The Economic Impact of Inefficient Distribution Network Pricing: Evidence from California and a Framework for a Proposed Solution

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Distribution Network Pricing

- Historically distribution network costs recovered through a cents per kilowatt-hour charge
  - Pricing mechanism did not lead to inefficient outcomes because consumers had no choice but to purchase electricity from grid
- Distributed solar provides consumer with ability to avoid purchases from grid
  - Consumer pays $/KWh charge only on electricity withdrawn from grid
  - Retail price is avoided cost of energy from solar panels
    - P(retail) = P(Energy) + P(Trans) + P(Dist) + Other
    - Other = retailing margin, energy efficiency programs, above market cost of Renewables Portfolio Standard (RPS) energy, low-income energy programs, distributed generation and storage support mechanisms

California Solar Initiative (CSI)

- California has almost 7,000 MW of distributed solar installed
  - Most of it installed since 2007 under California Solar Initiative (CSI)
  - Peak demand for California in 2017 is slightly more than 50,000 MW (hit during heat wave of past summer)
- CSI provided $2.167 billion to support distributed solar installations
  - CSI funded by electric ratepayers through higher retail prices
- Higher $/KWh retail price encourages more consumers to install distributed solar
- California has 33% Renewables Portfolio Standard (RPS) by 2020 and 50% by 2030
  - Above-wholesale-market-price costs of qualified renewable energy included in retail price

Distribution Network Price Increases: Reason I

- Fixed cost of distribution grid does not depend on how many KWh are withdrawn from grid
  - Very small marginal cost of delivering 1 KWh
- As more customers install distributed solar, the same fixed cost must be recovered from fewer total KWh
  - $/KWh charge must increase
- Higher distribution charge increases incentive to install distributed solar
  - Avoid paying higher retail price of electricity
- “Other” factors from previous slide also increase per unit retail price

Distribution Network Price Increases: Reason II

- As more distributed solar is installed in a given distribution grid, upgrades may be necessary
  - Manage large surges of energy injections into grid during periods of the day with significant solar activity
  - Solar system sized to produce close to customer’s monthly consumption produces more electricity than customer consumes during daylight hours
    - Capacity factor of California solar rooftop solar system is approximately 0.17 = (Annual Kwh)/(KW x 8760 hours)
- Grid upgrades raise fixed cost of grid, which further increases $/KWh charge for use of distribution grid

The “Utility Death Spiral”

- Two reasons for increase in $/KWh distribution network price due to solar PV installations
  - (1) Mechanical—Less electricity withdrawn from grid on annual basis (same total cost divided by less electricity withdrawals)
  - (2) Grid integration costs—Upgrades of distribution network to accommodate more distributed solar (increases distribution costs)
- “Utility Death Spiral”
  - Higher prices lead to more rooftop solar, which leads to less withdrawals, which leads to higher prices and more rooftop solar and less withdrawals, which leads to higher prices...

Research Question

Controlling for the "mechanical impact," does more distributed solar increase or decrease distribution network costs?

Distribution Network Pricing in CA

- Current average residential price in California is 23 cents/KWh
  - Highest marginal price in PG&E territory is 40 cents/KWh
  - At $3.50/Watt installed, rooftop solar photovoltaic (PV) panels have a levelized cost equal to 18 cents/KWh (at 3 percent real discount rate)
    - Going solar requires no subsidies to make it privately profitable for “average“ California consumer
- Average wholesale cost of energy in California in 2016 was 3.5 cents per KWh
  - Socially unprofitable to invest in rooftop solar, because it is much cheaper for customer to get electricity from wholesale market
- Divergence between privately optimal decision and socially optimal decision due to inefficient distribution network pricing

Distribution Price Determination

- Public Utilities Commission (PUC) sets distribution network charge to recover annual fixed and operating cost of distribution grid from annual electricity sales by utility
- F_{iy} = annual cost of distribution network for utility i in year y
- QF_{iy} = forecast of annual demand for utility i in year y
- Q_{iy} = actual demand for utility i in year y
  - Note actual demand equals total consumption less distributed generation production
- $P_{it} = (F_{iy}/QF_{iy})\exp(\varepsilon_{it})$ = distribution charge of utility i in quarter t
- ε_{it} = i.i.d. mean zero random variable

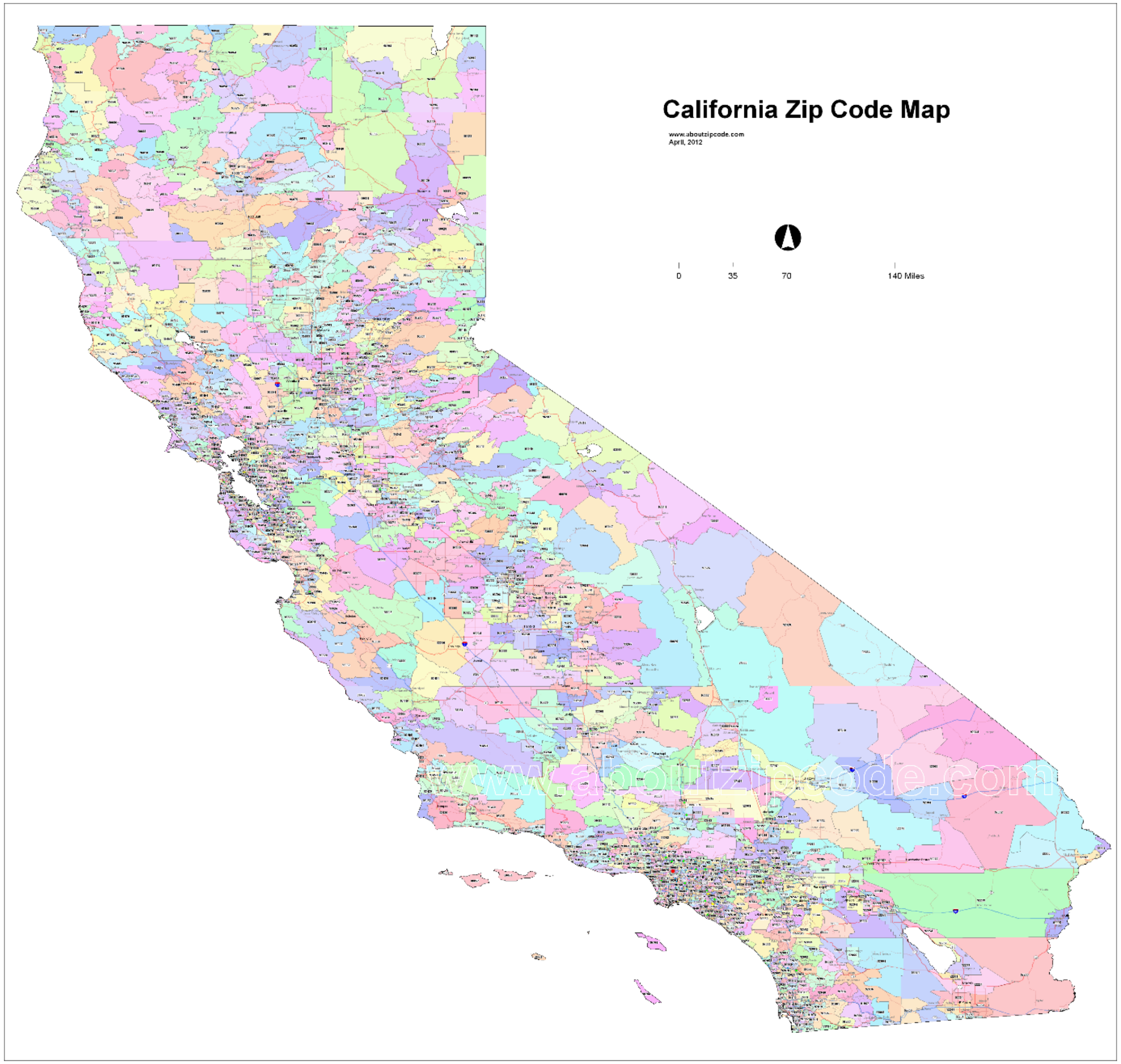
Distribution Price Determination

- Taking logs of both sides implies
  - $\ln(P_{it}) = \ln(F_{iy}) - \ln(QF_{iy}) + \varepsilon_{it}$
- Estimate econometric model
  - $\ln(P_{it}) = \alpha_{iy} + \beta\ln(QF_{iy}) + \delta\ln(CI_{it}) + \gamma\ln(CI_{it})\ln(CONC_{it}) + \varepsilon_{it}$
- CI_{it} = cummulative MWs of distributed solar installed in utility i's service territory as of the start of quarter t
- $CONC_{it} = \sum_{z=1}^{Z(i)} (\frac{CI_{zt}}{HH_{zt}})^2$
  - where CI_{zt} = cumulative MWs of distributed solar installed in zip code z of utility i's service territory as of start of quarter t
  - HH_{zt} = Number of households in zip code z of utility i's service territory in quarter t
  - Squared individual zip code-level ratios to emphasize large MW per household zip codes in index

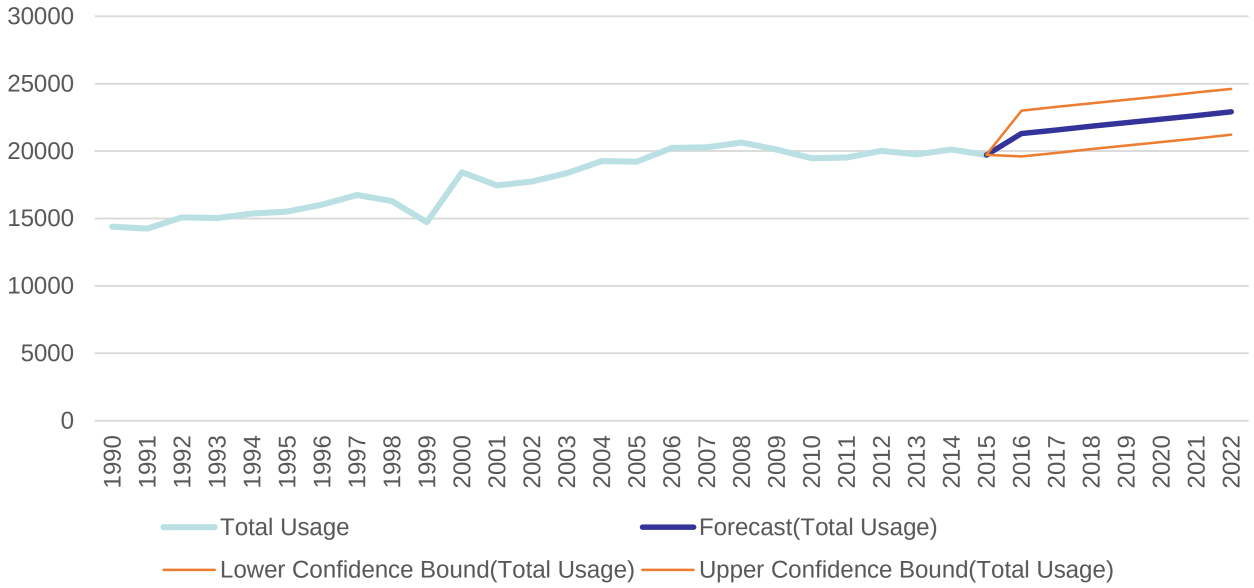
Distribution Price Determination

- Theory implies $\beta = -1$
  - If $\delta < 0$, then more distributed solar installs predicts reduced distribution grid costs
  - If $\delta > 0$, then more distributed solar installs predicts increased distribution grid costs
- If $\delta > 0$, then it is likely that the more concentrated solar installations are in utility i's service territory, larger the value of $\ln(CONC_{it})$, the larger is the marginal effect of $\ln(CI_{it})$
  - $\gamma > 0$ implies that one more 1 MW of solar PV in a more concentrated solar zip code increases impact of ln(CI) on distribution prices
    - More distribution upgrades are required to accommodate additional MW of solar PV

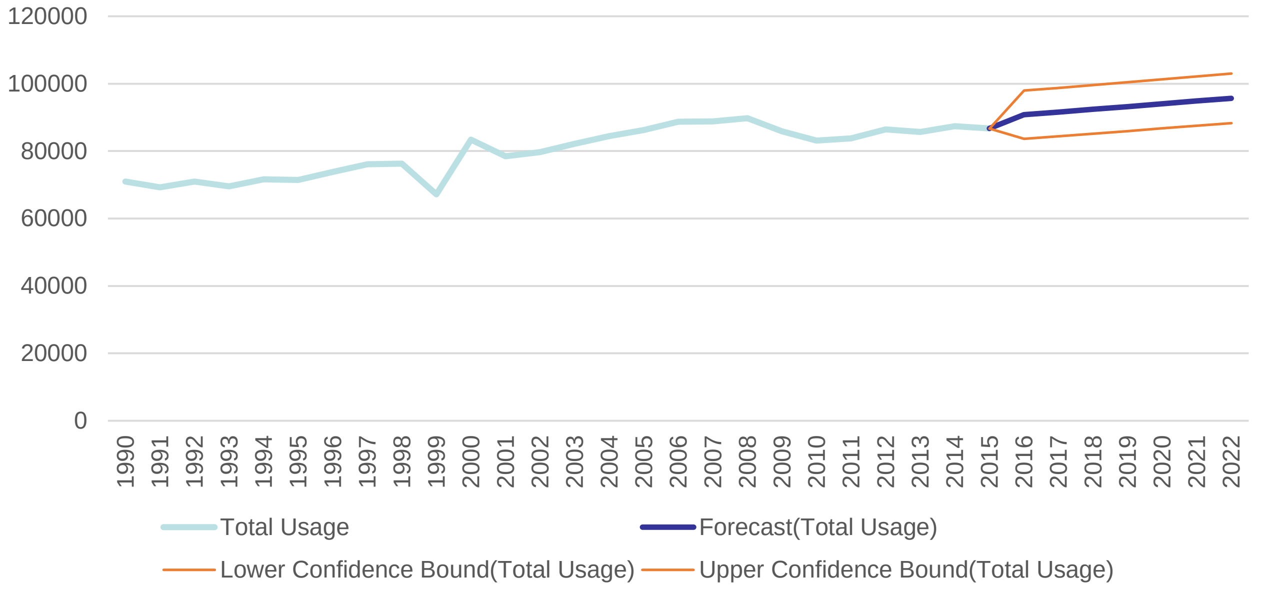
Map of California Zip Codes



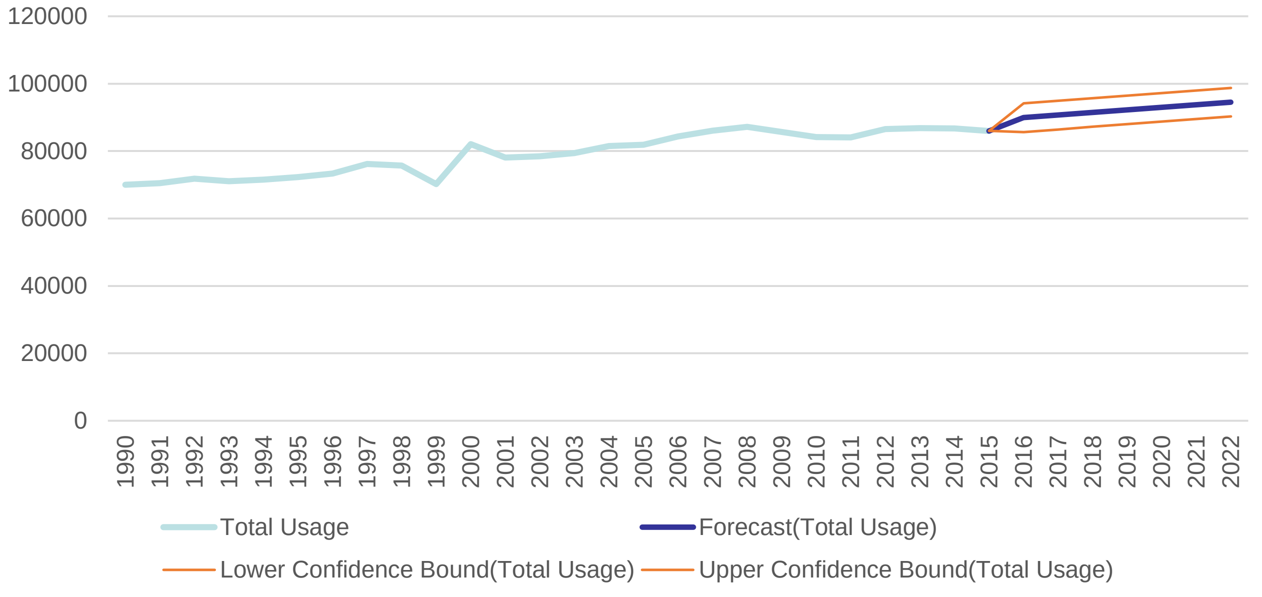
Annual Load—SDG&E 1990-2016 (GWh)



Annual Load--SCE 1990-2016 (GWh)



Annual Load—PG&E 1990-2016 (GWh)



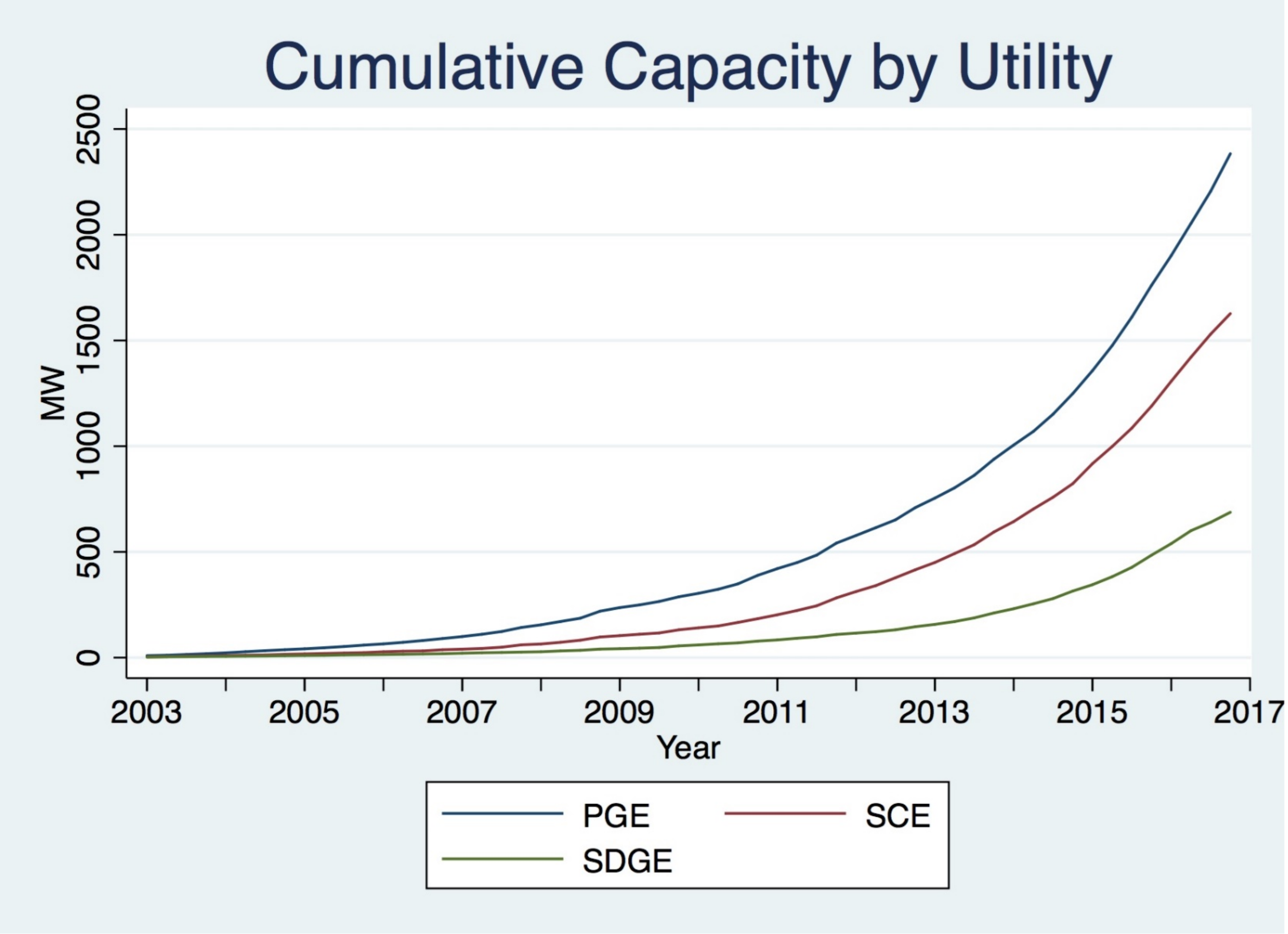
Distribution Price Determination

- Compute QF_{iy} using following procedure
- Using annual demand data from 2000 to 2016 for San Diego Gas and Electric (SDG&E), Southern California Edision (SCE), and Pacific Gas and Electric (PG&E) estimate model
  - $Q_{iy} = \lambda_i + \mu_y + \pi Q_{iy-1} + v_{iy}$
- Compute QF_{iy} as
  - $QF_{iy} = l_i + m_y + pQ_{iy-1}$ for y=2001 to 2016
- QF_{iy} is assumed forecast of annual demand for years 2001 to 2016

Distribution Price Determination

- Estimate models
  - $\ln(P_{it}) = \alpha_{iy} + \beta\ln(QF_{iy}) + \delta\ln(CI_{it}) + \varepsilon_{it}$
  - $\ln(P_{it}) = \alpha_{iy} + \beta\ln(QF_{iy}) + \delta\ln(CI_{it}) + \gamma\ln(CI_{it})\ln(CONC_{it}) + \varepsilon_{it}$
- Use quarterly data on distribution charges for SDG&E, SCE, and PG&E from Quarter 1 of 2003 to Quarter 2 of 2016
- Use quarterly data on cumulative MWs of distributed solar generation capacity installed for SDG&E, SCE, and PG&E from Quarter 1 of 2003 to Quarter 2 of 2016
  - Data obtained from California Solar Initiative (CSI)
- Zip code-level number of households (HH) data obtained from US Census

Distributed Solar PV Capacity in MWs



Base Model Estimation Results

Coefficient	Estimate	Standard Error
β	-1.351	0.641
δ	0.101	0.033

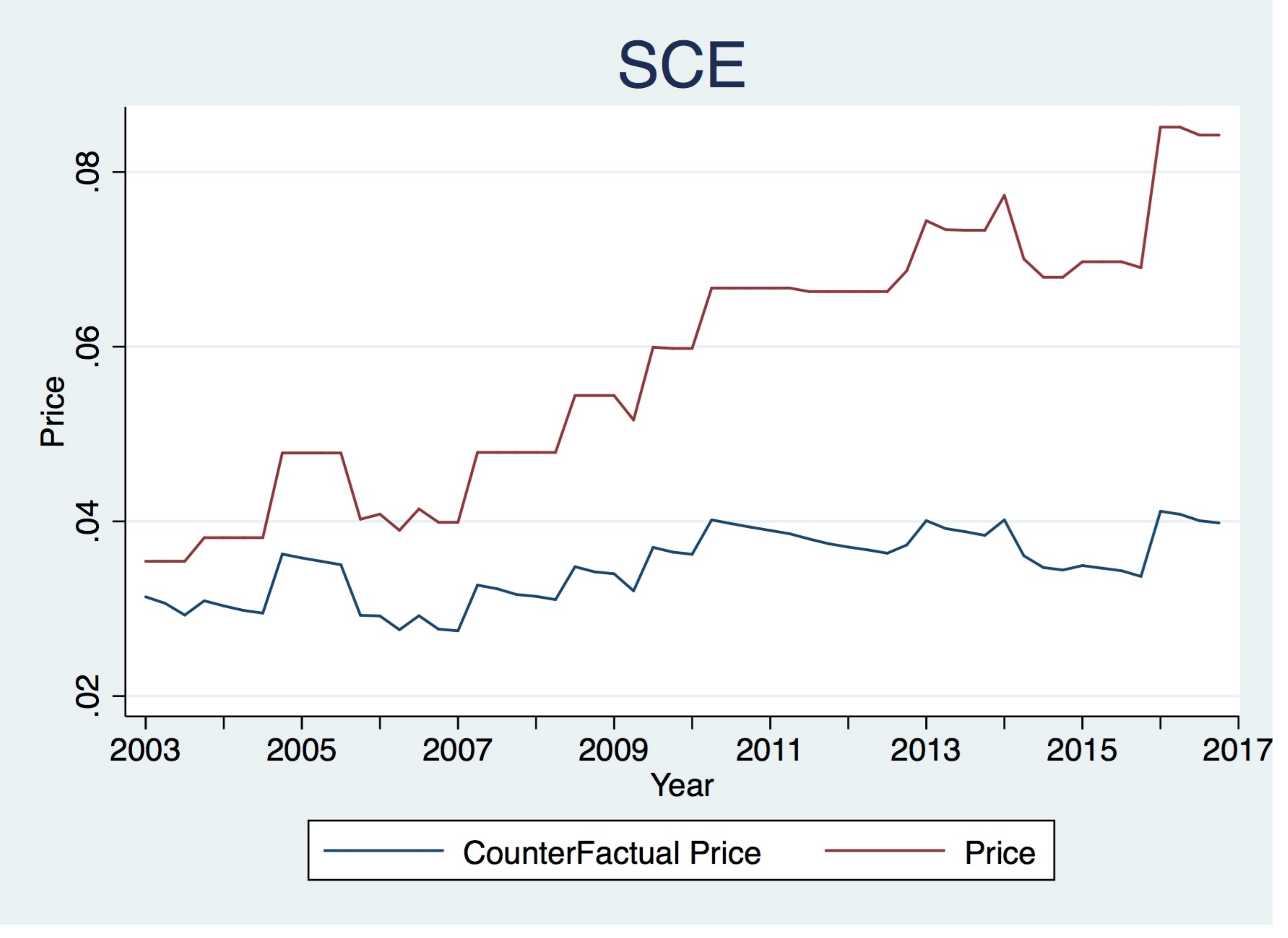
- Test of null hypothesis that β = -1 is not rejected
- Test of null hypothesis that δ = 0 can be rejected and null hypothesis that δ > 0 cannot be rejected
  - Increased distributed solar MWs predicts higher network charges beyond mechanical impact due to lower quantity of withdrawals from distribution grid

Full Model Estimation Results

Coefficient	Estimate	Standard Error
β	-1.405	0.630
δ	0.103	0.033
γ	0.003	0.001

- Test of null hypothesis that β = -1 is not rejected
- Test of null hypothesis that δ = 0 can be rejected and null hypothesis that δ > 0 cannot be rejected
- Test of null hypothesis that γ = 0 can be rejected and null hypothesis that γ > 0 cannot be rejected
  - Increased concentration of solar MWs predicts higher marginal impact of cumulative installs

Actual and Counterfactual Distribution Network Price (Baseline Model)



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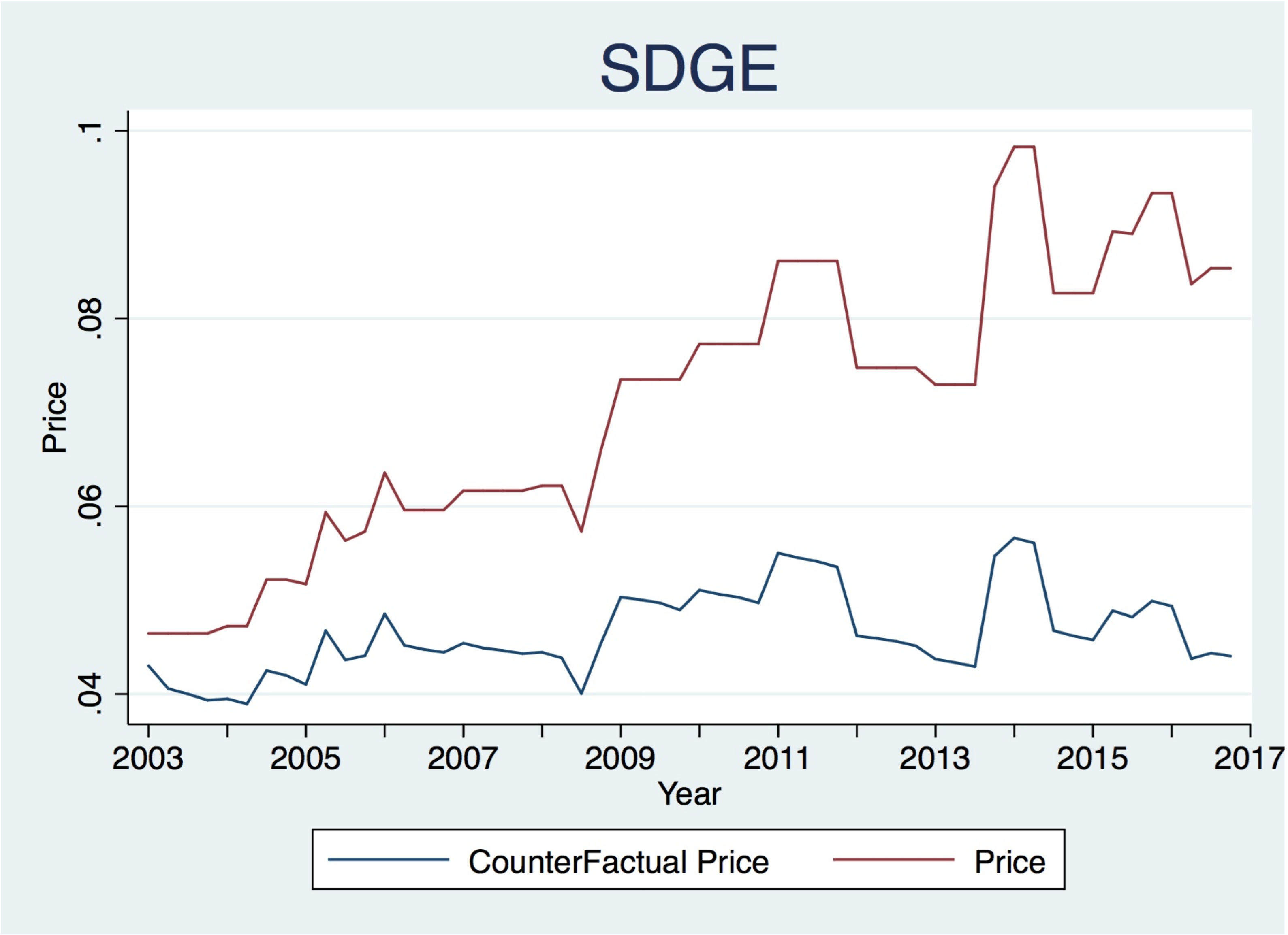
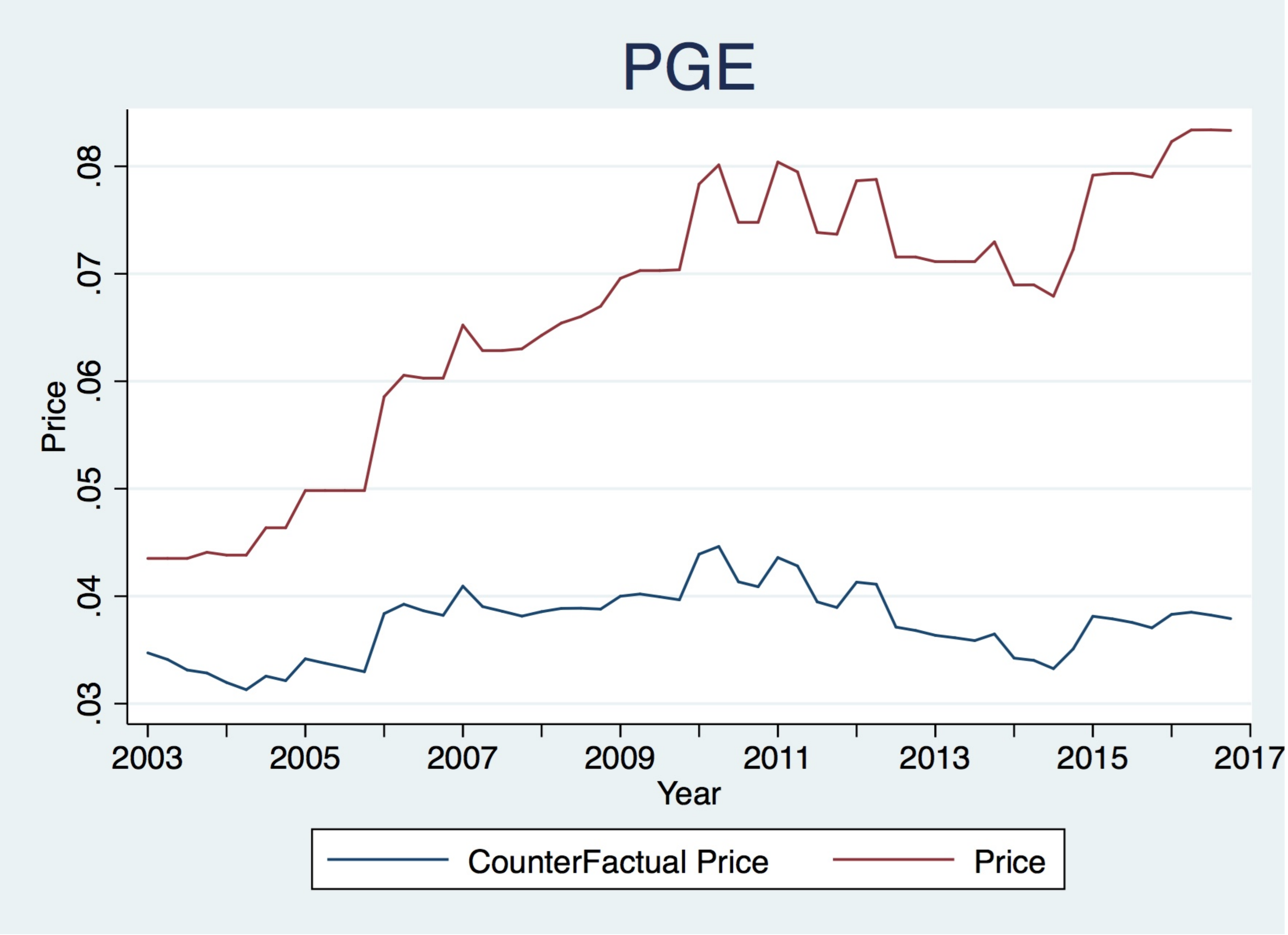
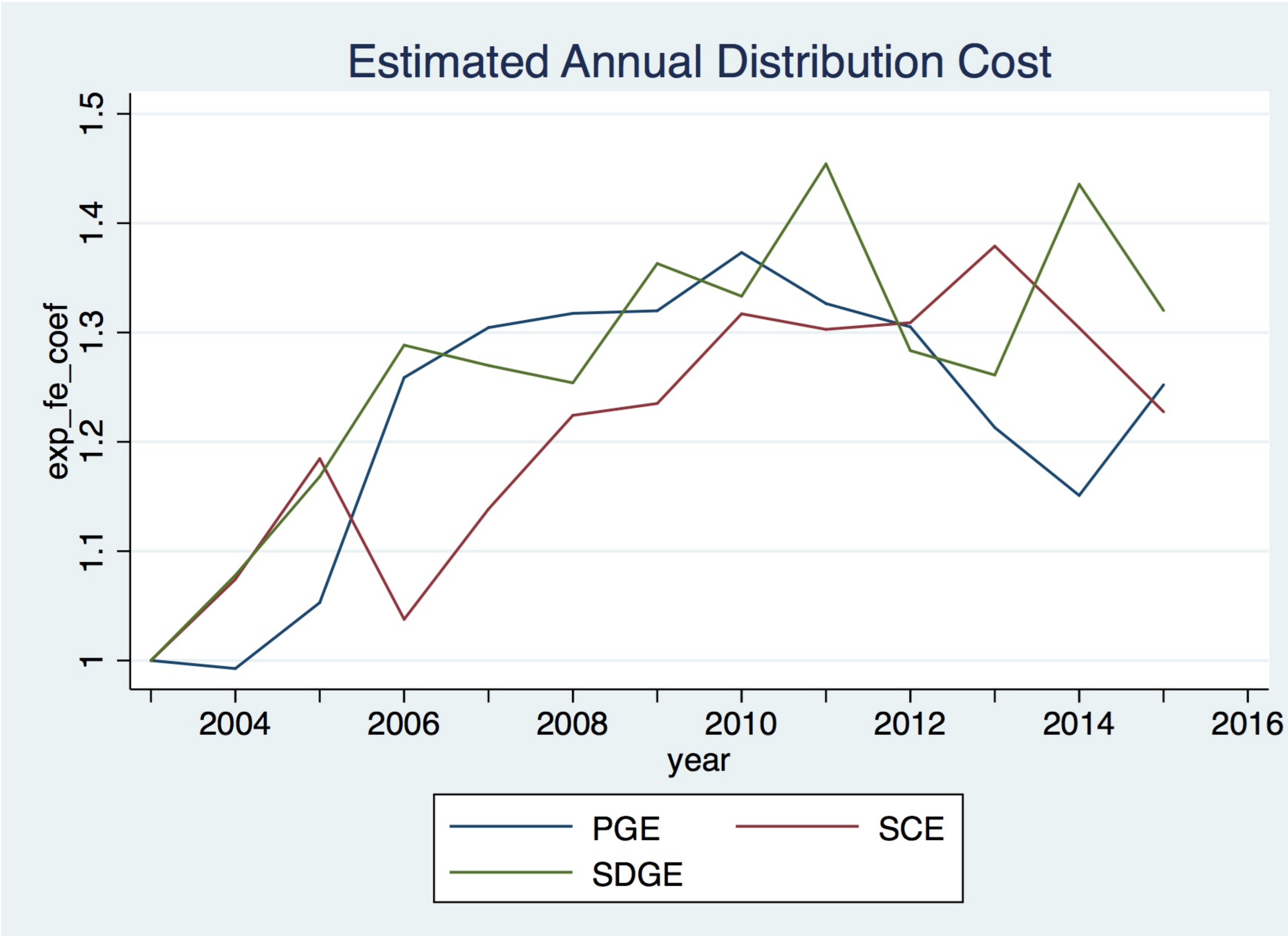


Actual and Counterfactual Distribution Network Price (Baseline Model)



Estimated Annual Distribution Costs for SDG&E, SCE, and PG&E (Normalized to 1 in 2003)



Implications of Results

- Results suggest that virtually all of the distribution price increase since 2003 for each investor-owned utility can be attributed to increasing integration cost of distributed solar (2nd explanation)
- Annual average wholesale energy, ancillary services and capacity costs per KWh of load in California in 2016 is 3.5 cents/KWh
- Counterfactual no renewables retail price is likely no higher than 9.5 cents/KWh =
  - 3.5 cents/KWh for energy
  - 4 cents/KWh for distribution
  - 2 cents/KWh for transmission and retail margin

Network Price Increases

- Reasons for increase in $/KWh distribution network price due to solar PV installations
  - (1) Mechanical—Less electricity withdrawn from grid on annual basis (same total cost divided by less electricity withdrawals)
    - Empirical evidence that this has had a small positive impact (~1 cent/KWh) thus far
  - (2) Grid integration costs—Upgrades of distribution network to accommodate more distributed solar (increases distribution costs)
    - Vast majority of distribution network price increase likely due to this fact (~3-4 cents/KWh)
  - (3) Additional possible explanation for empirical results—Shifting other costs to distribution prices

Network Sunk Cost Recovery

- Urgent problem--There is no guarantee that a utility receives cost recovery for an obsolete investment
  - "Utility only guaranteed an opportunity to earn a fair return" (Justice Brandeis)
  - Superior competitive technology that renders past investments obsolete makes cost recovery unlikely
- Ultimate outcome unclear because rooftop does not render transmission or distribution obsolete
  - It is unnecessary only certain times of the day
- Policy Question—Can a set of principles be established to determine how sunk cost recovery is split between
  - Full-requirements customers, distributed solar customers, and shareholders

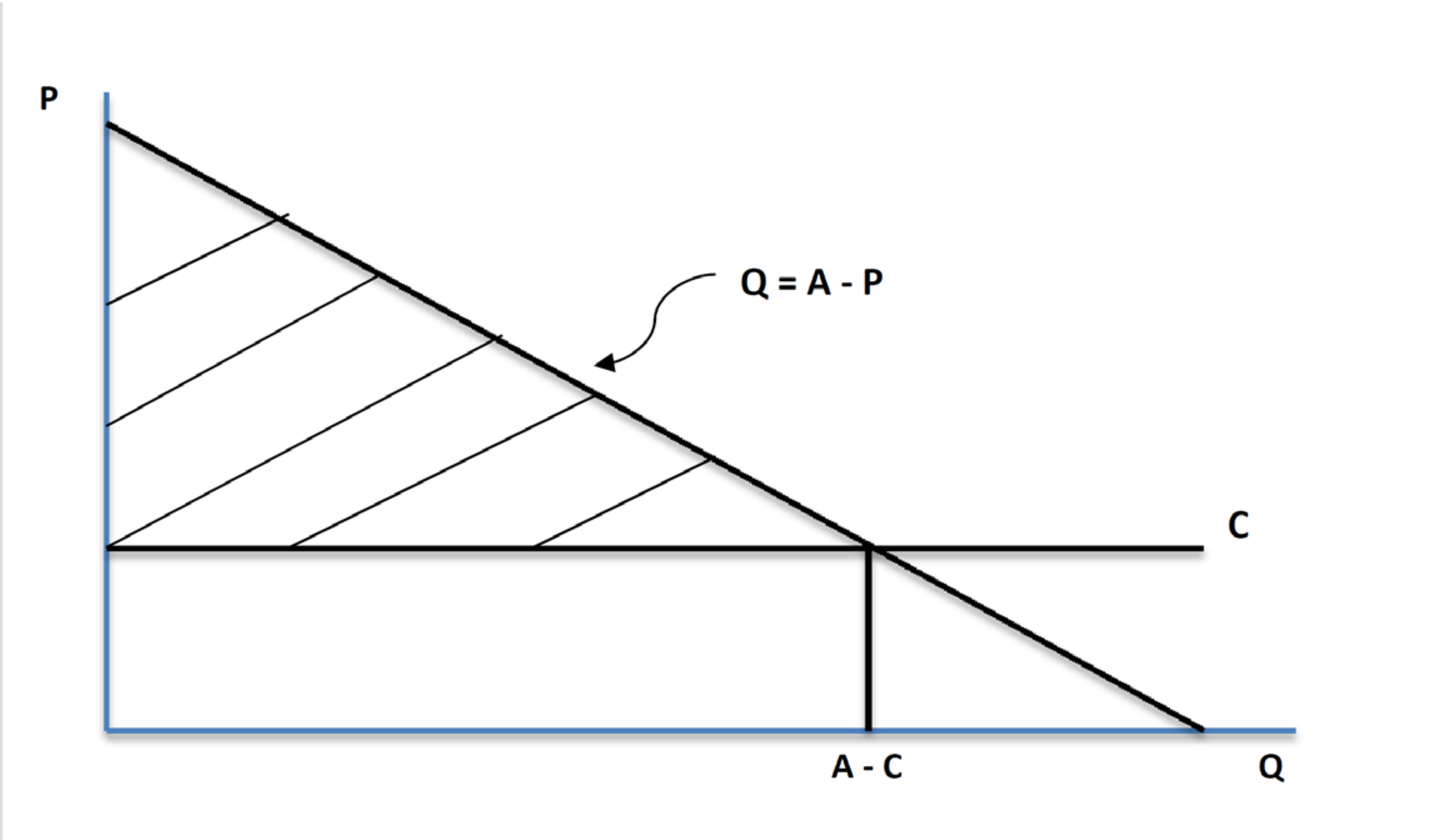
Improving Efficiency of Distribution Pricing

- Several utilities have recently attempted to revise distribution pricing mechanism
  - NV Energy in Nevada
  - Salt River Project in Arizona
  - Three California IOUs
- Base prices charged on cost causation principles
  - Wolak (2016) "Distribution Network Pricing to Support Cost-Effective Distributed Generation Investment."
    - Recover most of cost in monthly fee
      - Distribution network charges look much more like high-speed internet bill
    - Small, less than 1 cent/kWh, per KWh charge set to vary with real-time conditions in grid

Distribution Pricing Proposal

- For customers with interval meters there is a straightforward approach to more efficient distribution network pricing
  - $C(h,i)$ = marginal cost of retail electricity in hour h (wholesale price*(1+marginal losses)) for customer i
  - $Q(h,i)$ = demand in hour h for customer i
  - $P(h,i)$ = variable price in hour h for customer i
  - $Q(h,i) = A(h,i) - P(h,i)$ = demand curve in hour h for customer i

Distribution Pricing Proposal



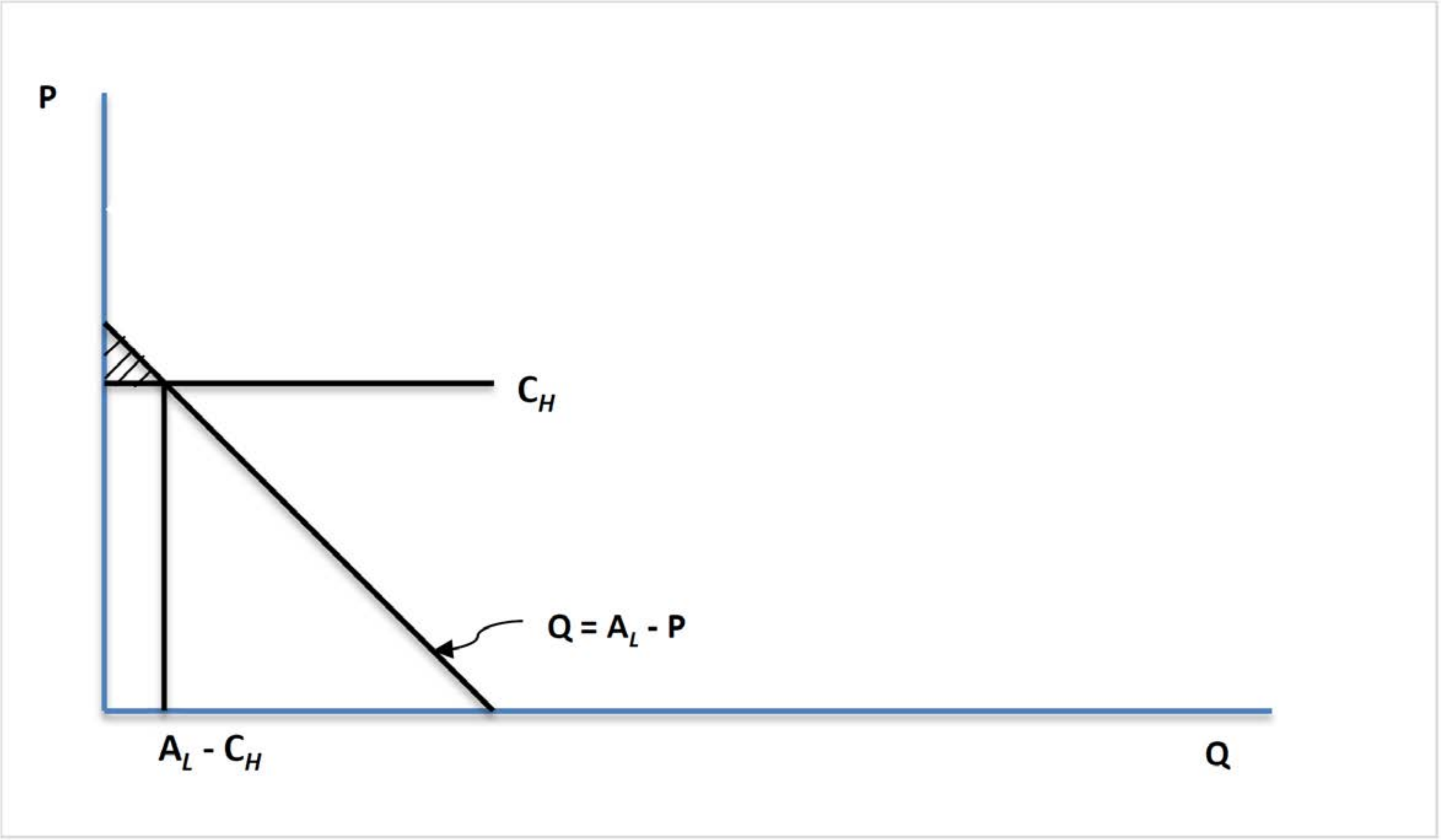
Distribution Pricing Proposal

- Efficient pricing for customer i sets the hourly variable price equal to P(h,i) = C(h,i)
- Customer's fixed charge must be less than or equal to its consumer surplus at C(h,i)
  - $CS(h,i) = ½*(A(h,i) – C(h,i))^2$
- Customer's maximum willingness to pay for (A(h,i) – C(h,i)) KWh is
  - CS(h,i) + (A(h,i) - C(h,i))C(h,i)

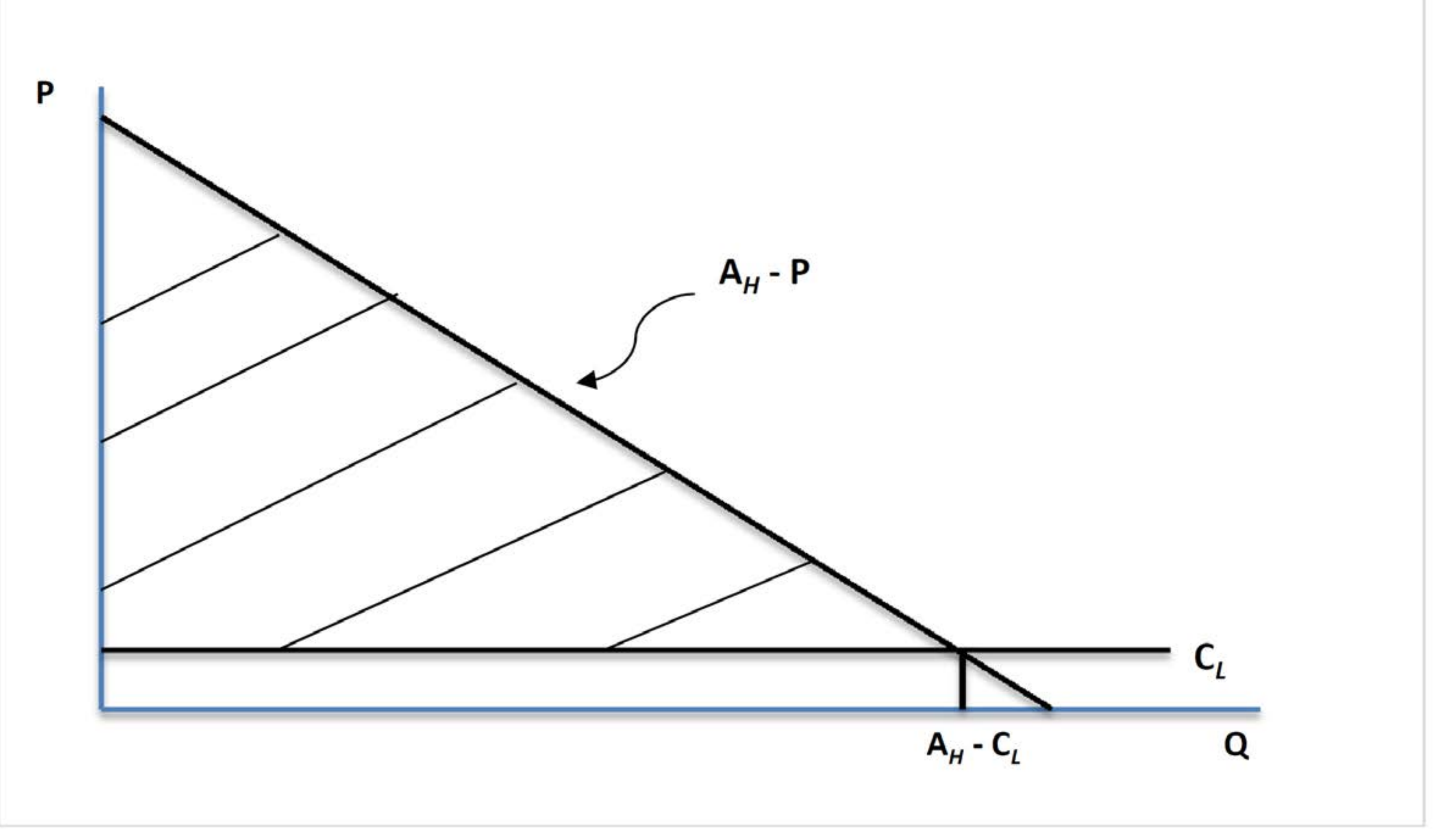
Distribution Pricing Proposal

- Customer's baseline demand A(h,i) and marginal cost of using the distribution network C(h,i) varies across hours of the year
- Suppose that (A(h,i),C(h.i)) has a joint distribution with compact support $[A_L,A_H]$ and $[C_L,C_H]$
- Suppose that the consumer will remain connected to the grid for the year if the annual fixed charge is less than the expected value of the annual consumer surplus obtained from consuming at P(h) = C(h) each hour of the year

Distribution Pricing Proposal



Distribution Pricing Proposal



Distribution Pricing Proposal

- Fixed charge to achieve sunk cost recovery adjusted across customers based on following logic
  - Expected consumer surplus is $E(½(A(h,i) – C(h,i))^2$

    $= ½ (Var(A(h,i)) – 2Cov(A(h,i),C(h,i)) + Var(C(h,i)) + (E(A(h.i) - E(C(h,i))^2$
- Note that $E(Q(h,i)) = E(A(h,i)) – E(C(h,i))$
- Customers with highest willingness to pay have
  - Higher expected demand
  - More volatile demand
  - Face more volatile prices
  - Price are negatively correlated with their demand
- Can set higher fixed fee for these customers to recover sunk cost of distribution network

Concluding Comments

- Major challenge of current system for distribution and transmission sunk cost recovery leads to inefficient bypass, inefficient electricity consumption, and under-recovery of fixed costs
- Legal case for full fixed cost recovery is not strong
  - Success more unlikely the longer the decision is delayed
- Default dynamic retail pricing with fixed charge set based on willingness to pay
  - Customer can hedge most of dynamic price risk
  - "Monthly cable bill" app network access
- No demand charges—Provides incentives for customers to take costly actions that are highly unlikely to benefit market efficiency

Questions/Comments

For more information

http://www.stanford.edu/~wolak