Supply Curves for Conserved Electricity

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Resources for the Future

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Introduction

- Failure of comprehensive federal cap and trade policy for greenhouse gas emissions means that climate policy will come in "chunks" (President Obama, *Rolling Stone* interview).
- One chunk is likely to be policies to promote energy efficiency
- Energy efficiency (EE) policies are also justified on basis of other market failures/behavioral issues (Gillingham et al. 2009)
  - Principal / Agent Issues
  - Asymmetric Information
  - Lack of access to capital
  - Behavioral "failures"
- How much electricity can such EE policies save and at what cost?
- <more>

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Approaches to EE Modeling: Bottom-up vs. Top-down

- Bottom-up
  - Structural, technology-rich models are ideal.
  - Data and preference characterization requirements are prohibitive with so many technologies.
  - Nonetheless, bottom-up models dominate the field.
- Top-down
  - Efficiency potential is based on econometrically estimated electricity demand functions.
  - Data on specific technologies and costs are unnecessary.
  - This is ultimately not the preferred model, but in the absence of strong bottom-up models, is informative.

Literature Review

- Many studies seek to measure potential energy savings from adopting more efficient technologies:
  - Regional: Itron, Inc. (2006), ACEEE (2008a, 2008b), Brown et al. (2010)
  - National : EPRI (2009), McKinsey & Company (2009), National Research Council (2009)
  - Studies estimate potential savings of between 8 and 40 percent
- Studies identify technical, economic and achievable savings
- Some studies trace out supply curves for energy savings/CO_2
  - Azevedo et al. (2010) for residential electricity and residential energy
  - Gellings et al. (2006) for electricity savings (roughly linear)
  - McKinsey et al (2007) for CO_2 emissions reductions (substantial number of tons at cost < 0)
  - Sweeney and Weyant (2008) for CO_2 reductions in CA

Electricity Demand System Overview

- Demand functions
  - Partial adjustment functional form proxies capital immobility.
  - Parameters derived in Paul et al (2009).
  - Calibrated to AEO 2010.
- Demand Conservation Incentive (DCI)
  - Simulates EE program (w/admin costs) as a non-discriminatory price subsidy to avoided electricity consumption.
  - Calibrated to EE program performance in Arimura et al (2009).
- Interaction
  - Long-run effects of short-run DCI consumption reductions captured by demand function capital adjustment parameters.

Electricity Demand Functions

- Partial Adjustment
  - Derived from long-run demand and an adjustment process.

$$\left.\begin{aligned} Q_t^L &= P_t^{\varepsilon_L} X_t^{\beta} \\ \frac{Q_t^{\,2}}{Q_{t-1}Q_{t-12}} &= \left(\frac{Q_t^L}{Q_{t-1}}\right)^{\theta_1}\left(\frac{Q_t^L}{Q_{t-12}}\right)^{\theta_{12}} \end{aligned}\right\} \Rightarrow \begin{aligned} Q_t &= P_t^{\varepsilon}\left(X_t^{\beta(\theta_1+\theta_{12})} Q_{t-1}^{1-\theta_1} Q_{t-12}^{1-\theta_{12}}\right)^{1/2} \\ \text{where } \varepsilon &= \frac{\theta_1+\theta_{12}}{2}\varepsilon_L \end{aligned}$$

  - Parameters β, θ_1, θ_{12}, ε_L estimated in Paul et al (2009).
- Dimensions and Calibration
  - Dimensions: month (t), state (i), customer class (c)
  - Calibrator, C_t, solved for AEO 2010 prices and quantities.

$$Q_t = C_t P_t^{\varepsilon} X^{\alpha} Q_{t-1}^{\phi_1} Q_{t-12}^{\phi_{12}}$$

where α and ϕ_x depend on β and θ_x.

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Short-Run and Long-Run Price Elasticity of Electricity Demand

	Residential		Commercial		Industrial		*CC Average*	
	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run
Regional Results in Annual Average								
New England	-0.17	-0.51	-0.13	-0.37	-0.08	-0.20	*-0.13*	*-0.37*
Middle Atlantic	-0.05	-0.14	-0.01	-0.02	-0.20	-0.48	*-0.07*	*-0.19*
East North Central	-0.12	-0.36	-0.17	-0.70	-0.09	-0.22	*-0.12*	*-0.35*
West North Central	-0.21	-0.61	-0.14	-0.34	-0.11	-0.25	*-0.16*	*-0.39*
South Atlantic	-0.08	-0.27	-0.04	-0.09	-0.16	-0.44	*-0.08*	*-0.24*
East South Central	-0.32	-1.16	-0.22	-0.54	-0.19	-0.61	*-0.24*	*-0.75*
West South Central	-0.11	-0.33	-0.08	-0.22	-0.11	-0.28	*-0.10*	*-0.28*
Mountain	-0.19	-0.49	-0.14	-0.34	-0.18	-0.42	*-0.17*	*-0.42*
Pacific	-0.13	-0.37	-0.17	-0.45	-0.31	-0.82	*-0.20*	*-0.53*
National Average	**-0.13**	**-0.40**	**-0.11**	**-0.29**	**-0.16**	**-0.40**	***-0.13***	***-0.36***
Seasonal Results in National Average								
Summer	-0.15	-0.52	-0.12	-0.34	-0.14	-0.36	*-0.14*	*-0.40*
Winter	-0.11	-0.32	-0.08	-0.22	-0.19	-0.48	*-0.13*	*-0.34*
Spring/Fall	-0.12	-0.35	-0.10	-0.27	-0.15	-0.39	*-0.12*	*-0.33*
Annual Average	**-0.13**	**-0.40**	**-0.11**	**-0.29**	**-0.16**	**-0.40**	***-0.13***	***-0.36***

source: Paul et al 2009

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Demand Conservation Incentive (DCI)

- Market clearing subsidy price, D_t, satisfies…

$$\frac{F_t(1-A)}{D_t} = KQ_t\left[1-\left(1+\frac{D_t}{P_t}\right)^{\varepsilon}\right]$$

consumption reductions
bought by EE program on LHS
provided by consumers on RHS

F_t=funding ($) in year t
A=administrative cost (%)
D_t=DCI price ($/MWh) in year t
K=calibrator
Q_t=electricity consumption (MWh) in year t
P_t=electricity price ($/MWh)in year t
ε=short-run price elasticity

- RHS is derived from simplified version of demand functions.
- DCI price is per unit of year-one reductions. Lagged reductions follow from adjustment parameters in demand functions.
- To be exact, Q_t is counterfactual electricity consumption.

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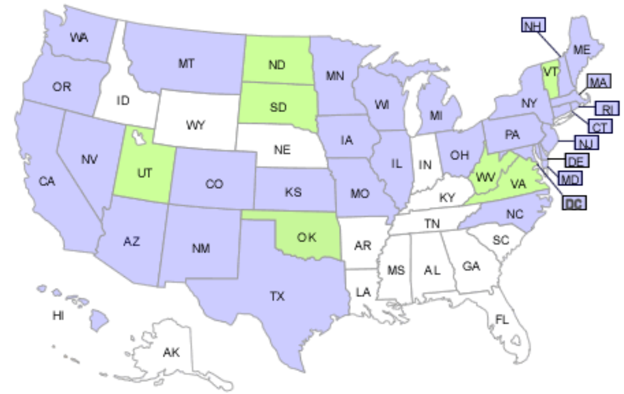
DCI Calibration

- Captures program implementation inefficiencies.
- Calibrate to Arimura et al (2009) who found that the average utility during 1995-2006 would have realized 1.1% electricity savings at an average cost of $30/MWh for spending of $8/customer on EE programs.
- Alternative calibration: 2.2% savings
  - Suppose that…
    - program proliferation and expansion improves implementation efficiency
    - consumer receptiveness to EE inducements improve
    - Arimura et al underestimated savings
  - … then assume double electricity savings = 2.2%.

Baseline (BL) Scenario

- AEO 2010 calibration
- Simulation horizon to 2035
- State RPS policies in 29 states + DC
  - characterized by level, timing, basis, coverage, technologies, inter-state REC trading, and ACP



- Tax Credits for Renewables
  - 6 state programs and federal ARRA
  - ARRA allows choice between production or investment credit
- Environmental regulations
  - Title IV of 1990 CAAA for SO_2, CAIR for SO_2 and NO_x, RGGI, state Hg MACT
- Demand forecasts reflect effects of state and federal efficiency standards modeled in AEO 2010

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Efficiency Spending and Policy Scenarios

- Efficiency spending
  - Trace out supply curves by varying levels of EE spending
    - $250 million, $1 billion, $2 billion, $5 billion, $10 billion
    - Spending starts in 2012 and ends in 2030 so model captures all savings
- DCI policy designs / combinations
  - DCI – standard approach (1.1% calibration, 40% admin costs)
  - CTP – standard approach with CO_2 cap and trade
  - Adm20 – standard approach with 20% admin costs
  - 2Red – DCI calibrated to 2.2% reductions
  - DCI_PD* – standard DCI approach with price discrimination
  - 2Red_PD* – 2.2% reductions case with price discrimination
    - *Post-processing calculation, not solved endogenously within Haiku.

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Results

- Electricity consumption
  - effects drive electricity prices and CO_2 emissions
- EE supply curve
- Sensitivity cases

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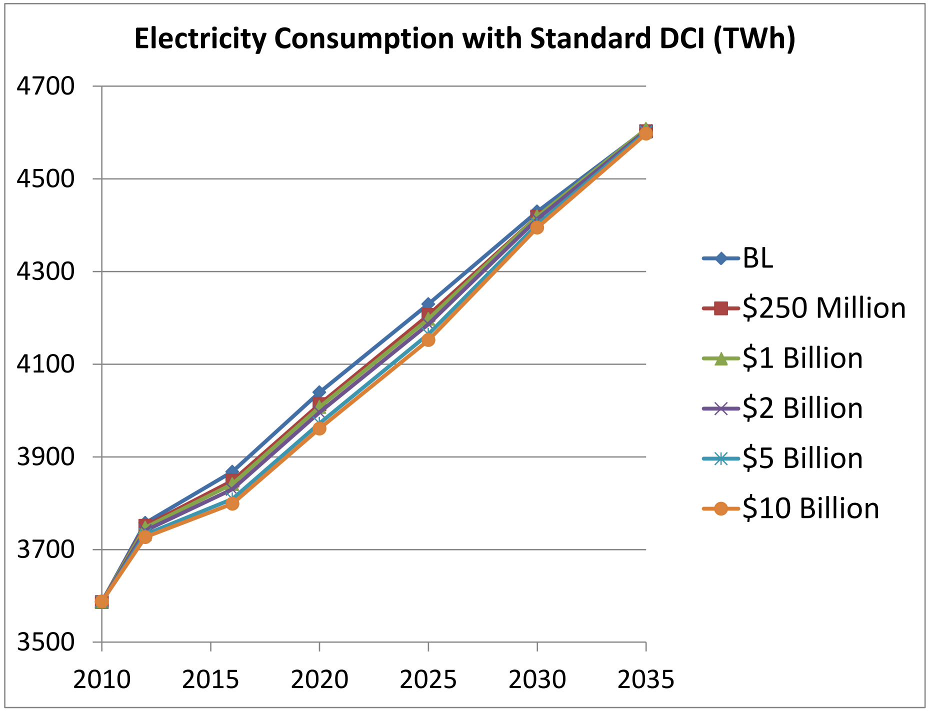
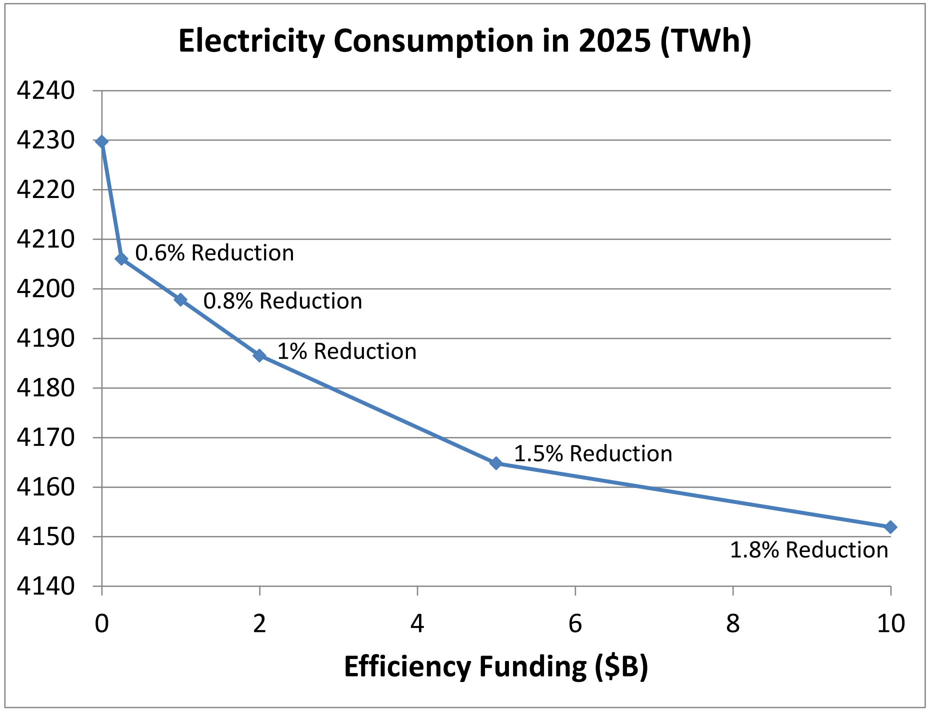
Electricity Consumption





- DCI programs buy electricity consumption reductions of up to 1.7% of BL consumption.
- By 2035 (5 years after DCI funding ends), consumption levels have approximately returned to BL levels.

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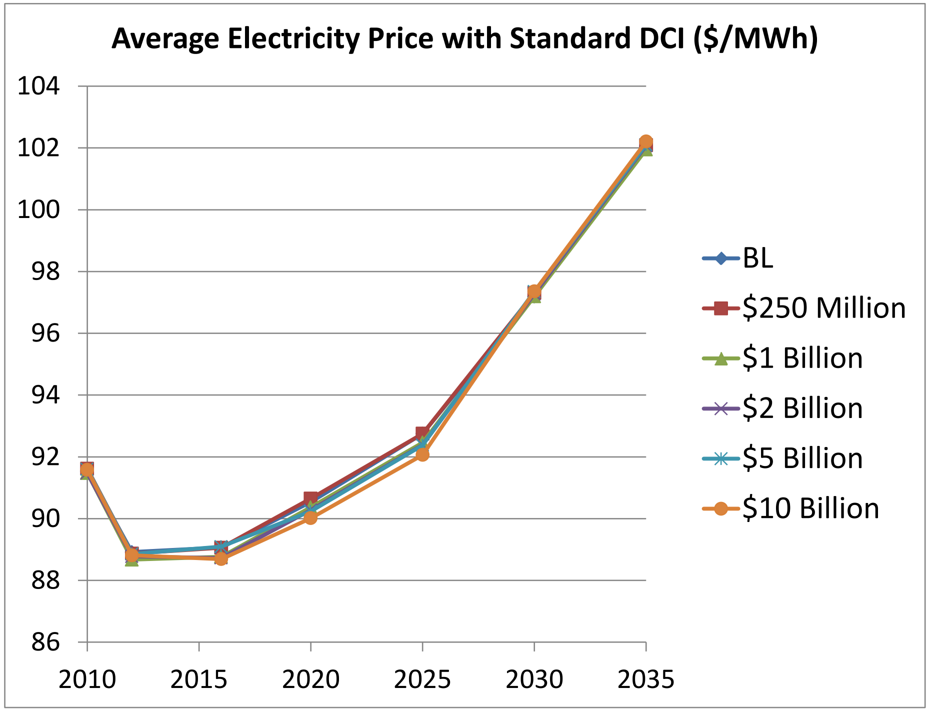
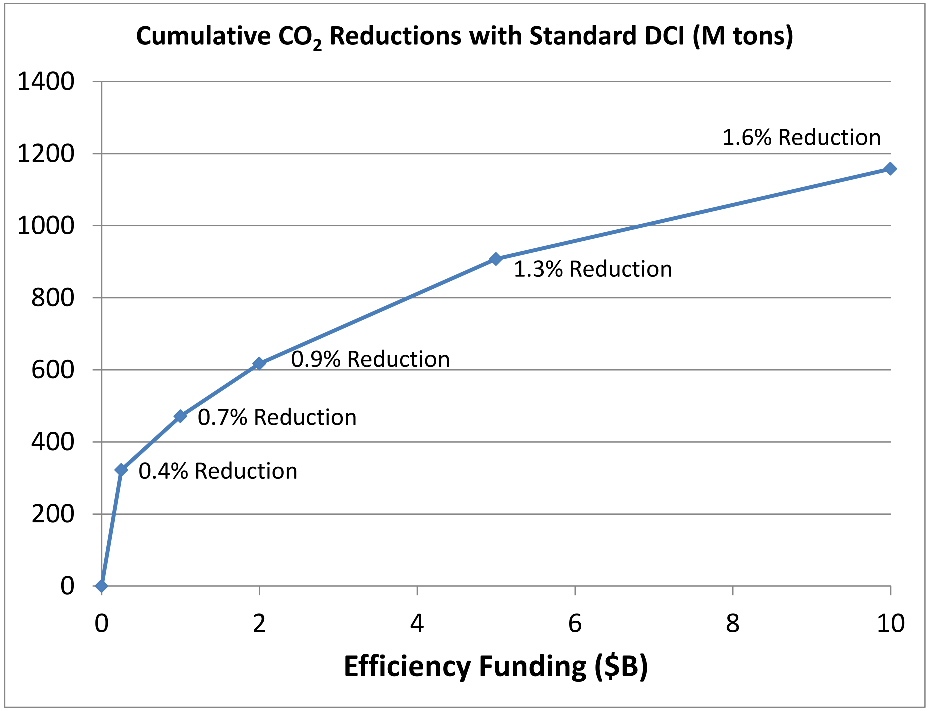
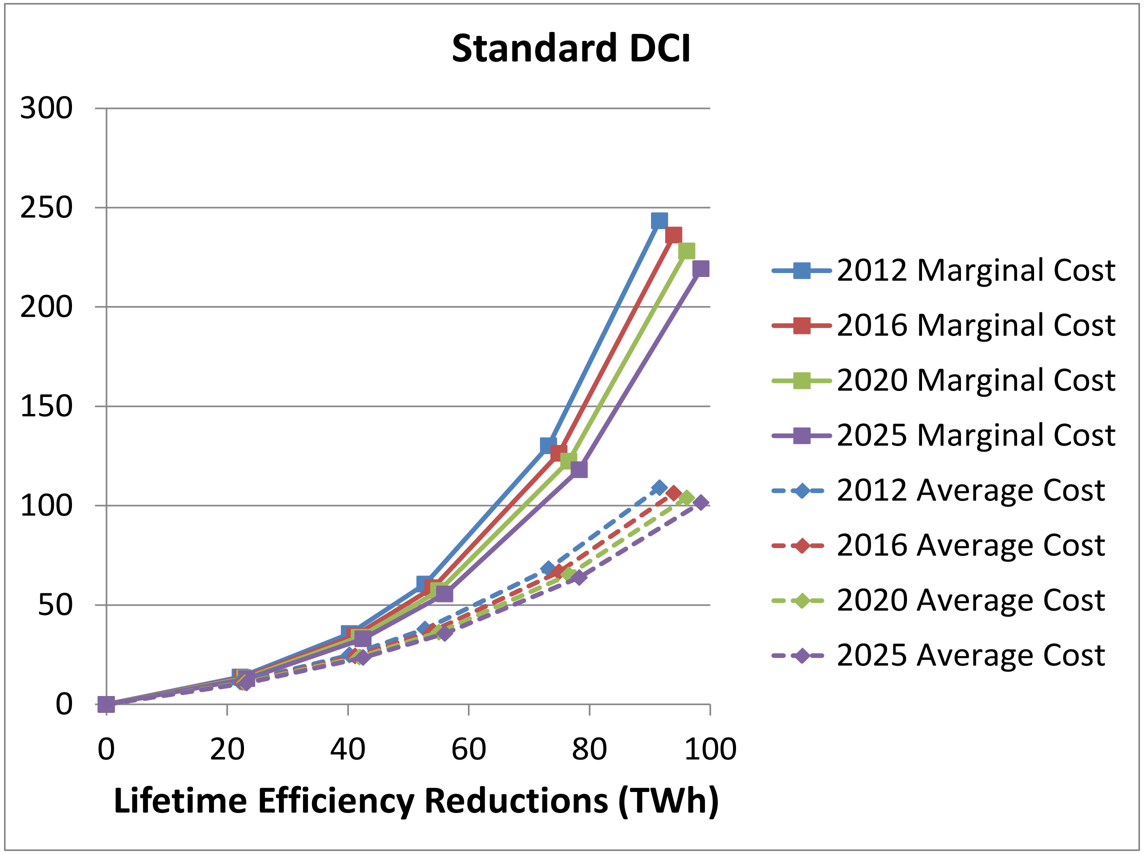
Electricity Prices and CO_2 Emissions





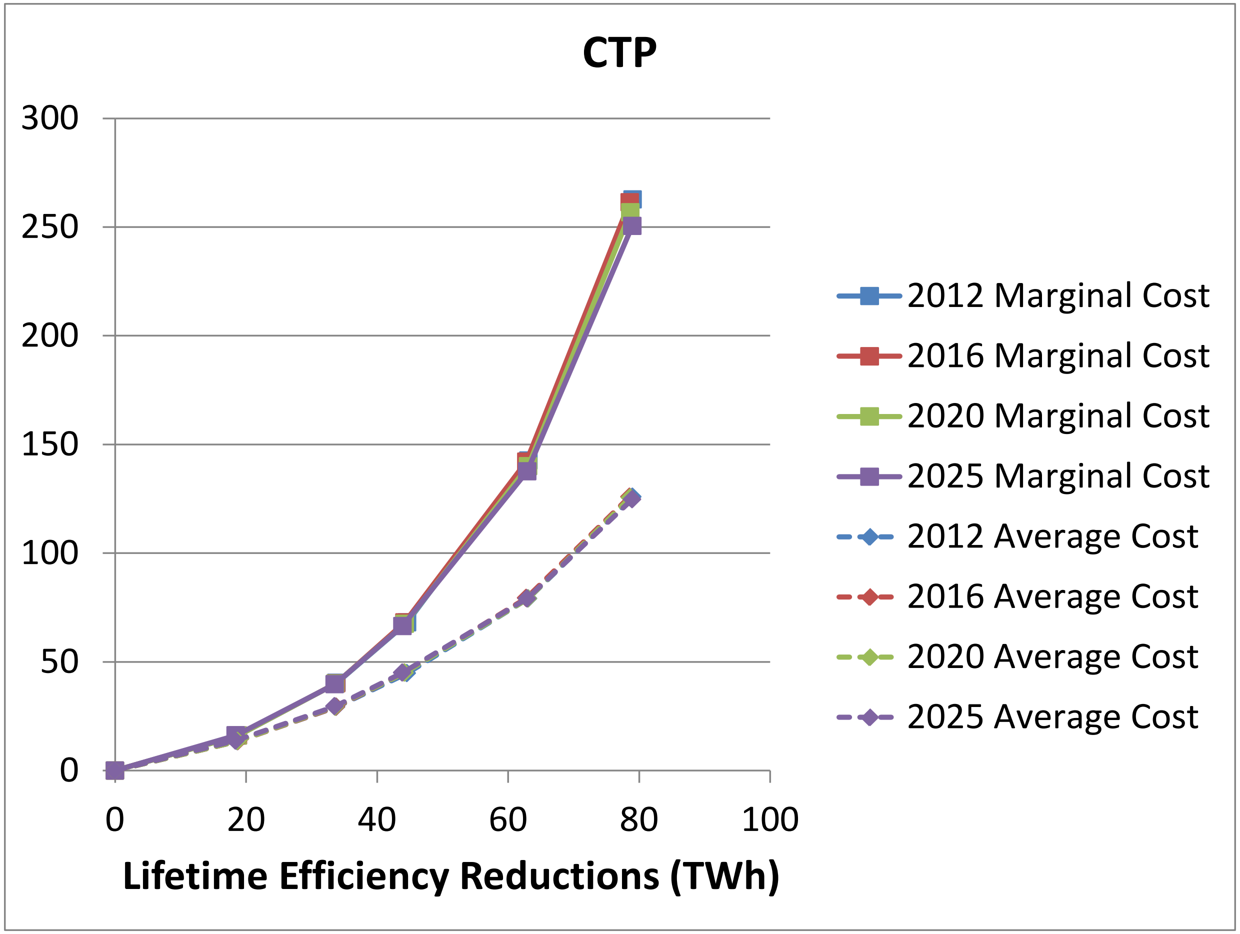
- Small changes in electricity consumption induce small changes in average electricity price and cumulative CO_2 emissions.

Conserved Electricity Supply Curve by Year



- Marginal costs of savings increase as savings levels rise.
- Higher demand in future years creates more opportunities for low-cost reductions.

Conserved Electricity Supply Curve by Year with Cap and Trade



- CO_2 trading raises electricity prices, lowers demand growth and lifetime demand reductions at given cost.
- Price induced demand reductions yields overlapping cost curves for different years.

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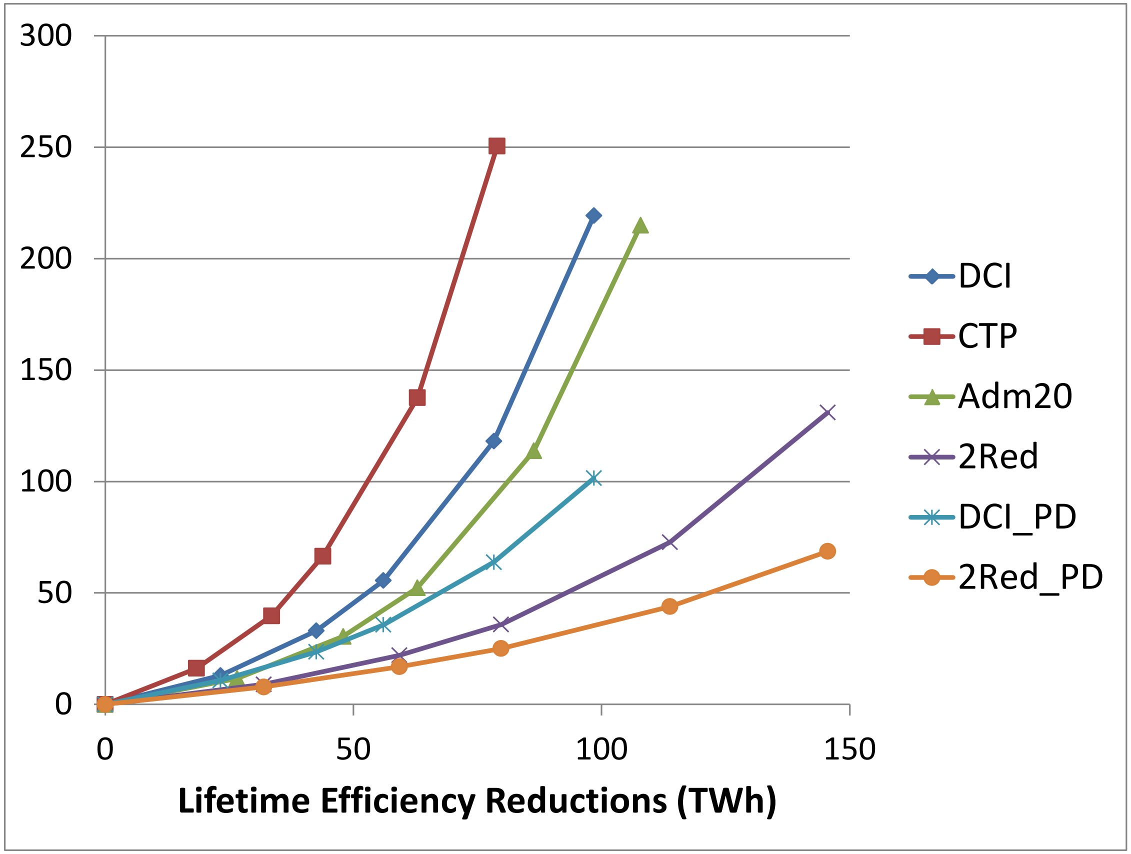
Conserved Electricity Supply Curve Sensitivities



- CTP increases the cost of efficiency.
- Adm20, 2Red and price discrimination reduce the cost of efficiency.

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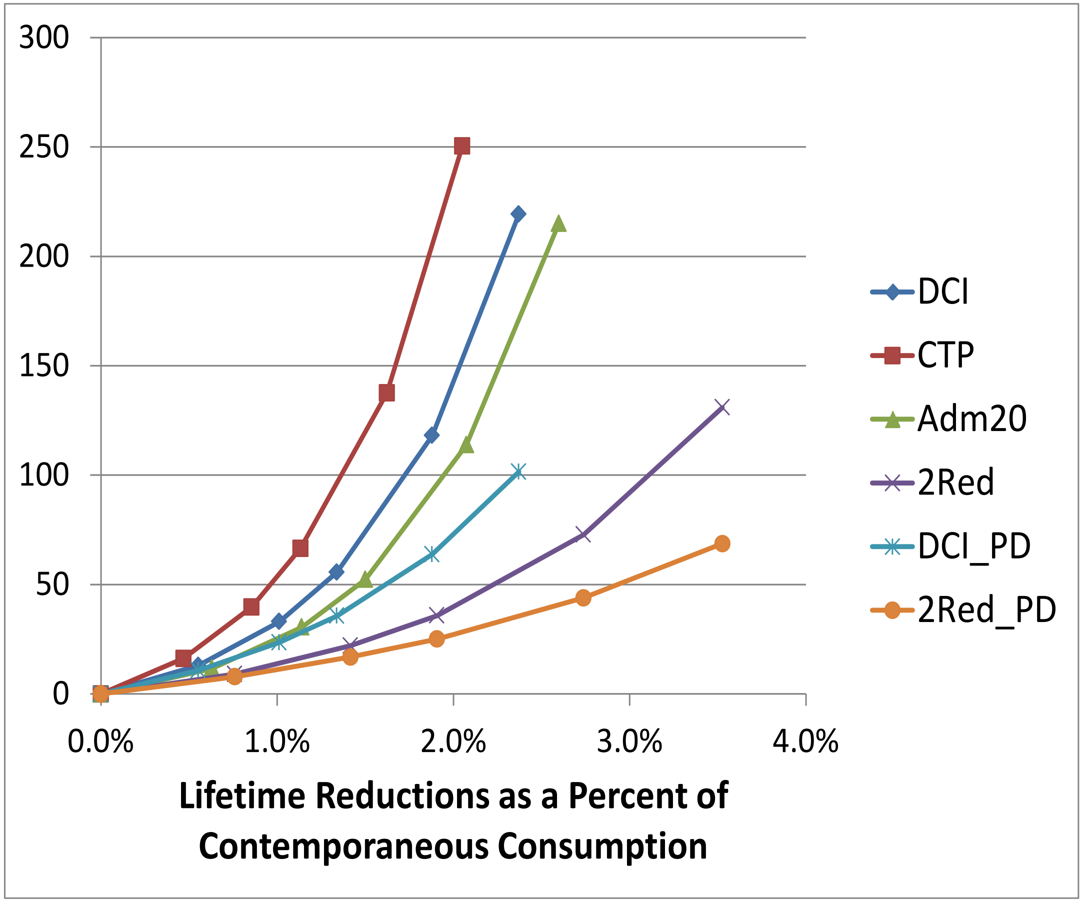
Conserved Electricity/Renewables



- This approach can be used to find amount of electricity savings available at any given REC price (integrated RPS/EE program).
- The percentage of electricity consumption that could be harvested as savings at a REC price of $50 per MWh is roughly 1% - 3%.

Conclusions

- The efficiency expenditure scenarios that we model have small effects on electricity price, electricity demand and CO_2 emissions.
- Conserved electricity supply curves are convex.
- Conserved electricity supply curves shift up under a cap and trade program as higher electricity prices reduce demand and opportunities for low cost savings.
  - This result hinges on allowance allocation.
- Position and shape of the conserved electricity supply curves depends importantly on demand elasticity estimates, calibration to real-world EE program costs and assumptions about program structure.
- Conserved electricity supply curves could be effectively integrated into an RPS/RES program modeling analysis.
  - Our results suggest that at a REC price of $50 per MWh we would get roughly 1% - 3% of the total RPS percentage from efficiency savings.

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Future Work

- Explore sensitivities of these results to our demand elasticity parameter values.
- Fully model price discrimination in the DCI mechanism and explore interim cases.
- Fully integrate EE into RPS/RES model capability.

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