Optimal Solar Subsidy Policy Design and Incentive Pass-through Evaluation: Using US California as an Example

Changgui Dong (董长贵)
Institute of Public Finance and Public Policy
School of Public Administration and Policy
Renmin University of China

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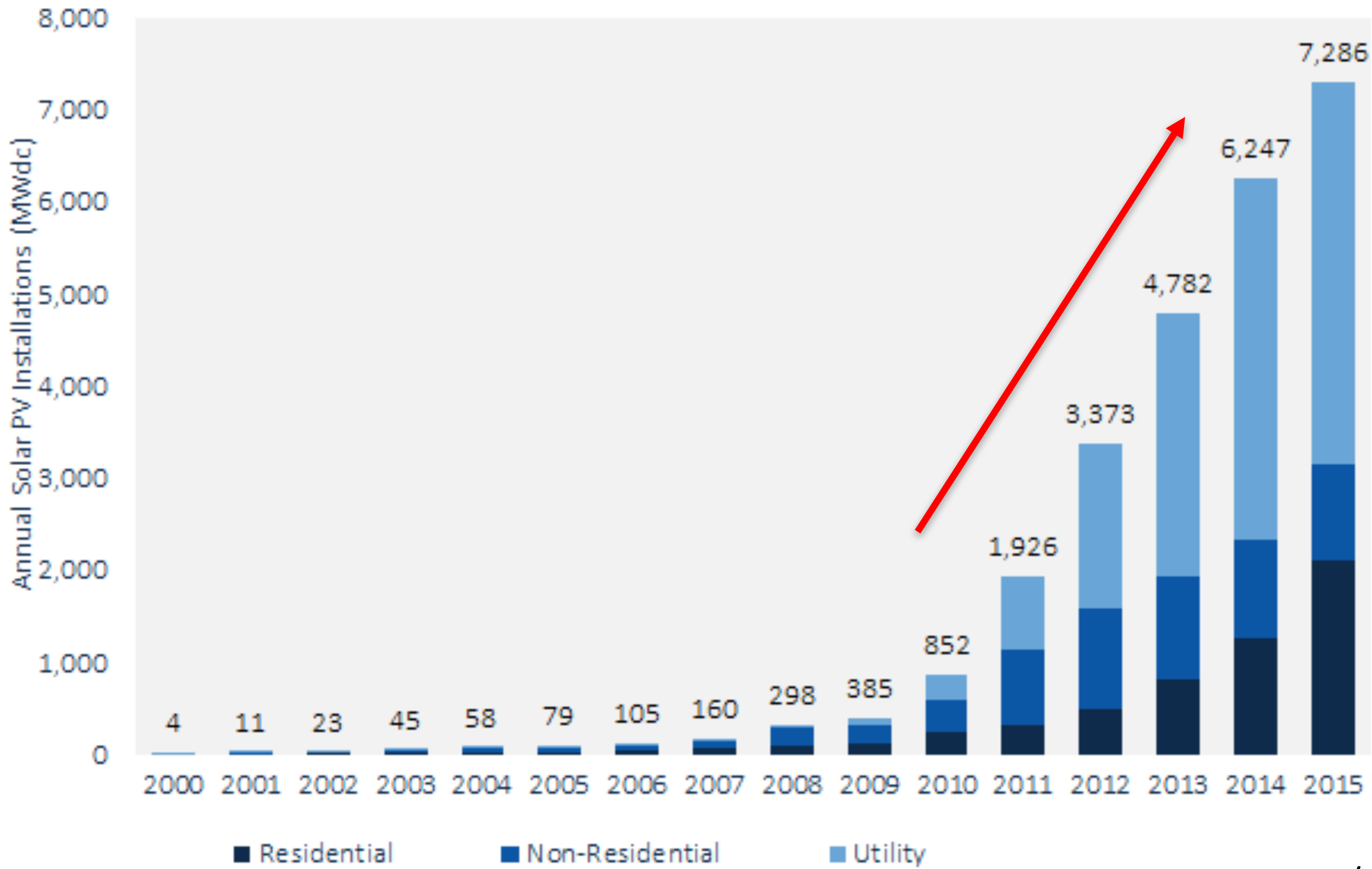
Outline

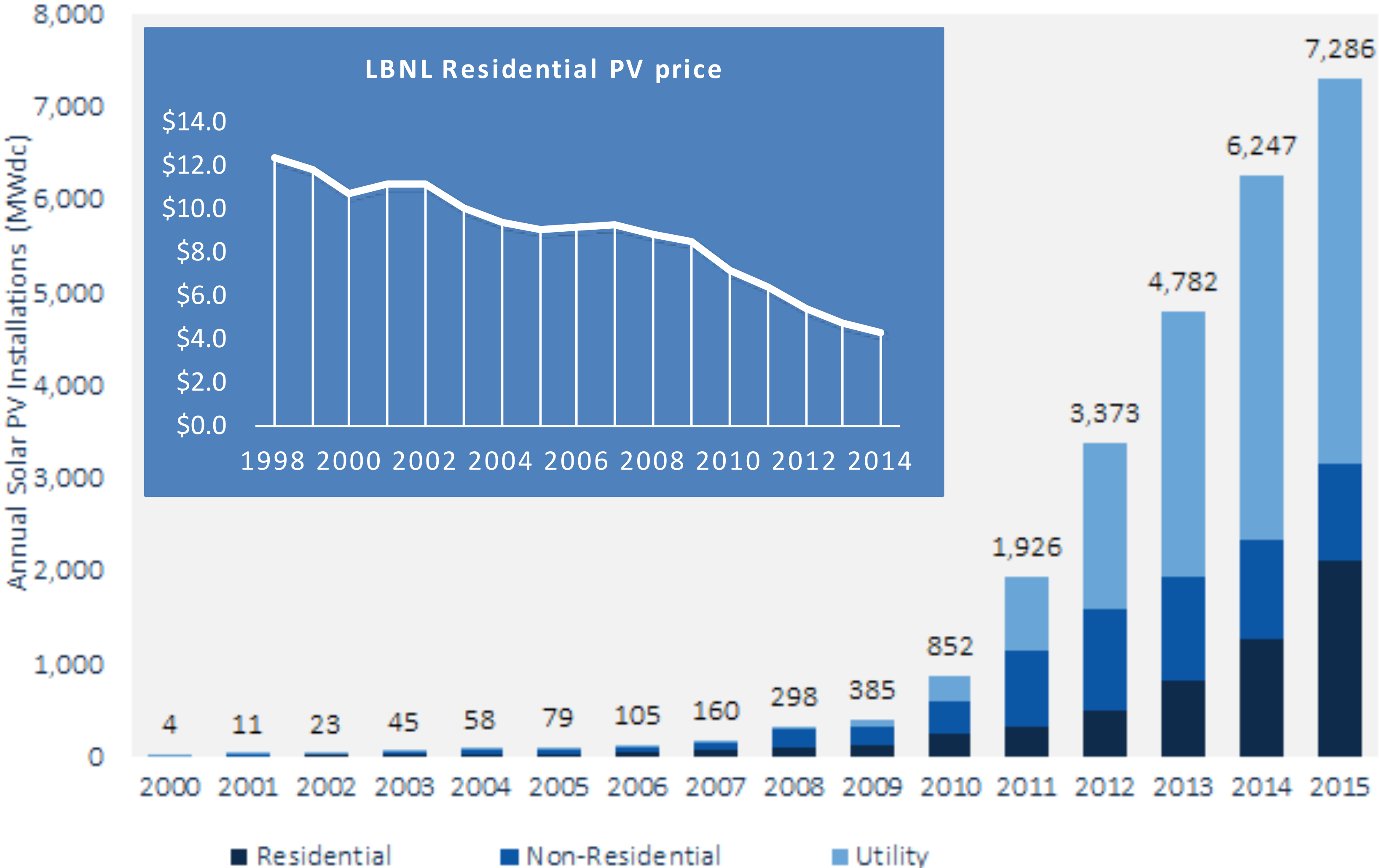
- Brief introduction on PV market and subsidies
- Detailed introduction on CSI
- My three research projects
  - – Cost-effectiveness analysis
  - – Incentive pass-through analysis
    - Structural approach
    - Regression discontinuity design

US Solar PV Market



Source: GTM/SEIA, 2016

US Solar PV Market



Source: GTM/SEIA, 2016

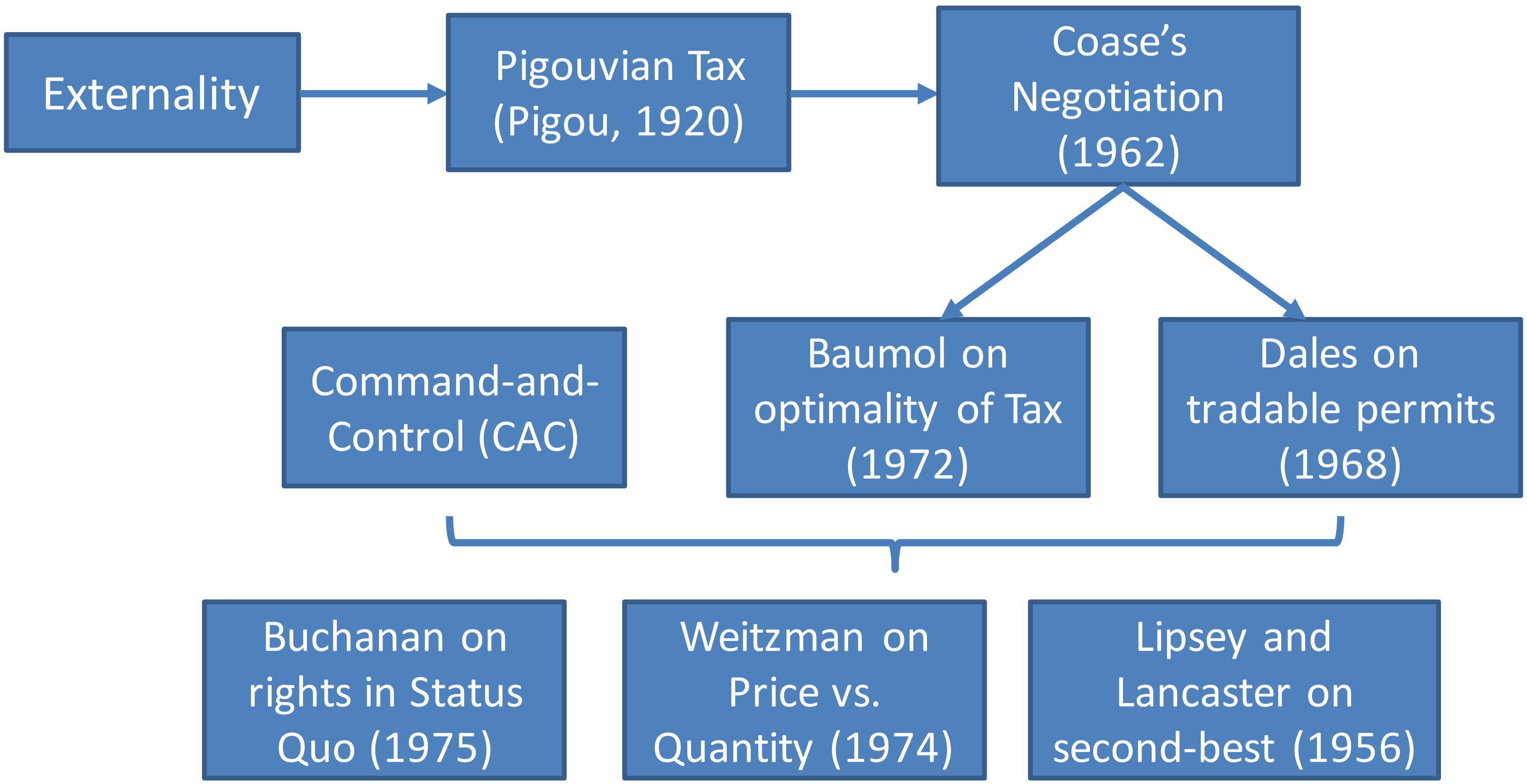
American Solar Subsidy Hierarchy

- Federal-level:
  - Investment Tax Credit (ITC, 30% of price)
  - Loan guarantee (6% to 10% credit subsidy ratio)
  - Accelerated depreciation (5 years)
  - Interests deduction for commercial and industrial systems
- State-level:
  - Renewable Portfolio Standard (RPS, % of generation or MW)
  - Upfront rebate ($/kW or $/kWh)
  - Net energy metering (NEM, retail rate)
  - Interest-exemption for residential customers
  - Subsidized loan program (e.g. PACE)
- City-level and Utility-level

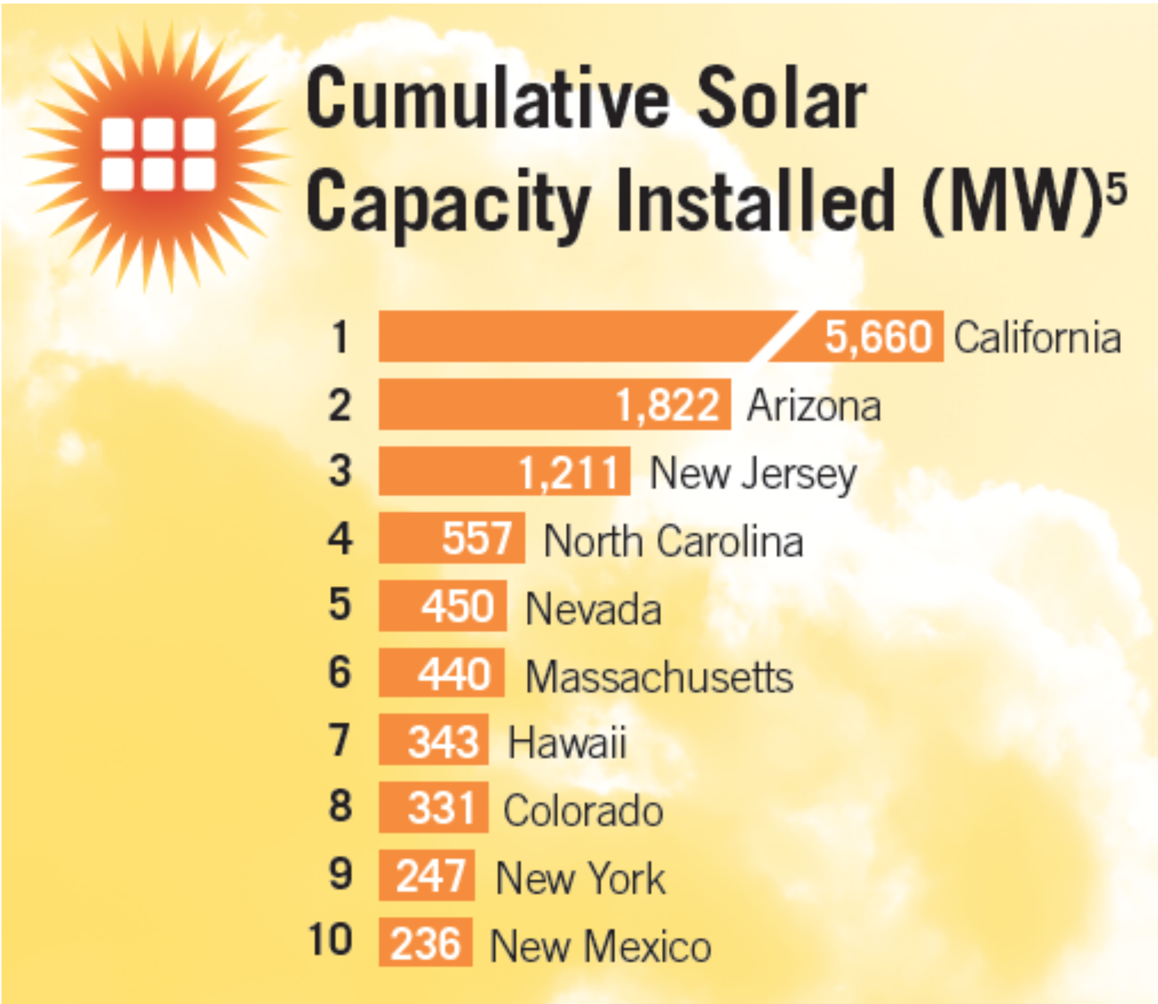
Role of Solar Subsidies

- Correcting for environmental externalities (van Benthem et al., 2008)
- Correcting for knowledge spillover effects (Bollinger and Gillingham, 2016)
- Creating Jobs and industry development (NREL's JEDI model)
- Promoting social equity: e.g. kerosene subsidy to the poor in Indonesia (Pitt, 1985)

Environmental Externalities



Solar PV in California



Source: SEIA/GTM, 2014

In 2015, cumulative capacity amounts to 13 GW, enough to power over 3 million homes in CA!

Policy Intro: California Solar Initiative

- California Solar Initiative (CSI) provides a $/W-based rebate to PV adopters. The goal is to spur 1.94 GW new solar capacity from 2007 to 2016, with a budget of $2.16 billion. Three biggest investor-owned utilities (IOUs) help administer the program.
- Its predecessor, Emerging Renewables Program (ERP) started in 1998 and provided $/W-based rebate, too.
- Another program -- Self Generation Incentive Program (SGIP) provided incentives for solar PV systems larger than 30kW (in addition to other self-generation energy systems) prior to the CSI.

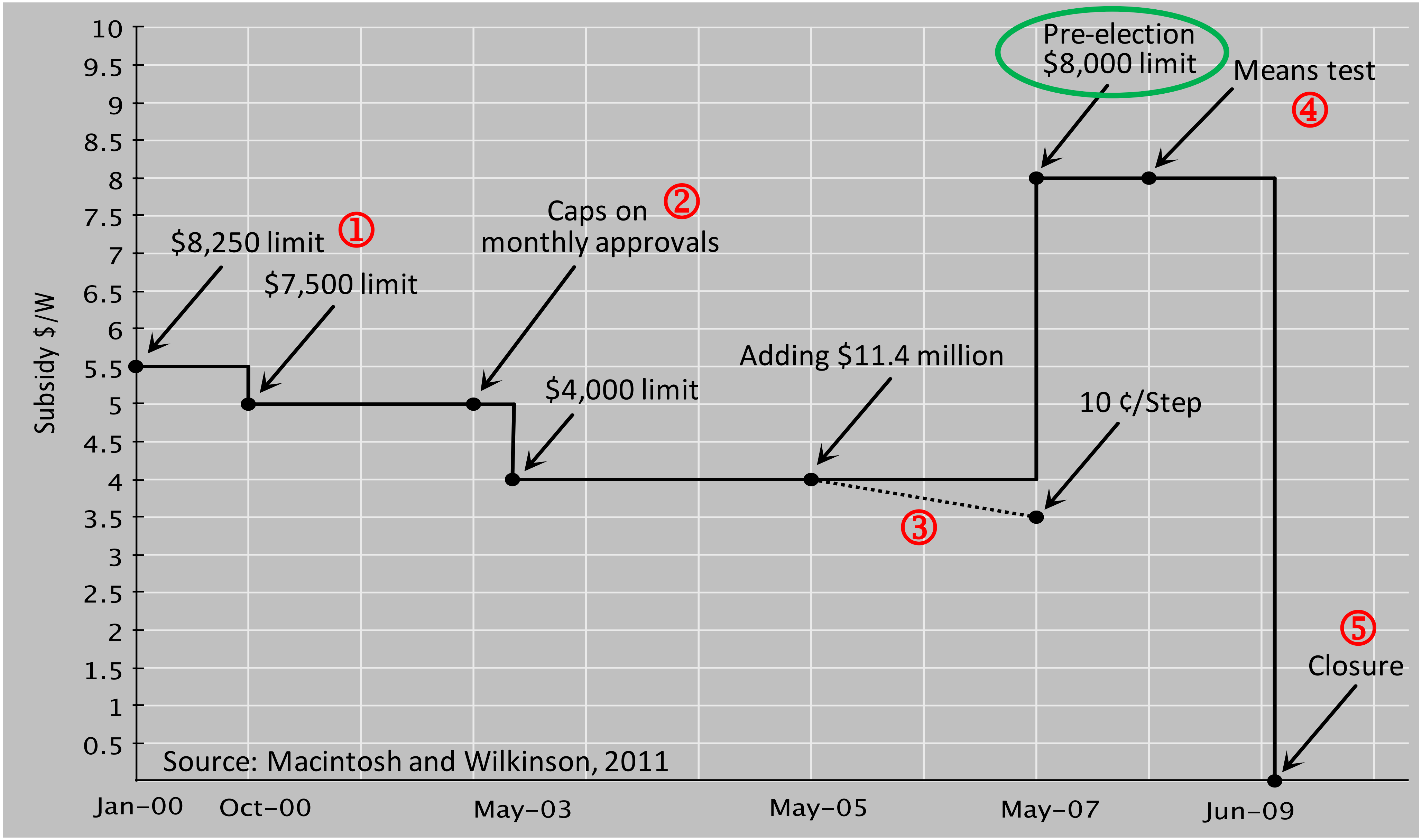
Policy Intro: Some Background

- Governor Schwarzenegger proposed the Million Solar Roofs Program in August 2004.
- California Public Utilities Commission (CPUC) and California Energy Commission (CEC) prepared the Joint Paper in June 2005.
  - $1.1–$1.8 billion for 3,000-MW
  - Received comments suggested $3.35 billion for 3,000 MW
- SB 1 cut the budget to $2.16 billion in August 2006, and CPUC assumed 65% of the target 1,940 MW.

Policy Intro: Policy Design

- CPUC and CEC Joint Paper reviewed PV development experiences in Germany, Japan and Spain.
- A common problem was that program budget run out too fast.
- Four alternatives before the final version:
  - Increased monitoring of market factors that impact installed system costs
  - A flexible quarterly market trigger based on whether the budget is constrained or not
  - An economic model accounting for various market variables and seeking optimum incentive levels
  - An auction design

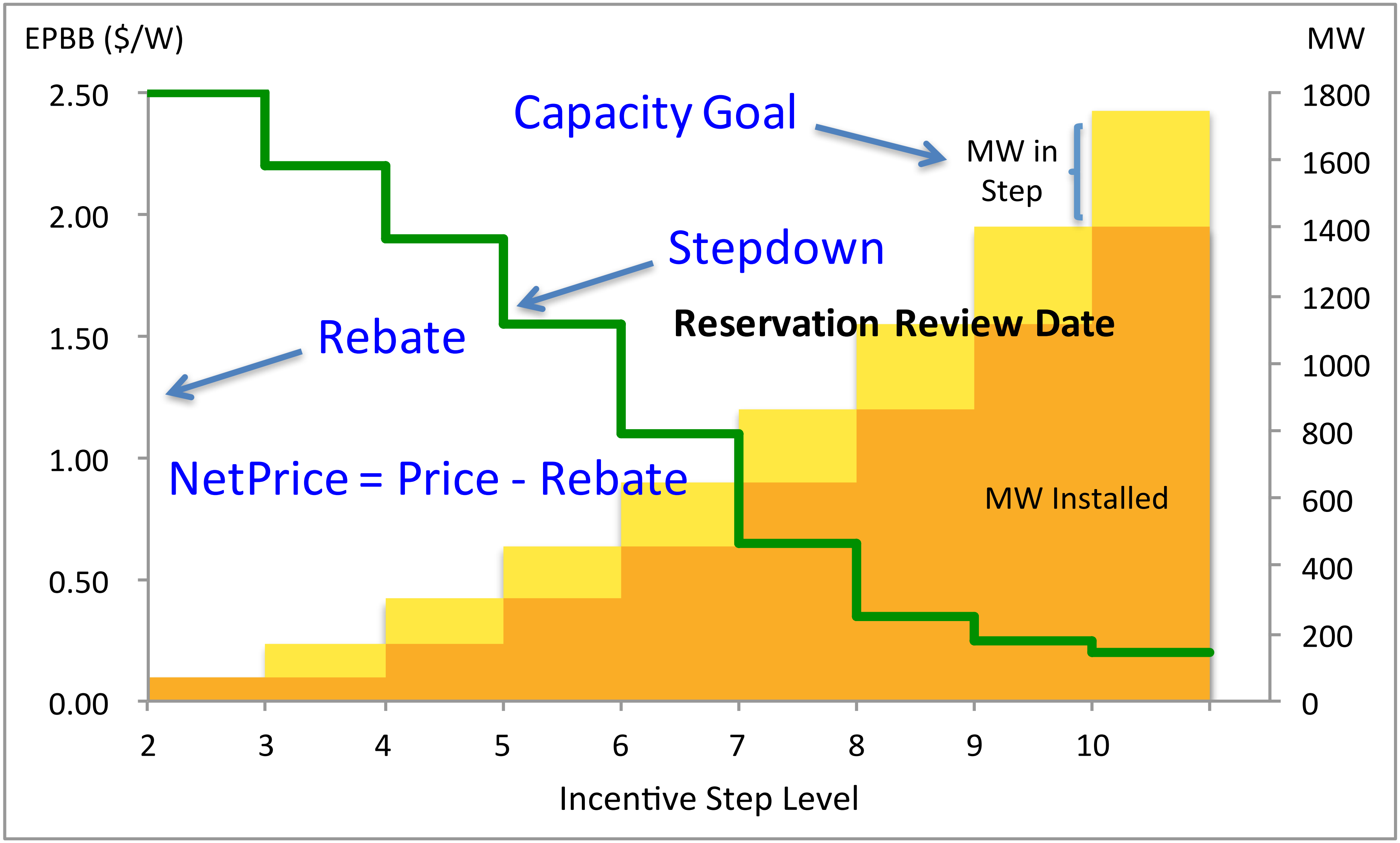
Australian Case: Solar Homes and Communities Program



Policy Intro: Simple Rules

- Incentive drops no more than $0.45 and no less than $0.05;
- Incentive drops of no more than $0.30 in the first two steps (to avoid disruption early on);
- $0.20 per watt to be the minimum meaningful incentive to offer during the last step to close out the program ($0.7/W for the government/non-profit sector);
- The government/non-profit sector starts with a higher incentive (SB 1 sets it to be $0.75/W higher), thus a larger drop in the incentive rate for this sector in Steps 9 and 10 to arrive at a comparable low level with residential and commercial sectors.

CSI: MW-triggering Mechanism



CSI Program Management

- Installers help apply for CSI and give customers an equal-valued discount;
- Upfront in nature, but customers reserve the rebate level at first and then request for the money after project completion and interconnection;
  - 22 key dates to track the project status
- Companies who sell system equipment must be certified by the California Energy Commission or some approved third party;
- PowerClerk – CSI Application Portal;
- Trigger Tracker (http://www.csi-trigger.com/) shows how many CSI megawatts (MW) worth of rebates are available in the current incentive step level.
- CaliforniaSolarStatistics: archive information on every project that ever applied for CSI;
  - "Find and compare solar contractors working in your area with just a few quick clicks."

Research Questions

- How cost-effectiveness is the California Solar Initiative in achieving its goal(s) under a budget constraint?
- Where does those incentive go: consumers or suppliers? It is the so-called incentive pass-through question.

Part I: Cost-effectiveness Analysis

Model Setup

Objective: $\max_{\{r_t\}} \sum_{t=1}^{T} \delta^t q_t$ (1)

Cumulative quantity: $Q_t = Q_{t-1} + q_t$ (2)

Penetration Effect

Demand equation: $q_t = \beta_0 + \beta_1 Q_{t-1} + \beta_2 (p_t - r_t) + \beta_3 E_t + \varepsilon_t$ (3)

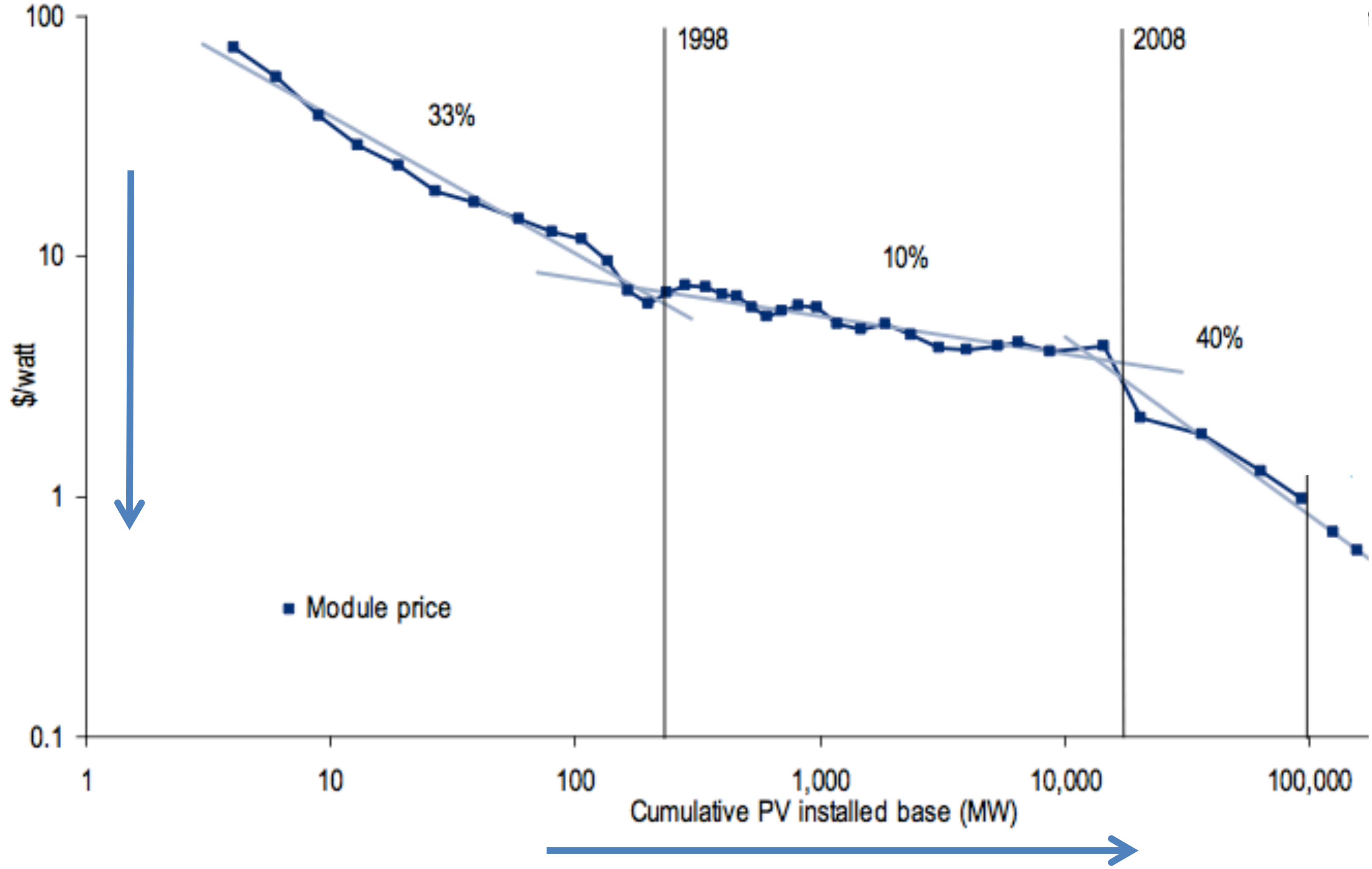
Learning-by-doing: $\log(p_t) = \log(p_0) + b\log(Q_{t-1}) + \omega_t$ (4)

Budget constraint: $B_t = B_{t-1} - r_t q_t$ (5)

Learning-by-Doing Effect (LBD)

Electricity price: $E_t = (1+\rho) E_{t-1}$ (6)

Technology Learning-by-Doing



Source: Bloomberg New Energy Finance, Citi Research

Analytic-form Solution

- Results from using Hamiltonian

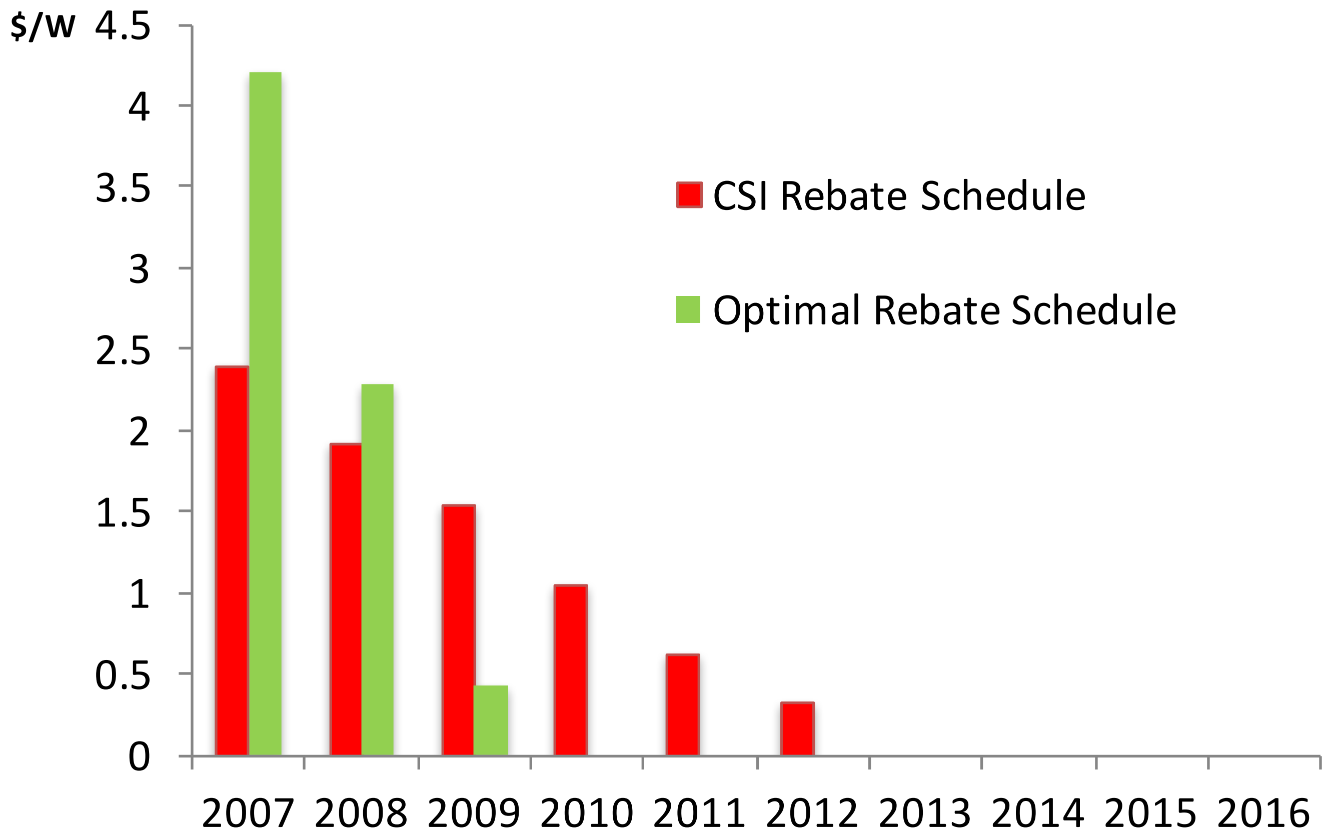
$$\frac{\dot{r}}{r} = \frac{d\left(\log(r)\right)}{dt} \propto \underbrace{\left(-\frac{1}{\eta} + \beta_2\right)}_{<0} \times \underbrace{\beta_1}_{\text{Penetration Effect}} + \underbrace{\left(-\beta_2 + \frac{\eta_2}{\eta^2}\right)}_{>0} \times \underbrace{b}_{\text{LBD }(<0)}$$

Higher rebate level in earlier periods than later, due to greater penetration effect or greater LBD effect (Kalish and Lilien, 1983).

Baseline Results

- Rebate starts at $4.2/W, and only lasts for 3 years

  CSI ~$2.5/W 6 years



$b = -0.075$

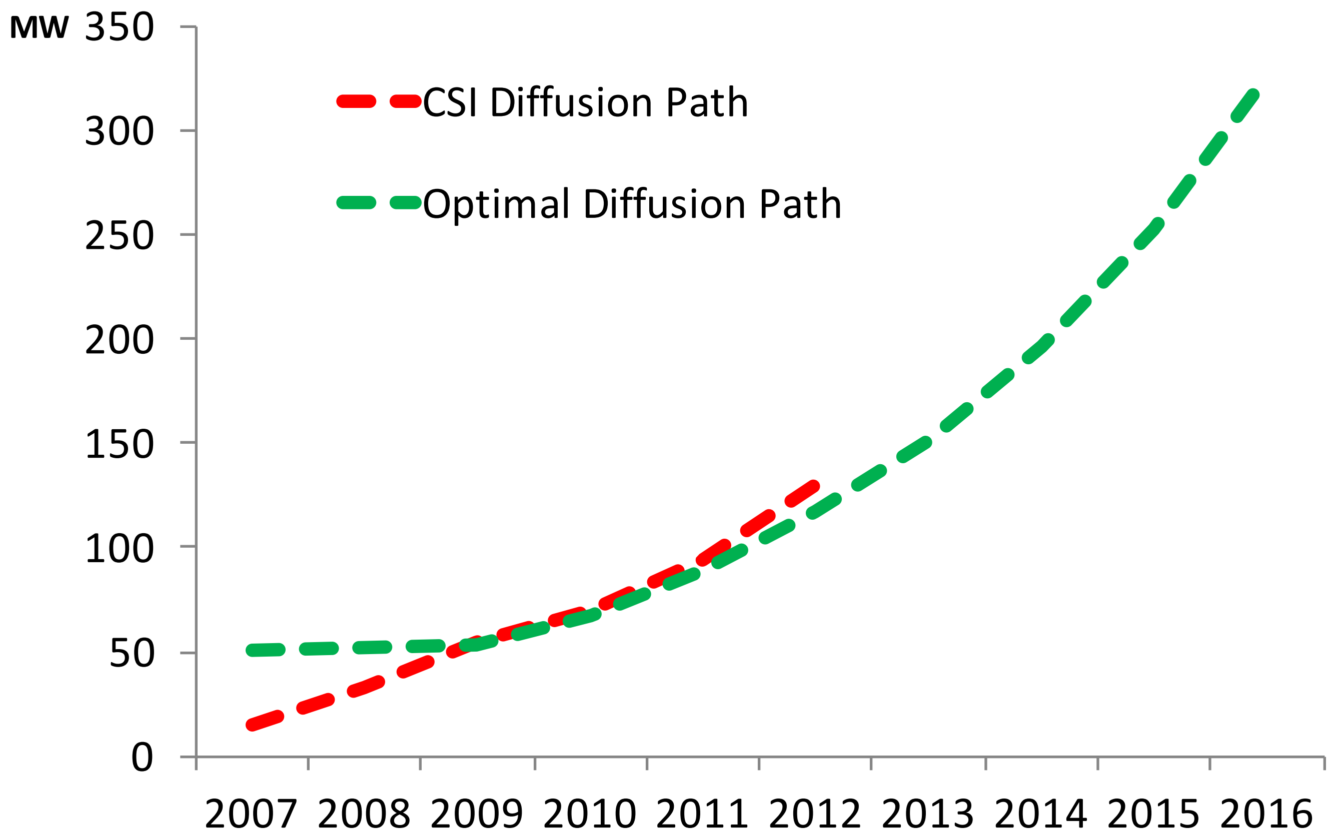
$\beta_1 = 0.268$

$\beta_2 = -9120$

$\rho = 0.03$

Baseline Results

32.2 MW more adoption from 2007-2012 (8.1% higher) than CSI



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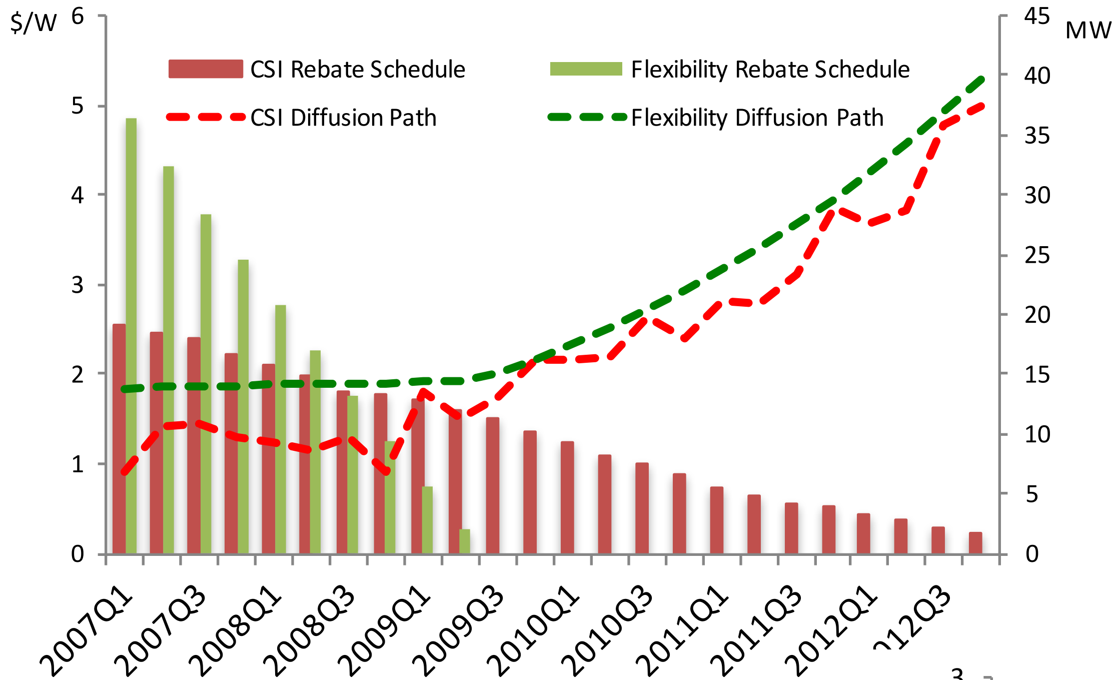
Policy Flexibility and Policy Certainty



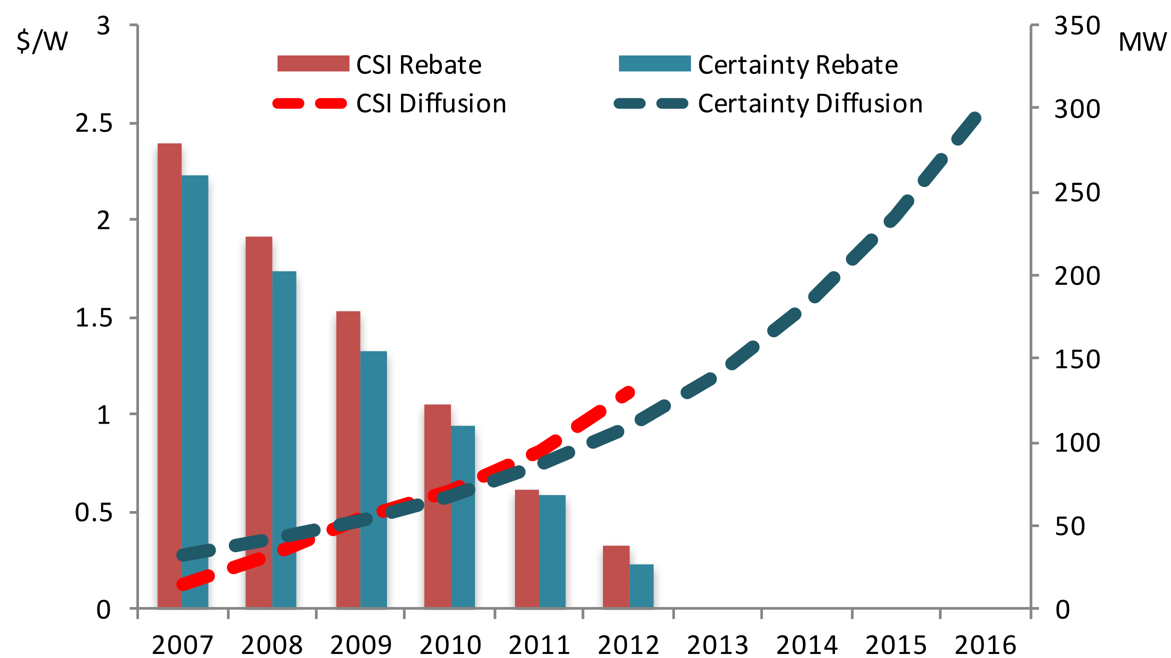
$$\max_{\{r_t\}} \left(\sum_{t=1}^{T} \delta^t q(r)_t + \lambda \operatorname{var}(r_T) \right)$$

Policy Certainty

Policy Flexibility

with

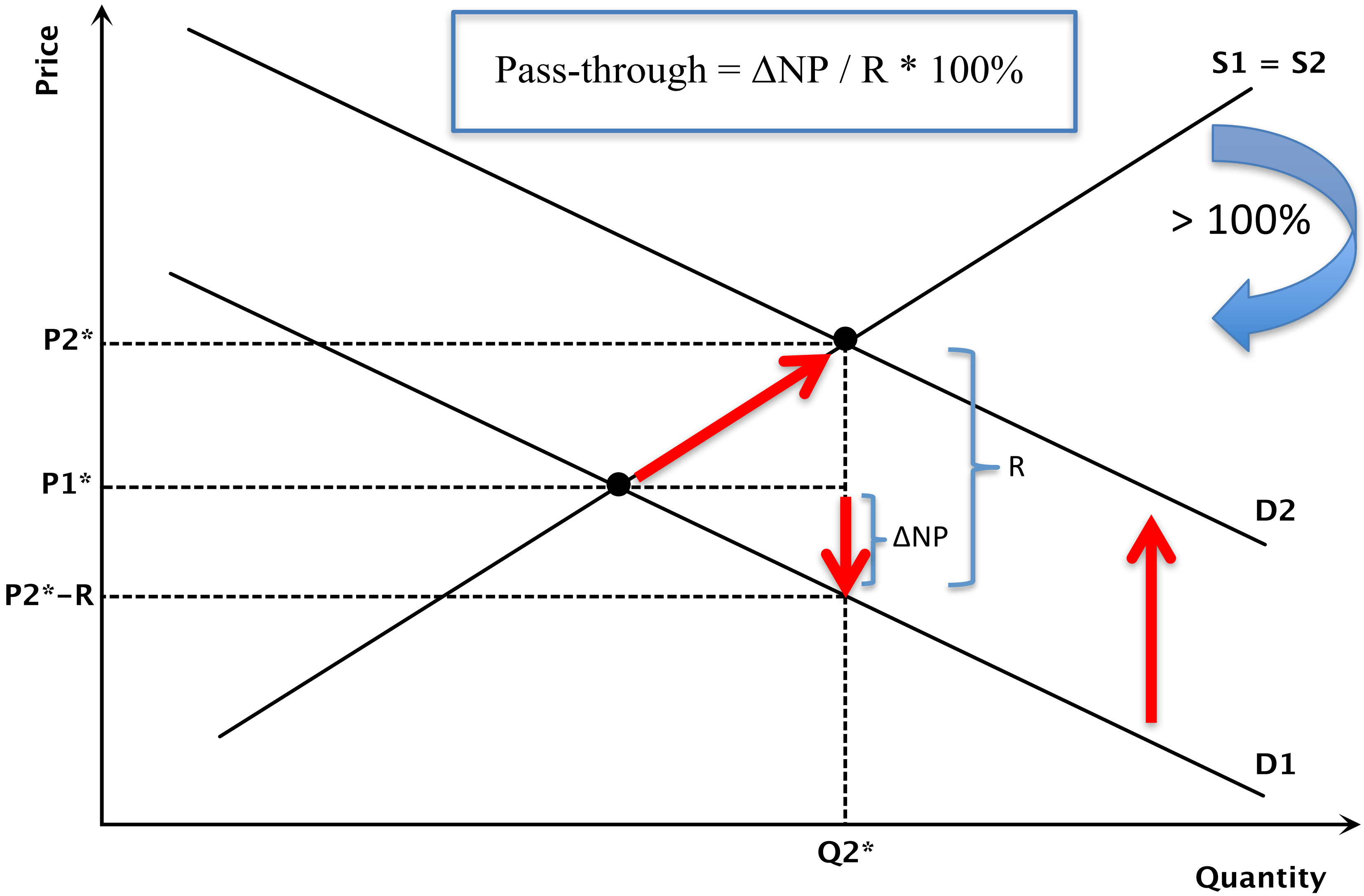
Quarterly Change



Sensitivity analysis and time-varying LBD are omitted

Part II: Incentive Pass-through Analysis

Pass-through Definition



Method I: Structural Modeling

Structural Modeling: Setup

- Typical in the tax or subsidy incidence literature, in studies on the impact of changes in cost on price, and in market power evaluations.
- Specify the demand and supply relation at the market level (one county), then derive the pass-through rate formula.
  - Demand: $Q = Q(P, X) \qquad P = \tilde{P} + s$
  - Supply relation: $\tilde{P} + s + \theta^* P_Q Q = C_Q = MC(Q, Z)$
  - Pass-through rate: $-\frac{d\tilde{P}}{ds} = \frac{1}{1 + \theta^*(1 + A + E)}$

$$A = -\frac{C_{QQ}}{\theta^* N \cdot P_Q} \quad \text{and} \quad E = -P_{QQ}\frac{Q}{P_Q}$$

- Estimate parameters involved in the pass-through rate formula, and estimate pass-through rate for each county.

Data Sources

- Dataset leveraged LBNL's Tracking the Sun (TTS) VI report, and complemented it with wage data from BLS and social demographic data from the Census Bureau.
- TTS data contain PV system information on:
  - price and rebate level; date of installation; system size; geographical location; customer segment (residential, commercial, or other); technology type (module and inverter manufacturer and model, tracking system vs. fixed-tilt); hardware cost
  - can also infer BIPV vs. rack-mounted PV; thin film vs. crystalline modules; Chinese made vs. non-Chinese made modules; and micro-inverters vs. central or string
  - can further calculate county-level installer experience, county-level installer density
- Various screens applied to select data for use in this analysis.

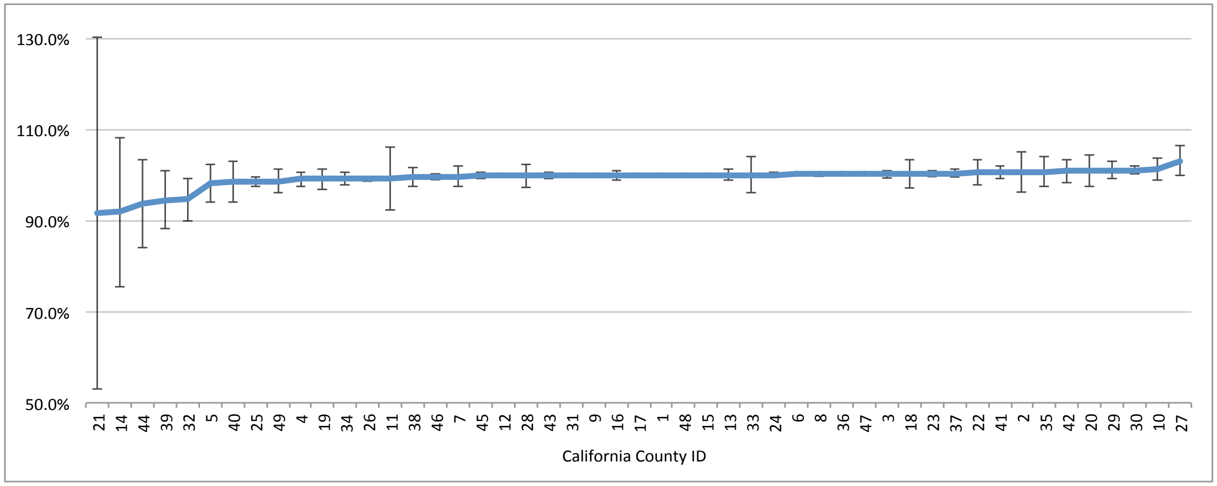
Summary Statistics: Structural Modeling

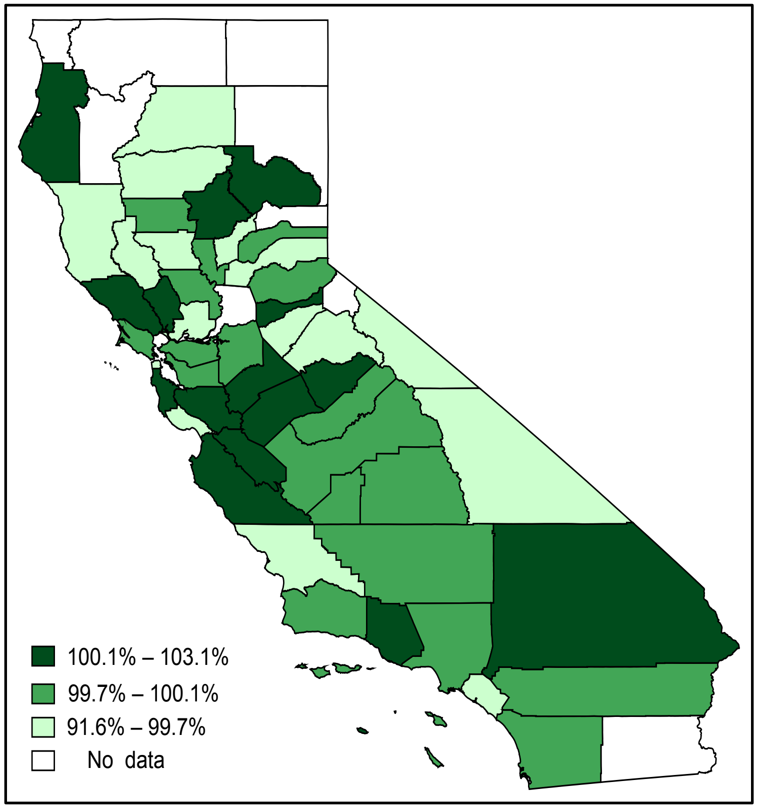
We averaged all the variables to the county-level for those 49 counties in California with the longest PV installation history (>= 30 months).

Variables (County Level)	Mean	Std. Dev.	Min	Max	N
Installation price (real $/W)	8.50	1.94	2.71	21.48	5,677
Net price (real $/W)	6.19	1.23	0.20	18.24	5,677
Rebate (real $/W)	2.32	1.44	0.12	6.50	5,677
Monthly installation (kW)	80.36	150.3	0.58	1,799	5,677
TPO share	0.10	0.21	0	1	5,677
Summer season	0.50	0.50	0	1	5,677
# of zip codes	8.14	11.01	1	102	5,677
# of installers	6.92	8.89	1	69	5,677
Financial crisis year	0.09	0.29	0	1	5,677
Hardware cost (real $/W)	5.68	1.27	2.71	7.93	5,677
Labor cost (in $100,000)	2.85	0.80	1.49	6.64	5,677

Results: Structural Modeling

- County-level pass-through rates vary from 92% to 103%, with an average rate at 99%.
- The 95% confidence intervals are generally narrow, though wider for smaller counties.





Method II: Regression Discontinuity

Regression Discontinuity: Idea

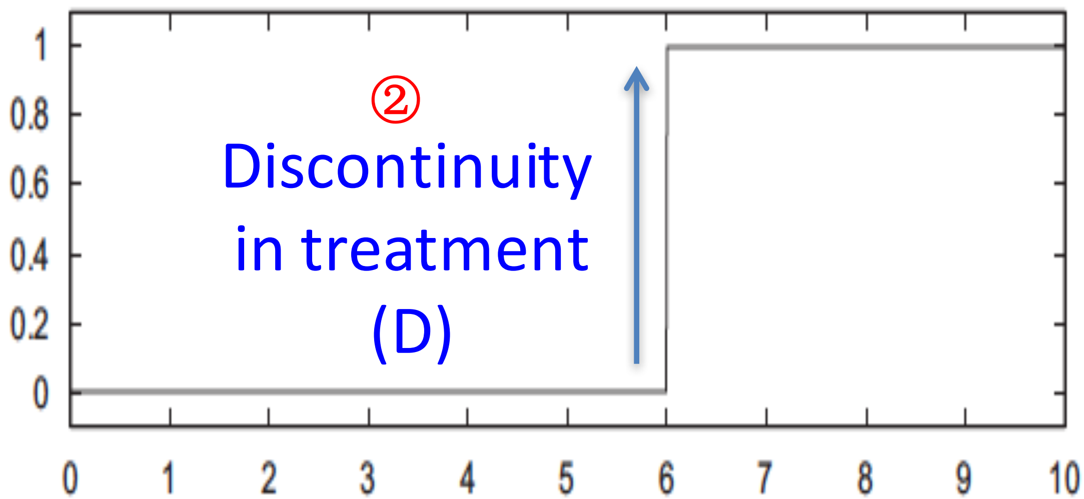


Fig. 1. Assignment probabilities (SRD).

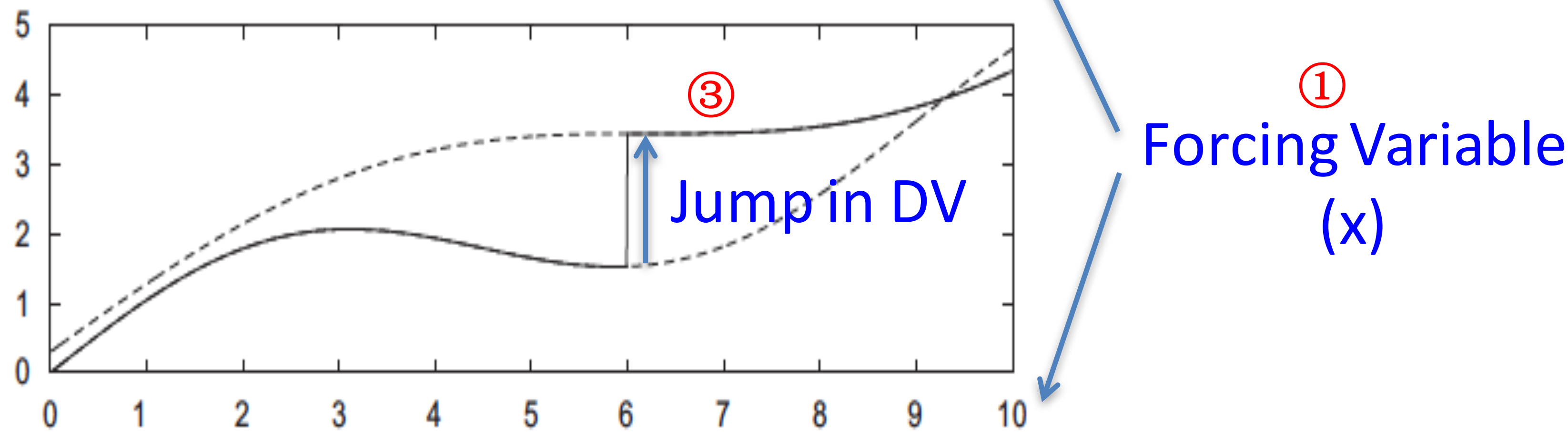
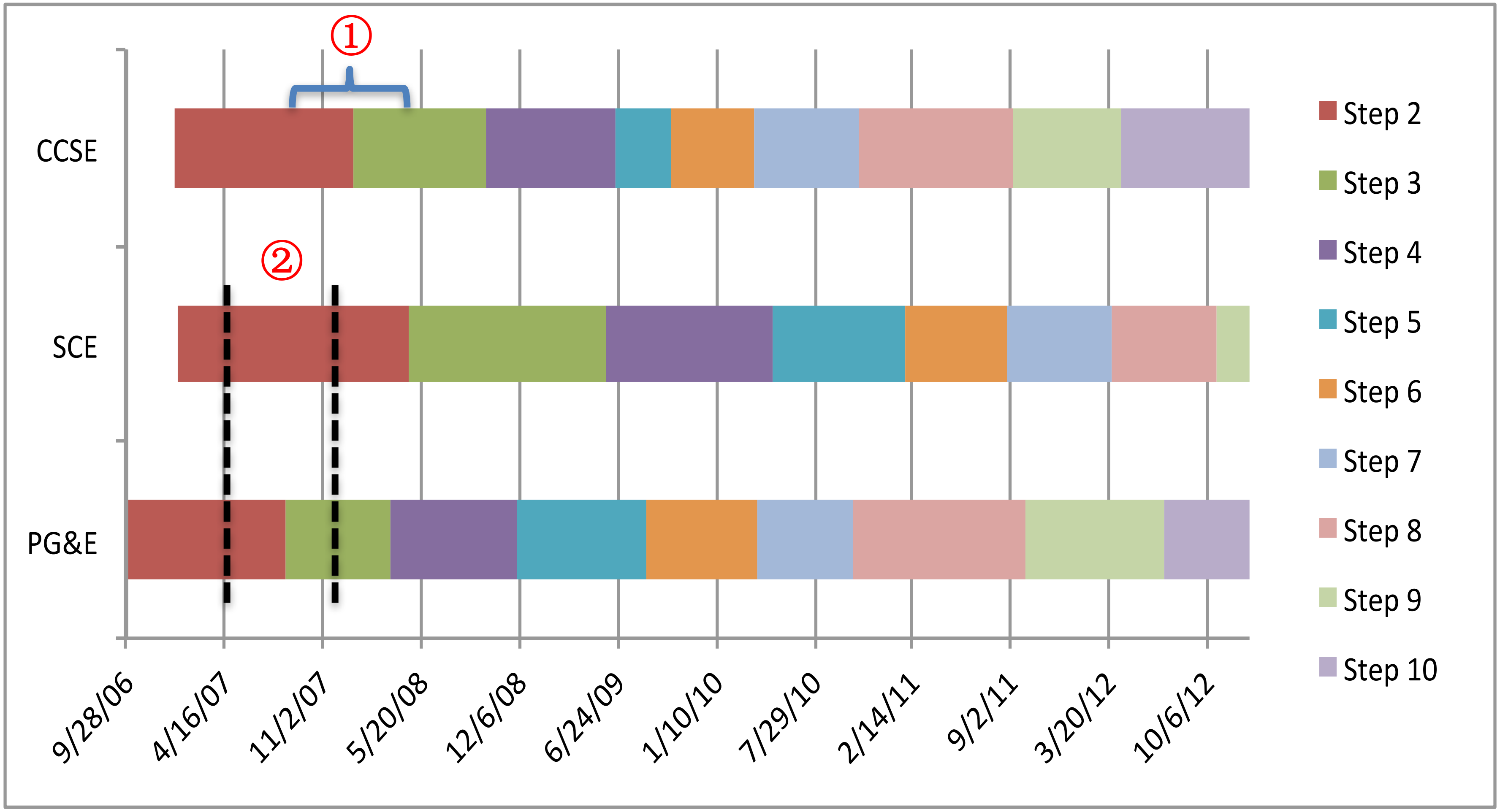


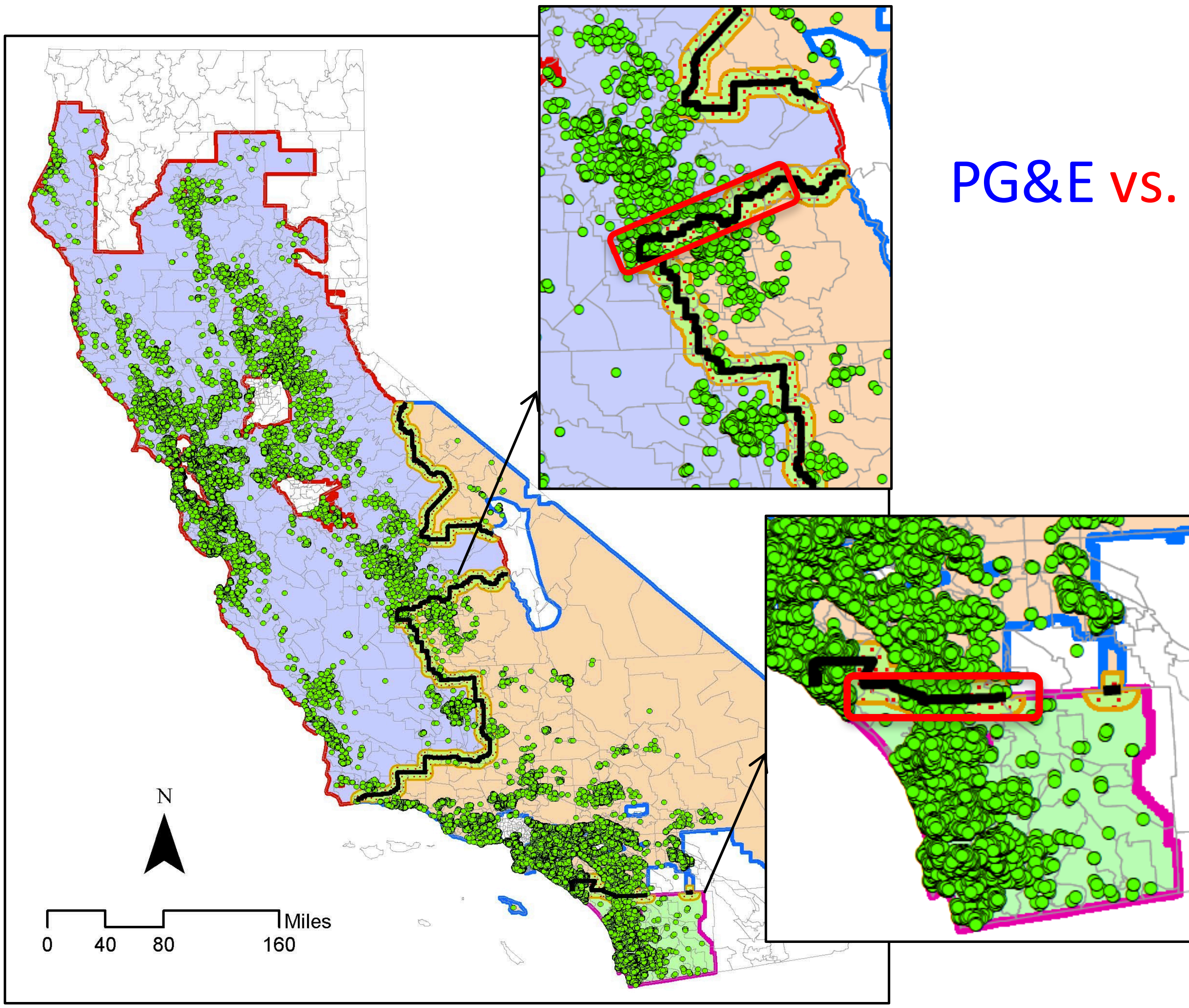
Fig. 2. Potential and observed outcome regression functions.

Source: Imbens & Lemieux, 2008.

Time Discontinuity: Date



Geo-Discontinuity: Map



PG&E vs. SCE

SCE
vs.
SDG&E
(CCSE)

Regression Discontinuity Design: Method

- There are parametric and non-parametric ways to estimate coefficients within the RD framework.

Parametric way:

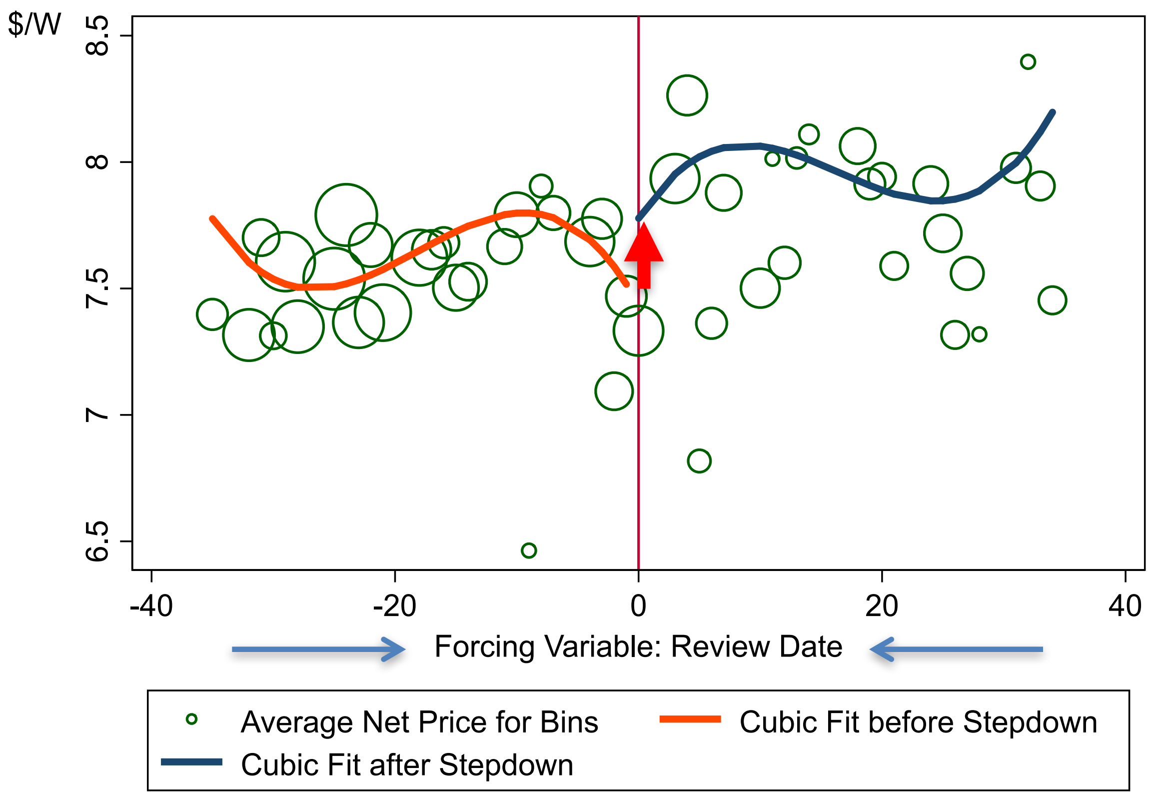
$$NP_{it} = \beta_1 \cdot r_{it} + f(x_i) + f(x_i) \cdot D_i + \theta_t + \varepsilon_{it}$$

Nonparametric way:

$$\text{NetPricepw}_i = \beta_1 \cdot \text{Rebatepw}_i + \beta_2 \cdot x_i + \beta_3 \cdot (\text{Rebatepw}_i \times x_i) + u_i$$

Time Discontinuity: Results for PG&E

- Pooling all eight stepdowns produces a 123% pass-through rate for cubic control, and 102% for quartic control.



*** Sizes of the bubbles are proportional to number of observations they represent

Overview of Other Results

- Time discontinuity
  - How to handle the pull-forward effect or selection bias?
  - Robustness checks on control variables, window size, placebo effect, installer heterogeneity, income effect.
- Geo-discontinuity
  - How to handle different time trends between two IOUs?
  - How to deal with the bias in the Difference-in-RD design?
  - Robustness checks on window size and placebo effect
- How to understand complete pass-through

My Other Works

- Forecasting residential PV deployment in California using four methods and evaluating the impacts of three policies: ITC extension, NEM 2.0, and VOS scheme
- Estimating WTP for PV adopters and non-adopters and simulating PV adoption for the whole United States
- Using machine learning algorithms to classify PV adopters and non-adopters

Thank you for your attention!