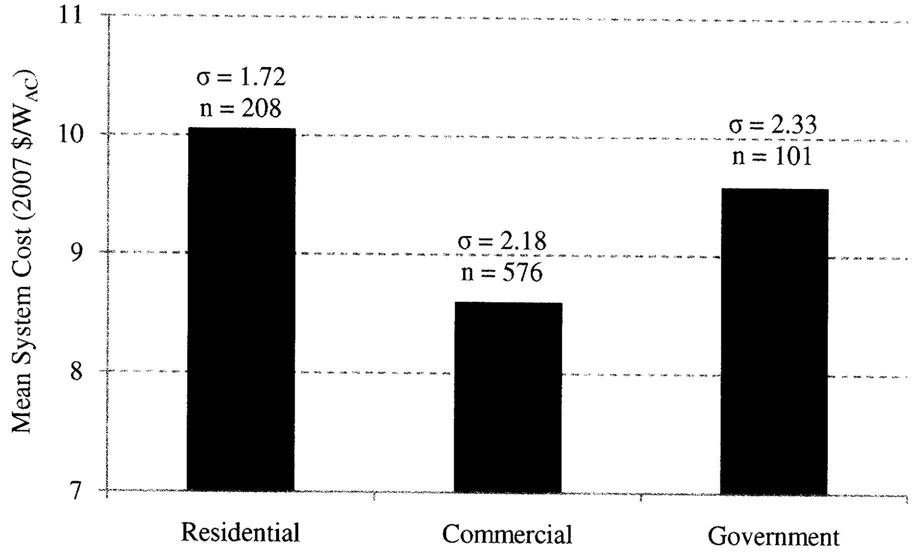

Figure 12: Mean system cost by buyer type, 2007-2008 (PBI).

Figure 13 shows the mean system cost within a given range of cumulative capacity. It is difficult to discern any trend in the system cost behavior, which oscillates. Error bars represent one standard deviation in the data.

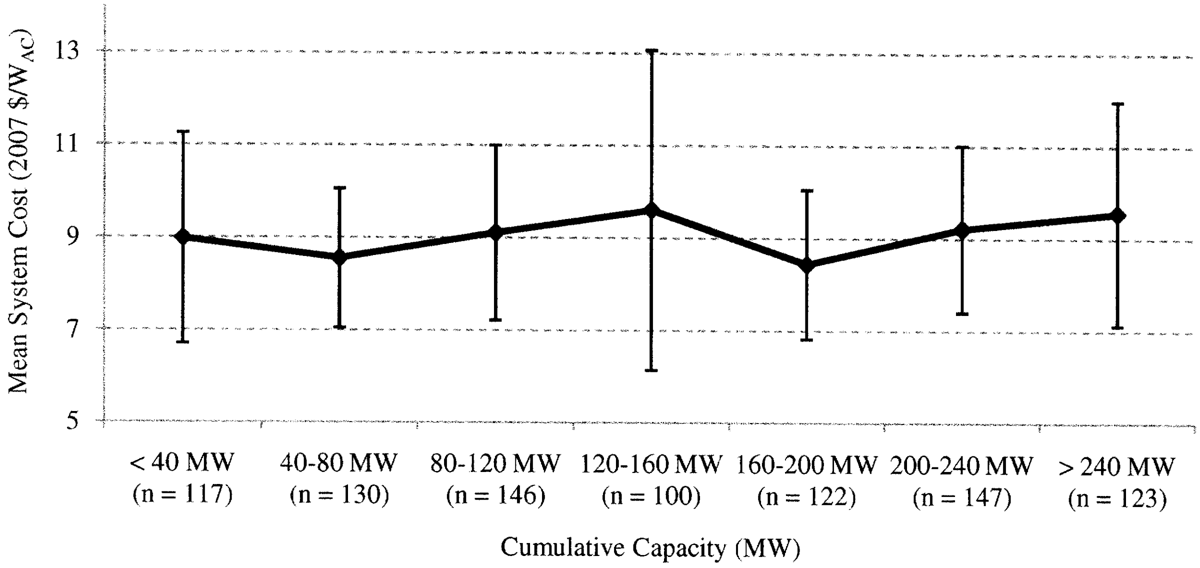

Figure 13: Mean system cost by MW of cumulative capacity, 2007-2008 (PBI).

5.2 Regression Results

Table 5 summarizes the regression results for Models 1-4. The R^2 values of the models range from 0.091 to 0.163. Although the models explain only a small part of the variation in the data, many of the results are statistically significant and useful for analyzing trends in PV system costs. In some cases, the size of the dataset does seem to limit the robustness of the model and we weigh these results with less emphasis than the EPBB results. Appendix C includes the results from Models W1, W2, and W3.

Table 6: Regression results for PBI dataset (Models 1, 2, 3, and 4).

Variable	Model 1		Model 2		Model 3		Model 4	
	coef.	*p*	*coef.*	*p*	*coef.*	*p*	*coef.*	*p*
Intercept	7.367	0.062	16.186	0.108	9.661	0.284	18.241	0.071
TIME_MONTH			0.034	0.256			0.030	0.305
LN_SYSTEM_SIZE			-0.272	< 0.01	-0.273	< 0.01	-0.288	< 0.01
CUMUL_CAPACITY					0.000	0.700		
PBI_REBATE			2.218	0.053	1.781	0.124	2.148	0.050
COMMERCIAL			-0.133	0.670	-0.196	0.532	-0.072	0.819
GOVERNMENT			0.493	0.149	0.497	0.146	0.583	0.092
THIN_FILM			-0.200	0.294	-0.214	0.265	-0.924	< 0.01
RETAIL_RATES	0.225	< 0.01	0.030	0.600	0.024	0.672	0.018	0.748
APPROVED	0.713	< 0.01	0.483	0.010	0.476	0.011	0.488	< 0.01
SCE	-0.671	< 0.01	-0.685	< 0.01	-0.688	< 0.01	-0.677	< 0.01
SDGE	-0.624	< 0.01	-0.684	< 0.01	-0.684	< 0.01	-0.695	< 0.01
INSTALLER_EXPERIENCE	-0.642	< 0.01	-0.600	< 0.01	-0.604	< 0.01	-0.592	< 0.01
SQRT_POP_DENSITY	0.000	0.982	0.003	0.314	0.003	0.316	0.003	0.237
MODULE_COST_INDEX	-0.230	0.787	-1.040	0.617	0.364	0.847	-1.386	0.506
THIN_FILM x TIME_MONTH							0.085	< 0.01
R-SQUARED	0.091		0.156		0.155		0.163	
OBSERVATIONS (n)	885		885		885		885	

5.2.1 The Effect of Time

The positive coefficient of TIME_MONTH and the volatile rising behavior of system cost in Figure 8 suggest that the price of PV systems in the PBI program has increased over time. In contrast, Wiser et al. (2006) find that systems in the PBI program (> 30kW) demonstrate an average annual decline of \$0.36/W_{AC} during 1998-2005. What is more surprising in our results is that module costs seem to drive system cost down in Models 2 and 4, which is inconsistent with the hypothesis. However, these results are not statistically significant and may be due to the limitations of a small dataset.

5.2.2 The Effect of System Size

Larger systems are less expensive than smaller systems as shown in Models 2, 3, and 4. The coefficients in each of these models for LN_SYSTEM_SIZE are nearly identical and statistically significant. However, it is difficult to directly interpret the meaning of this coefficient without taking the anti-log of the coefficient. Figure 14 shows the predicted system cost under Model 2 in untransformed space as system size is varied and the mean value is used for all other variables. The EPBB program's predicted system cost curve is also shown for comparison.

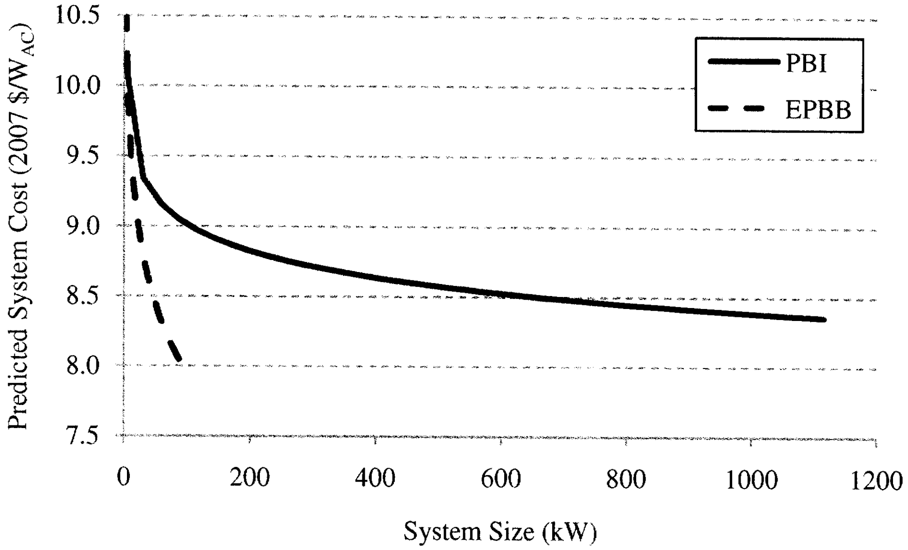

Figure 14: Predicted system cost as a function of system size (EPBB & PBI).

Economies of scale are clearly present in the data which drives the behavior of the PBI curve shown in Figure 14. Systems smaller than 100kW are substantially more expensive than larger systems although EPBB systems are systematically cheaper. The mean PBI system cost of $\$9.06/W_{AC}$ corresponds to a system size of 84.7kW in the PBI data.

5.2.3 The Effect of Thin Film Technology

The THIN_FILM and THIN_FILM x TIME_MONTH variables in Model 4 show that thin film systems were cheaper than crystalline systems at the start of 2007 but then became more expensive as time went on. Initially, thin film systems were $\$0.924/W_{AC}$ cheaper than crystalline systems but their cost then rose by $\$0.085/W_{AC}$ each month. This behavior is shown in Figure 15, which compares the predicted system cost by module technology over time.

On average, the negative THIN_FILM coefficients in the models suggest that thin film systems were cheaper during 2007-2008. For larger systems, Wiser et al. (2009) found that thin film systems were more expensive than crystalline systems in 2007, which is different from our results. It is possible that the increasing cost of thin film systems is due to increased demand generated by consumers choosing not to buy crystalline modules, whose costs rose on average from 2007 to 2008.

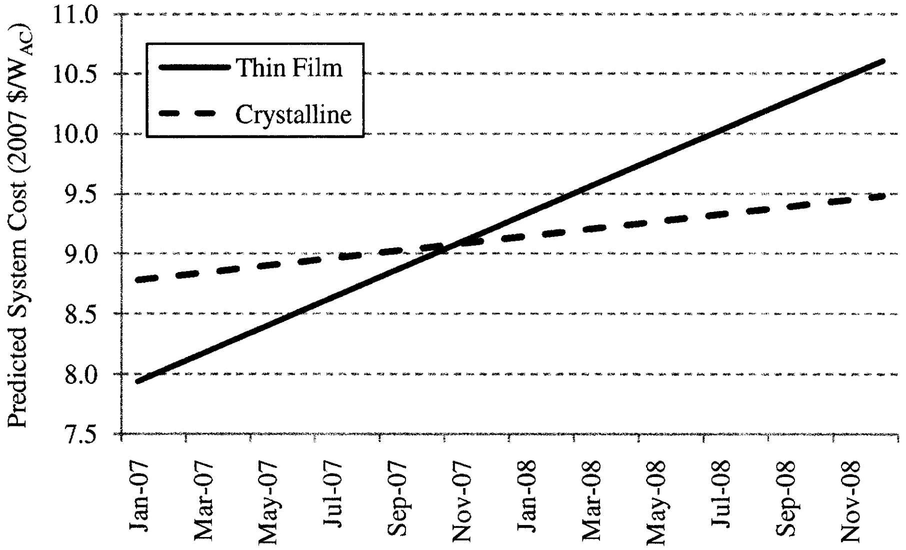

Figure 15: Comparison of predicted system cost by module technology over time (PBI).

5.2.4 The Effect of Buyer Type

The coefficients for commercial and government buyers are not statistically significant and do not support the observations of the dataset shown in Figure 12. In the dataset, the mean system cost is greatest for residential buyers followed by government buyers and then commercial buyers. However, Models 2 and 3 suggest that government buyers pay more than residential buyers who pay more than commercial buyers.

5.2.5 The Effect of the PBI Rebate

The coefficient for PBI_REBATE in Models 2 and 4 is approximately 2.2 and significant at the 10% level. It is more difficult to interpret the meaning of the PBI_REBATE coefficient because the rebate is paid monthly over five years based on the actual PV system output. Figure 16 shows the predicted system cost under Model 2 as the PBI rebate is varied and the mean value is used for all other variables. This finding is consistent with the rebate effect found in the EPBB dataset, which suggests that PV system providers are absorbing some of the consumer rebate through higher prices.

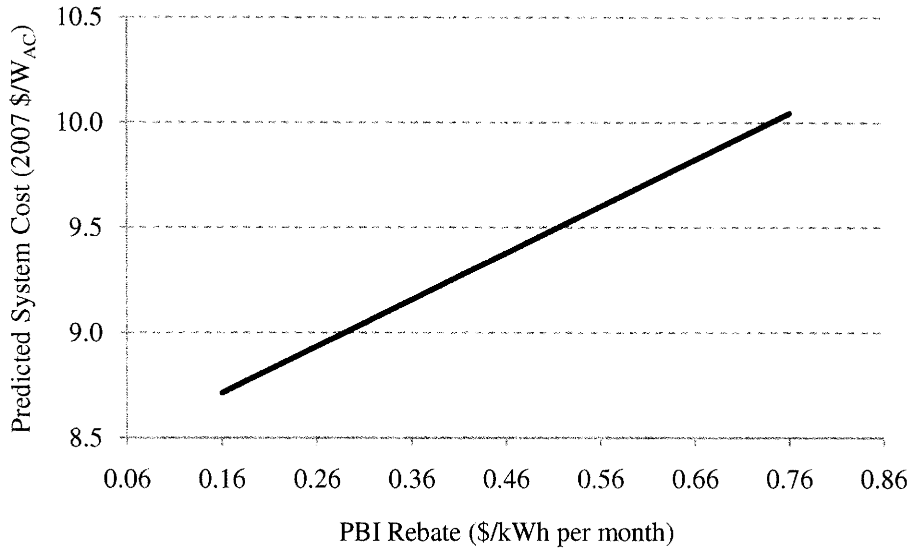

Figure 16: Predicted system cost as a function of rebate (PBI).

5.2.6 The Effect of Cumulative Capacity

The coefficient of 0.000 for CUMUL_CAPACITY in Model 3 suggests that cumulative capacity has no effect on system cost, which is what was found in the EPBB dataset. However, the coefficient in the PBI dataset is not statistically significant. As mentioned earlier, our finding may have risen from the construction of cumulative capacity variable, which could be improved in future research.

Unlike the EPBB dataset, the INSTALLER_EXPERIENCE coefficient in the PBI dataset is negative and statistically significant. Installers with greater experience can potentially offer lower costs to customers because of their expertise, which would support learning effects over time. Models 2, 3, and 4 suggest that experienced installers can reduce system costs by approximately $0.60/W$_{AC}$. This is very similar to the result found for CPUC systems (> 30kW) during 1998-2005 by Wiser et al. (2006).

5.2.7 Service Area, Population Density, Retail Rates, and System Status

Compared to the base service area of PG&E, systems installed in the SDGE and SCE are cheaper by approximately $0.68/W$_{AC}$. This result differs from the finding that systems installed in these areas are more expensive from 1998-2005 for CPUC systems (Wiser et al. 2006). The magnitude of the savings in the SDGE and SCE service areas is greater than in the EPBB dataset and could be a function of system size. However, nothing present in the data allows us to explain the system cost differences in these service areas.

The coefficient for SQRT_POP_DENSITY is positive and slightly lower than the value found in the EPBB dataset. The explanation provided by Wiser et al. (2006) about population density being a proxy for the cost of living and thus labor costs could explain why the PBI coefficient value of 0.003 is smaller than the EPBB coefficient value of 0.004. However, the PBI coefficient is not statistically significant, which could be a result of the small dataset.

An increase of \$1/W_{AC} in retail rates can increase PV system cost by up to \$0.03/W_{AC}. It is possible that as retail rates for electricity increases, people may be more willing to buy PV systems, which would allow sellers to increase their prices. Wiser et al. (2006) find a negative coefficient for CPUC systems (> 30kW) but it is not statistically significant.

Models 2 and 4 suggest that approved systems can cost approximately \$0.48/W_{AC} more than completed systems, which is similar to the result found in the EPBB dataset. Wiser et al. (2006) also find that approved CPUC systems (> 30kW) cost more than completed systems.

6. Conclusions

As the need for alternative energy increases in the world, the potential contribution of photovoltaic technology is indicated by its increasing rate of adoption in markets such as California's. Historical data show that solar costs tend to decline over time, a finding that is also supported by learning curve theory (IEA 2000). Government incentives such as the California Solar Initiative's EPBB and PBI programs aim to accelerate the decline of PV system costs by subsidizing consumer investment to increase production and learning. However, our analysis of photovoltaic systems in California during 2007-2008 suggests that PV costs have increased in recent years.

Although historical behavior and our hypothesis expected pre-rebate system cost to decrease with time, the analysis in this thesis finds that pre-rebate system costs increased by 2.36% annually for systems in the EPBB program during 2007-2008. The mean cost of EPBB systems was \$10.18/W_{AC} and is \$7.08/W_{AC} greater than the \$3.10/W_{AC} necessary to reach grid parity[7]. The models showed that rising system costs were driven by a worldwide surge in module prices, which can account for more than 50% of a system's cost. According to the EPBB regression coefficients, an increase or decrease in module price by \$0.10/W could lead to an increase or decrease in system cost up to \$0.26/W, respectively. However, even controlling for module costs, other factors mattered too.

Providers were hypothesized to sell larger systems at lower costs and to exhibit cost-reducing learning effects over time. Economies of scale existed in both datasets with larger systems being cheaper than smaller systems on average. The EPBB models showed a cost decrease of about \$1.50/W_{AC} going from 5kW to 50kW in size while the PBI models showed a cost decrease of about \$0.50/W_{AC} going from 84.7kW to 500kW in size. Learning effects were not observed in our models. The cumulative capacity variable was zero in both programs' models.

Surprisingly, thin film technology tended to increase PV system cost. Systems funded by the EPBB program during 2007-2008 showed an increase in cost of \$0.33/W_{AC} when thin film technology was employed. In the case of larger systems funded by the PBI program, thin film systems were initially cheaper than crystalline systems in 2007. However, the cost difference vanished by the beginning of 2008 when thin film systems began to be more expensive than crystalline systems.

Government incentives designed to subsidize consumer investment in PV systems were only partially successful. The models suggest that providers lower costs at a rate less than the decline in the rebate. In the EPBB model, if the rebate decreased by \$1/W_{AC}, the retailer decreased his price by \$0.73/W_{AC}. This can be due to the inability or reluctance to lower prices quickly. So while lowering rebates in the CSI may help to reduce prices in the long run, the effect is slower than desired.

We did not hypothesize any difference in cost based on buyer type but the EPBB results suggest that commercial and government buyers face higher costs than residential buyers. Commercial buyers paid \$1.45/W_{AC} more than residential buyers and government buyers paid

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[7] This is equivalent to \$0.13/kwh in San Francisco assuming a 5% discount rate, 30 year system lifetime, 10 year inverter lifetime, and output of 1700kwh per kW_{AC} of capacity.

$0.47/W$_{AC}$ more than residential buyers when controlling for other variables. The PBI models did not produce statistically significant results.

Further research is necessary to explore the fundamental forces driving the behaviors of the variables we have discussed. One of the most surprising results is the increase in system cost over time. The passage of time clearly does not affect costs directly so it must be due to something with which it is correlated. We attempted to characterize this with a cumulative capacity variable to represent learning effects, but the results showed no effect on system costs. It is possible that our construction of the variable ignored learning effects that are only present when analyzing specific regions such as utility service areas or individual providers of PV systems. The data necessary to analyze these possibilities can be found in the CSI database.

Another mystery is the reversal of the effect of thin film technology on system costs. In Wiser et al.'s 2006 findings, thin film systems are cheaper. Our results show that thin film systems in the PBI program began cheaper in 2007 but became more expensive in 2008. It seems unlikely that consumers would have a rational reason for selecting thin film technology if they knew it was more expensive than crystalline technology so it is possible that installers are not providing accurate quotes or prices change dramatically during the course of construction. However, this is speculation and interviews with installers in California may provide insight on the actual issues. Interviews may also help explain why installer experience was significant at lowering system costs in the PBI dataset but not in the EPBB dataset.

Although system costs increased during 2007-2008, economies of scale were still present in the data and demonstrate one way of reducing system costs that is less sensitive to module prices or other factors. However, the reasons why economies of scale are present in the solar industry are not clearly understood and could be due to many factors including labor efficiencies, a lower proportion of non-module costs as system size increases, or declining profit margins for larger systems. The ideal dataset would break down costs for each system and allow us to construct variables that measure their effects on economies of scale.

Finally, one of the most important issues for policymakers is the effect of government incentives on reducing solar costs. Our results showed that installers may be lowering prices slower than rebate reductions. If it was possible for EPBB or PBI rebate to rise, the alternative explanation, which is provided by Wiser et al. (2006), is that installers are trying to capture some of the benefits from rebates that should go to consumers. This could help explain why commercial customers face greater costs than government or residential customers in the EPBB program. Does this imply that installers are greedy or are the economics of the solar industry so tight that it is necessary for installers to create market inefficiencies just to stay in business? There are many potential explanations that cannot be addressed by the CSI datasets but could be the focus of further studies.

Solar energy advocates should be wary of the ability of PV systems to reach grid parity in the near future if module costs do not decrease and the expectations of thin film technology fail to materialize. Although the California Solar Initiative's declining rebate structure can help to reduce PV costs over time, improvements are necessary to prevent future periods of price increase that can damage industry progress. Additional research into the driving factors behind economies of scale and the pricing behavior of installers may lead to improved mechanisms of cost reduction that can aid policymakers.

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Appendix A: Data Cleaning Procedures

The initial CSI database contained 19,270 EPBB systems and 1,298 PBI systems. Table 7 summarizes the data cleaning performed to prepare the EPBB and PBI datasets. First, systems with critical missing entries were eliminated. Outliers were then eliminated based on Cook's D, which is described in the SYSTEM_COST row below. The final datasets included 17,072 EPBB systems and 885 PBI systems.

Table 7: Summary of data cleaning procedures.

Variable	**Cleaning Procedure**
SYSTEM_COST	Dependent variable, expressed in $\$/W_{AC}$. The variable was constructed using the Total Cost and CEC PTC rating fields in the CSI database. All values were converted to January 2007 dollars using the monthly CPI index. Systems less than or equal to $\$0/W_{AC}$ were eliminated from the analysis. Other observations were then removed if its Cook's D fell more than three standard deviations away from the dataset's mean Cook's D.
TIME_MONTH	The variable was constructed using the Reservation Request Review Date in the CSI database. Months are numbered consecutively from January 2007 to December 2008. January 2007 is 1, February 2007 is 2, etc. Only systems from January 1, 2007 to December 31, 2008 were considered.
LN_SYSTEM_SIZE	The variable was constructed using the CEC PTC rating field in the CSI database in watts instead of kilowatts. The natural log transformation was used to ensure a linear relationship with the dependent variable upon visual inspection.
CUMUL_CAPACITY	For each dataset, the data was sorted based on the Reservation Request Review Date field (used to construct the TIME_MONTH variable). CUMUL_CAPACITY was constructed by summing the CEC PTC rating in kW in chronological order for each observation.
PBI_REBATE	The variable was only used in the PBI models and was determined by the PBI rebate table and the System Owner Sector (Non-Profit, Government, Residential, Commercial) and Incentive Step fields in the CSI database. In many cases the Incentive Design field would list a varying rebate such as "100% @ \$0.37, 90% @ \$0.26, 10% @ \$0.22 per kWh FiveYearPBI". In these cases we did a weighted average based on the provided percentages.
EPBB_REBATE	The variable was only used in the EPBB models and was determined by the CSI rebate table and the System Owner Sector (Non-Profit, Government, Residential, Commercial) and Incentive Step fields in the CSI database. In some cases the Incentive Design field would list a varying rebate such as "95% @ \$2.50, 5% @ \$2.20 per Watt EPBB". In these cases we did a

	weighted average based on the provided percentages. Systems with an empty System Owner Sector field were usually determined to be residential based on system characteristics.
COMMERCIAL	Variable equaled 1 if the System Owner Sector field value in the CSI database was Commercial, 0 otherwise.
GOVERNMENT	Variable equaled 1 if the System Owner Sector field value in the CSI database was Government or Non-Profit, 0 otherwise.
THIN_FILM	Variable equaled 1 if the PV Module#1 Model field in the CSI database contained a thin film module model number, 0 otherwise. This information was discernable based on the Eligible PV Modules List provided by the CSI website (http://gosolarcalifornia.org/equipment/pvmodule.php).
RETAIL_RATES	The average monthly retail electricity rate (cents/kWh) in California, obtained from the EIA website. There are different rates for residential, commercial, and government users.
APPROVED	Equaled 1 if the Confirmed Reservation date field was nonempty and the Completed Date field was empty, 0 otherwise.
WAITLISTED	Equaled 1 if the Reservation Request Review Date field was nonempty and the Confirmed Reservation date field was empty, 0 otherwise.
SCE	Equaled 1 if the Program Administrator field's value was SCE, 0 otherwise.
SDGE	Equaled 1 if the Program Administrator field's value was CCSE, 0 otherwise.
INSTALLER_EXPERIENCE	Equals 1 if the system was installed by an "experienced" installed, 0 otherwise. The variable was constructed in the same way as by Wiser et al. (2006). Installers are identified as experienced if they rank in the top 5% of installers by the number of systems they installed during 2007-2008.
SQRT_POP_DENSITY	The population density was derived from the Host Customer Physical Address ZipCode field in the database. The 2000 U.S. Census Zip Code Tabulation Area (ZCTA) population density was used in most cases. When the zip code was not provided, the city or county's population density was used.
MODULE_COST_INDEX	Monthly variable constructed from the Solarbuzz monthly solar module index. The data was converted to January 2007 dollars.

Appendix B: EPBB Model 2 and Model 2a

In the EPBB Model 2, there is no upper bound cost restriction as described in Section 3.1. In the EPBB Model 2a, costs are restricted to $\$50/W_{AC}$, which eliminates 13 observations from the data ranging from $\$55.36/W_{AC}$ - $\$324.71/W_{AC}$. Although the R^2 of the model improves with the stricter cost restriction in Model 2a, the results are very similar.

Table 8: Regression results for EPBB Model 2 and Model 2a.

Variable	**Model 2**		**Model 2a**	
	coef.	*p*	*coef.*	*p*
Intercept	0.735	0.764	0.322	0.839
TIME_MONTH	0.020	0.022	0.025	< 0.01
LN_SYSTEM_SIZE	-0.702	< 0.01	-0.701	< 0.01
CUMUL_CAPACITY				< 0.01
EPBB_REBATE	0.728	< 0.01	0.746	< 0.01
COMMERCIAL	1.446	< 0.01	1.471	< 0.01
GOVERNMENT	0.467	< 0.01	0.561	< 0.01
THIN_FILM	0.332	< 0.01	0.304	< 0.01
RETAIL_RATES	0.008	0.798	0.014	0.461
APPROVED	0.257	< 0.01	0.244	< 0.01
WAITLISTED	-0.313	0.059	-0.255	0.108
SCE	-0.060	0.284	0.010	0.806
SDGE	-0.314	< 0.01	-0.207	< 0.01
INSTALLER_EXPERIENCE	0.022	0.739	0.051	0.143
SQRT_POP_DENSITY	0.004	< 0.01	0.004	< 0.01
MODULE_COST_INDEX	2.567	< 0.01	2.585	< 0.01
THIN_FILM x TIME_MONTH				< 0.01
R-SQUARED	0.027		0.116	
OBSERVATIONS (n)	17,072		17,059	

Appendix C: Models W1, W2, and W3

Table 7 and 8 summarize the regression results for Models W1, W2, and W3, which are analogous to the models found in Wiser et al. (2006). These models' results are sometimes inconsistent because they were chosen purely for comparison with Wiser et al. (2006) and not necessarily for appropriateness.

Table 9: Regression results for Models W1, W2, and W3 (EPBB)

Variable	**Model W1**		**Model W2**		**Model W3**	
	coef.	*p*	*coef.*	*p*	*coef.*	*p*
Intercept	15.362	< 0.01	0.593	0.796	0.735	0.764
TIME_MONTH	0.031	< 0.01	0.020	0.023	0.020	0.022
LN_SYSTEM_SIZE	-0.721	< 0.01	-0.702	< 0.01	-0.702	< 0.01
EPBB_REBATE			0.730	< 0.01	0.728	< 0.01
COMMERCIAL	1.315	< 0.01	1.436	< 0.01	1.446	< 0.01
GOVERNMENT	0.710	< 0.01	0.454	< 0.01	0.467	< 0.01
THIN_FILM	0.323	< 0.01	0.333	< 0.01	0.332	< 0.01
RETAIL_RATES					0.008	0.798
APPROVED	0.189	0.014	3.270	< 0.01	0.257	< 0.01
WAITLISTED	-0.391	0.018	-1.890	0.058	-0.313	0.059
SCE	0.153	< 0.01	-1.080	0.280	-0.060	0.284
SDGE	-0.155	0.011	-5.160	< 0.01	-0.314	< 0.01
INSTALLER_EXPERIENCE	0.056	0.386	0.340	0.736	0.022	0.739
SQRT_POP_DENSITY	0.004	< 0.01	4.290	< 0.01	0.004	< 0.01
MODULE_COST_INDEX			5.960	< 0.01	2.567	< 0.01
R-SQUARED	0.025		0.027		0.027	
OBSERVATIONS (n)	17,072		17,072		17,072	

Table 10: Regression results for Models W1, W2, and W3 (PBI).

Variable	Model W1		Model W2		Model W3	
	coef.	*p*	*coef.*	*p*	*coef.*	*p*
Intercept	12.438	< 0.01	15.175	0.120	16.186	0.108
TIME_MONTH	0.009	0.390	0.032	0.277	0.034	0.256
LN_SYSTEM_SIZE	-0.277	< 0.01	-0.272	< 0.01	-0.272	< 0.01
PBI_REBATE			2.108	0.074	2.218	0.053
COMMERCIAL	-0.401	0.163	-0.198	0.516	-0.133	0.670
GOVERNMENT	0.480	0.143	0.450	0.176	0.493	0.149
THIN_FILM	-0.222	0.245	-0.203	0.288	-0.200	0.294
RETAIL_RATES					0.030	0.600
APPROVED	0.451	0.016	0.483	0.010	0.483	0.010
SCE	-0.643	< 0.01	-0.680	< 0.01	-0.685	< 0.01
SDGE	-0.575	< 0.01	-0.667	< 0.01	-0.684	< 0.01
INSTALLER_EXPERIENCE	-0.614	< 0.01	-0.604	< 0.01	-0.600	< 0.01
SQRT_POP_DENSITY	0.002	0.366	0.003	0.308	0.003	0.314
MODULE_COST_INDEX			-0.740	0.707	-1.040	0.617
R-SQUARED	0.154		0.156		0.156	
OBSERVATIONS (n)	885		885		885	