Cap-and-Trade Climate Policies With Price-Regulated Industries: How Costly Are Free Allowances?

Sebastian Rausch

Joint Program on the Science and Policy of Global Change,
MIT

(joint with Bruno Lanz - ETH Zurich)

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Motivation

- Free allocation of allowances fails to exploit revenue-recycling effect (Bovenberg and Goulder, 1996)
- Additional deadweight loss if price-regulated firms fail to pass through opportunity costs of free allowances to consumers
- In United States, electricity generation accounts for 40% of total CO2 emissions. 30% of total CO2 emissions produced by price-regulated regional monopolies that generate 60% of electricity generation
- For regulated firms, electricity rates are typically set on a cost-of-service basis (average cost pricing)

Objective

- Under cost-of-service regulation carbon price is reflected in output prices only if costs are affected
- Cost of free allowances is zero, hence electricity rates at regulated utilities will not fully reflect the value of emissions (implicit subsidy)
- House-passed 2009 "cap-and-trade" legislation to mitigate U.S. GHG emissions proposed to initially grandfather $\approx 40\%$ of permits to electric utilities
- Objective of this paper:
  - Quantify efficiency and distributional impacts of free permits in the presence of price-regulated electricity producers
  - Focus on two design elements of cap-and-trade policy: method of permit allocation (free permits vs. auctioning) and allocation rule (emissions- vs. output-based)

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Model Overview

- Model needs to capture:
  - Abatement costs for regulated and non-regulated electricity producers as well as firms in non-electricity sectors
  - Electricity markets' structure
  - Inter-sectoral interactions and economy-wide effects (tax interaction effect, impacts on relative goods and factor prices)
  - Heterogeneity in regional production and household impacts
- Numerical general equilibrium model of the U.S. economy
  - "Bottom-up" technology representation based on all 16,891 electricity generators in the contiguous U.S
  - Electricity markets' structure and differential regulatory treatment of electricity producers
  - Multi-region, multi-sector GE model
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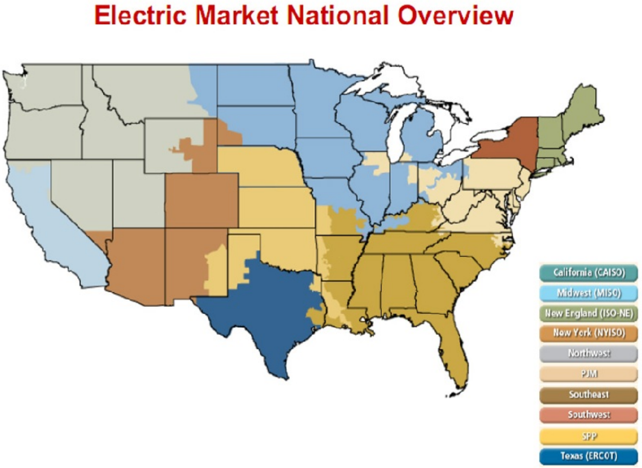
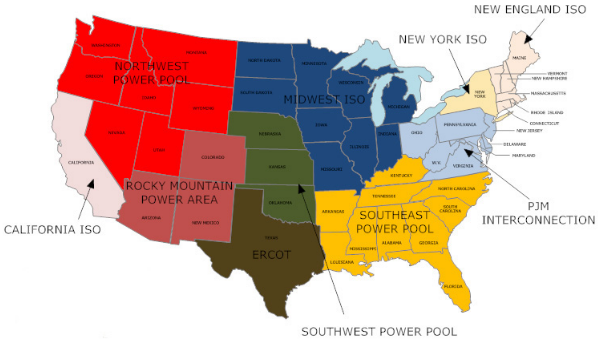
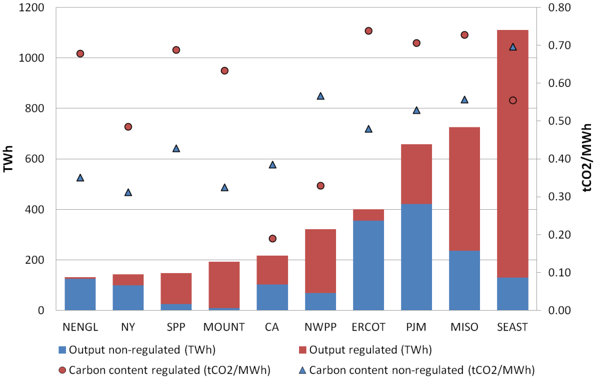
10 National Power Markets (FERC: Federal Energy Regulatory Commission)



Approximation of National Power Markets in Model



Regional Electricity Generation and CO_2 Intensity by Regulatory Status



Note: Own calculations based on EIA data. Data refers to 2006.

Numerical General Equilibrium Model

- Comparative-static variant of the MIT U.S. Regional Energy Policy (USREP) model (Rausch et al., 2010, 2011)
  - State-level SAM data combining social accounting matrix (IMPLAN, 2009) and physical energy and price data (EIA, SEDS 2009)
  - State-level data aggregated into 10 regions to approximate wholesale transmission regions
  - 5 energy sectors (COL, GAS, CRU, OIL, ELE); 5 non-energy sectors (AGR, SRV, TRN, EIS, MAN)
  - Primary production factors: capital, labor, land, fossil-fuel resources
  - Nested CES production functions and preferences
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"Bottom-up" Electricity Generation Model

- Load dispatch electricity generation model with fixed capacity
- Determines least-cost fuel and technology mix to meet demand on each market
- 16,000+ generators based on EIA Form 860 and 906-920 (2007), EIA (2008, 2009) data characterized by capacity, technology, fuel switching possibilities, output, and fuel demand
- 2 types of operators (operators hold a portfolio of generators)
  - Independent power producers compete to meet demand on 10 regional wholesale markets
    - "large" independent power producers are Cournot players (Bushnell et al., AER, 2008)
  - 319 regulated operators (regional monopolies) charging average costs
- Temporal resolution on each market: 3 seasons $\times$ 3 load blocks

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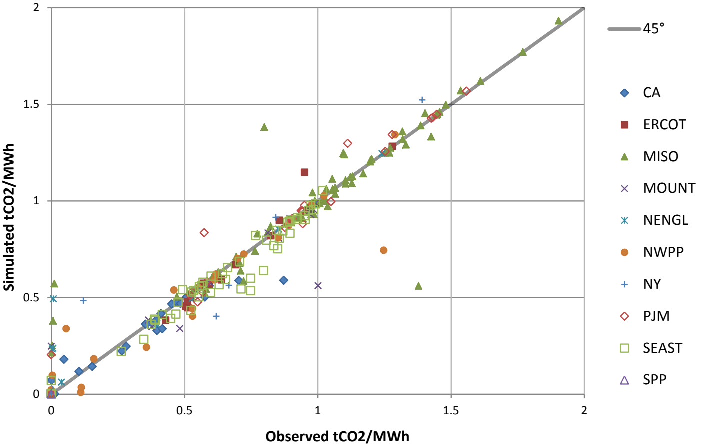
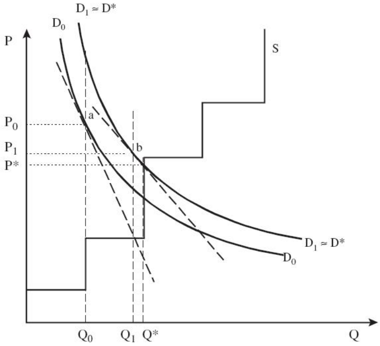
Simulated and Observed CO_2 Intensity



- R^2 based on output per fuel and technology: 90.2% and 84.1% for regulated operators and wholesale producers, respectively.

Integrating Bottom-up Technology Detail in CGE Model



- Large dimensionality of electricity sector model makes integrated solution infeasible $\Longrightarrow$ use decomposition approach based on Böhringer and Rutherford (JEDC, 2009)
- Iterative solution procedure:
  1. Solve top-down CGE model given net supplies from the bottom-up electricity sector model
  2. Solve bottom-up electricity sector model based on a locally calibrated demand function for electricity

CGE with Heterogeneous Households

- 15,000+ households from the Consumer Expenditure Survey (Bureau of Labor Statistics, 2006) endogenously incorporated as separate agents within GE framework
- Representative sample of US population
- Each "real" household solves a utility maximization problem
- Key idea of decomposition algorithm by Rausch and Rutherford (2010) is to solve the model through a sequence of representative agent economies:
  1. Compute candidate equilibrium price vector from a representative agent (RA) variant of the economic model
  2. Partial equilibrium (PE) relaxation: Evaluate demand functions for each household
  3. Iterative procedure reconciles individual household and GE model responses through sequential re-calibration of preferences of the RA agent based on PE quantity choices by "real" households

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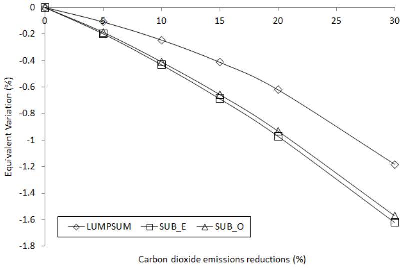
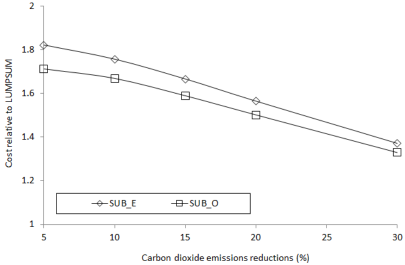
Scenarios

- National CO_2 cap-and-trade policy covering all sectors of the economy
- 3 scenarios that differ with respect to treatment of regulated electricity operators:
  1. Value of free allowances distributed to households as lump-sum transfer on a per-capita basis (LUMPSUM)
  2. Value of free allowances passed to consumers through subsidized electricity prices. Allowances allocated to regulated firms based on:
     CO_2 emissions (SUB_E)
     Electricity output (SUB_O)
- To isolate impact of allowances allocated to regulated electricity producers, allocation of allowances to non-regulated electricity firms and non-electricity sectors held fixed across scenarios (assume that allowances are given out freely)

Aggregate efficiency costs





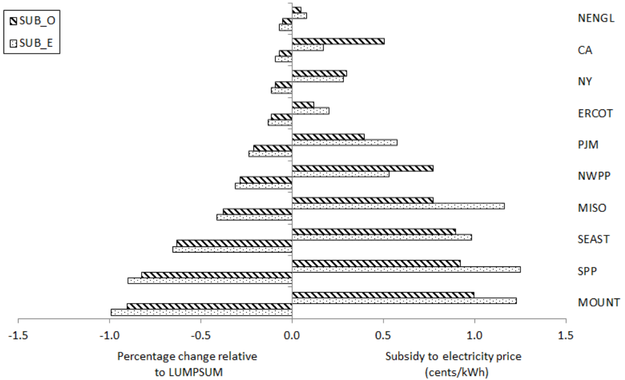
- Subsidy increases aggregate compliance costs by 40-80% (for a 20% reduction target, $46 billions or $230 per household)
- Efficiency costs decrease with stringency of cap
- Output-based allocation induces always smaller welfare costs (but difference is small, $5 billions)

Summary results (national level)

Table: Efficiency costs, sectoral CO_2 abatement, electricity price impact, and equilibrium permit price (20% reduction target).

	LUMPSUM	SUB_E	SUB_O
Compliance cost			
Total ($billion)	83.0	129.9	124.7
Electricity price (%)	43.9	33.9	36.8
CO_2 abatement			
Economy-wide (million tons)	1,170	1,170	1,170
Contribution by sector (%)			
Regulated electricity	38.9	23.7	27.9
Wholesale electricity	14.0	20.5	19.1
Non-electricity sectors	47.1	55.8	53.0
Carbon price ($ per ton)	31	41	37

Regional welfare costs and average subsidy rate (20% cap)



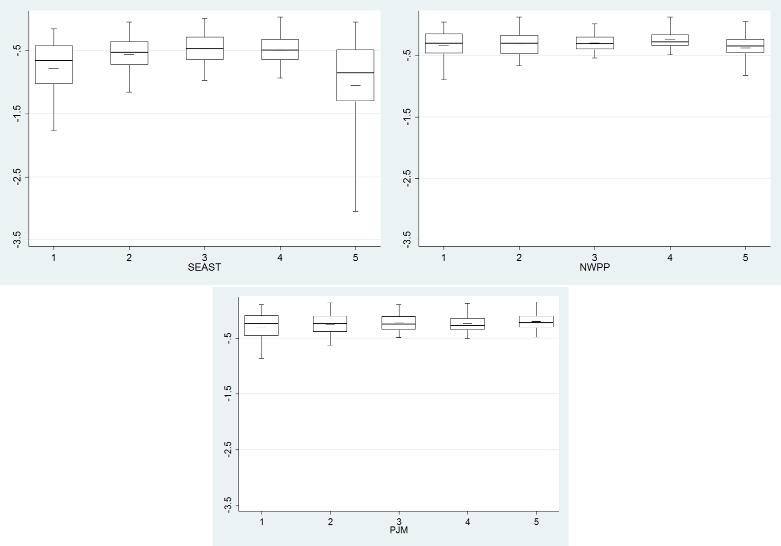
- Efficiency costs correlate closely with the size of emission-based subsidies $\longrightarrow$ share and carbon intensity of electricity generated under regulation are key drivers

National mean welfare impacts by income decile (relative to LUMPSUM, 20% cap)

Income decile	SUB_E		SUB_O	
	%	$ per household	%	$ per household
1	-0.50	-76	-0.50	-77
2	-0.34	-91	-0.34	-90
3	-0.32	-111	-0.31	-108
4	-0.32	-136	-0.29	-127
5	-0.29	-151	-0.26	-139
6	-0.29	-182	-0.26	-163
7	-0.30	-220	-0.26	-194
8	-0.29	-253	-0.25	-220
9	-0.34	-362	-0.29	-308
10	-0.46	-676	-0.38	-564
All	-0.34	-227	-0.31	-200

- Over bottom 80 percent of income distribution mean impacts are regressive, over top two deciles progressive
- Replacing per-capita lump-sum transfer with subsidy adds to regressivity
- Sources side of income effects are progressive

Distribution of household welfare impacts by income quintile (SUB_E relative to LUMPSUM, 20% cap)



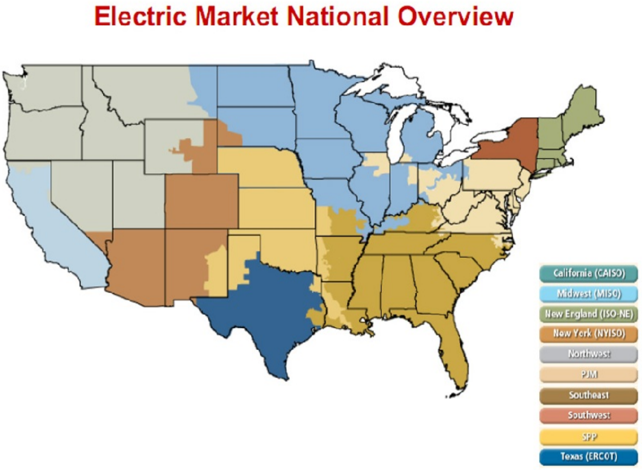
Conclusions

- Numerical general equilibrium analysis that combines bottom-up technology representation of electricity sector, electricity markets' structure, and household heterogeneity
- Efficiency: Free distribution of permits to regulated utilities increases welfare costs by 40-80% relative to an auction if electricity rates do not reflect opportunity costs of permits
- Distributional impacts:
  - Focusing on average welfare impacts across income groups swamps important variations within income groups
  - Assumptions about how allowance revenue is distributed in reference case are important
  - Accounting for sources side of income effects is important and suggests that higher-income households bear disproportionately large burden of efficiency costs
  - Highly regulated regions are worse off
- Output- and emissions-based allocation schemes generate largely similar outcomes with respect to efficiency and distributional impacts

Thank you.

Questions and comments: rausch@mit.edu

Map of integrated markets



Regional Electricity Generation, Market Structure and CO_2 Intensity in 2006

Region	Generation (TWh)	Regulated generation %	Regulated generation N	Regulated generation tCO_2/MWh	Non-regulated generation N	Non-regulated generation HHI	Non-regulated generation tCO_2/MWh
SEAST	1,126.6	87.0	87	0.61	287	310	0.60
SPP	142.4	86.2	133	0.78	30	1,570	0.42
MOUNT	214.1	85.7	38	0.73	57	1,160	0.38
NWPP	317.4	79.5	64	0.38	154	1,130	0.63
MISO	724.4	67.7	305	0.85	315	1,680	0.47
CA	231.3	49.8	39	0.19	317	220	0.42
PJM	665.0	35.5	51	0.79	259	580	0.58
NY	142.9	29.6	14	0.30	148	550	0.37
ERCOT	348.9	13.2	20	0.84	157	820	0.52
NENGL	132.8	4.8	28	0.79	214	510	0.40
US	4045.7	61.2	731	0.65	1938	–	0.51

Own calculations based on EIA data. Regulated operators that represent together less than 0.1% of electricity generated in each region are not included in the model.

Equilibrium Conditions for Electricity

- Zero profit condition determines output level (Y_t^g) for each generator and load segment:

$$-\pi_t^g \geq 0 \quad \perp \quad Y_t^g \geq 0 \tag{1}$$

where

$$\pi_t^g = \begin{cases} C_t^f - c^g - \mu_t^g - \nu^g \tau & \text{if } g \in G_f \\ p_t^r + \frac{\partial D^r(p_t^r)^{-1}}{\partial Y_t^g} - c^g - \mu_t^g - \nu_t^g \tau & \text{if } g \in G_r^{\text{cournot}} \\ p_t^r - c^g - \mu_t^g - \nu_t^g \tau & \text{if } g \in G_r^{\text{fringe}} \end{cases}$$

- Shadow price of capacity (μ_t^g):

$$Y_t^g \leq \kappa_t^g \quad \perp \quad \mu_t^g \geq 0 \tag{2}$$

- Marginal generation cost (C_t^f) for regulated firms:

$$\sum_{g \in G_f} Y_t^g \geq d_t^f \quad \perp \quad C_t^f \geq 0 \tag{3}$$

- Wholesale price in each load segment (p_t^r):

$$\sum_{g \in G_r} Y_t^g \geq d_t^r \quad \perp \quad p_t^r \geq 0 \tag{4}$$

- Given benchmark demand at each operator, we simulate benchmark output by solving (1)–(4)

Equilibrium Conditions for Electricity (Cont.)

- Average cost pricing for regulated firms:

$$P^f = \frac{\sum_{g \in G_f} \sum_t Y_t^g c^g + \nu_t^g \tau}{D^f} - s^f \tag{5}$$

where firm-specific subsidy rate (s^f) equals the value of free allowances received by operator f (V_f) divided by total yearly output:

$$s^f = \frac{V_f}{D^f} \tag{6}$$

- Wholesale price transmitted to consumers:

$$P^r = \frac{1}{\sum_t d_t^r} \sum_t p_t^r d_t^r \tag{7}$$

- *Local* demand response in market $m = \{f, r\}$ is given by a linear function calibrated at the benchmark price ($\overline{P}^m$) and benchmark demand ($\overline{D}^m$):

$$D^m = \overline{D}^m \left(1 + \epsilon \left(\frac{P^m}{\overline{P}^m} - 1\right)\right) \tag{8}$$

- We assume that the shape of the load profile is unchanged, i.e. $d_t^f = D^f \, \overline{d}_t^f / \overline{D}^f$ and $d_t^r = D^r \, \overline{d}_t^r / \overline{D}^r$.

Benchmark Model Fit: Wholesale Electricity Price and Carbon Intensity

Region	Price (\$/MWh)		CO_2 intensity (tCO_2/MWh)	
	Observed	Simulated	Observed	Simulated
CA	48.9	48.7	0.42	0.34
ERCOT	52.9	57.5	0.52	0.50
MISO	44.0	47.7	0.47	0.50
MOUNT	57.4	44.9	0.38	0.35
NENGL	60.8	61.5	0.40	0.36
NWPP	50.2	48.6	0.63	0.62
NY	70.2	71.2	0.37	0.36
PJM	55.1	52.2	0.58	0.58
SEAST	58.1	53.5	0.60	0.61
SPP	55.4	63.6	0.42	0.43

Observed price is a load-weighted average reported by FERC for 2006. Observed CO_2 emissions are based on fuel consumption for each operator (EIA 2007) and fuel-specific CO_2 emission factors (EIA, 2009).

Electricity Market Aggregation and Retail Price

1. Price aggregation:

$$P^r_{\text{ele}} = \left[\theta^r \left(\frac{P^r}{\overline{P}^r} \right)^{(1-\sigma)} + \sum_{f \in r} \theta^f \left(\frac{P^f}{\overline{P}^f} \right)^{(1-\sigma)} \right]^{\frac{1}{1-\sigma}}$$

θ^r, θ^f observed benchmark market shares for wholesale market and regulated markets in region r
P^r, P^f price for wholesale and regulated markets
σ degree of market integration

2. Electricity generation model does not account for transmission & distribution costs (TD). These are imputed as:

$$\overline{TD}^r = \overline{P}^r_{\text{retail}} - \overline{P}^r_{\text{ele}}$$

$\overline{P}^r_{\text{retail}}$ observed benchmark retail price
$\overline{P}^r_{\text{ele}}$ output-weighted average of benchmark prices

3. Regional retail price of electricity is given by:

$$P^r_{\text{retail}} = P^r_{\text{ele}} \, \overline{P}^r_{\text{ele}} + \overline{TD}^r$$

Electricity Market Aggregation and Retail Price

1. Price aggregation:

$$P^r_{\text{ele}} = \left[\theta^r \left(\frac{P^r}{\overline{P}^r}\right)^{(1-\sigma)} + \sum_{f \in r} \theta^f \left(\frac{P^f}{\overline{P}^f}\right)^{(1-\sigma)}\right]^{\frac{1}{1-\sigma}}$$

θ^r, θ^f	observed benchmark market shares for wholesale market and regulated markets in region r
P^r, P^f	price for wholesale and regulated markets
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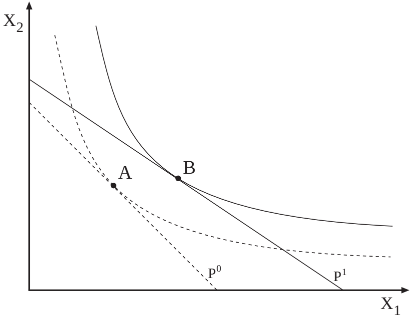
Step 1: Solving the Initial Representative Agent Problem



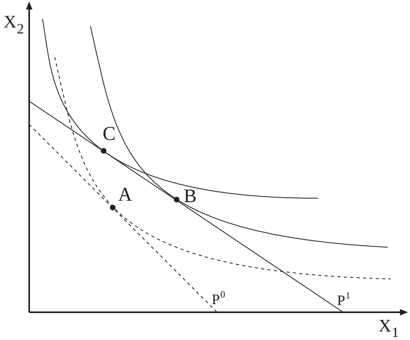
- CES utility function for representative agent (household utility has identical structure):

$$Q_{n,i} = \left[\sum_{j \in i} \Theta_{n-1,j} \left(\frac{Q_{n-1,j}}{\bar{Q}_{n-1,j}} \right)^{\tilde{\rho}_{n,i}} \right]^{\frac{1}{\tilde{\rho}_{n,i}}}$$

- Benchmark consumption ($\bar{Q}$) and value share (Θ) based on observed behavior of heterogeneous households:

$$\bar{Q}_{n,j} = \sum_{h=1}^{H} \bar{q}^{h}_{n,j}\,, \quad \Theta_{n,j} = \frac{\bar{p}_{n,j}\,\bar{Q}_{n,j}}{\sum_{j' \in i} \bar{p}_{n,j'}\,\bar{Q}_{n,j'}}$$

Step 2: Evaluation of Household Demand and Re-calibration of Preferences

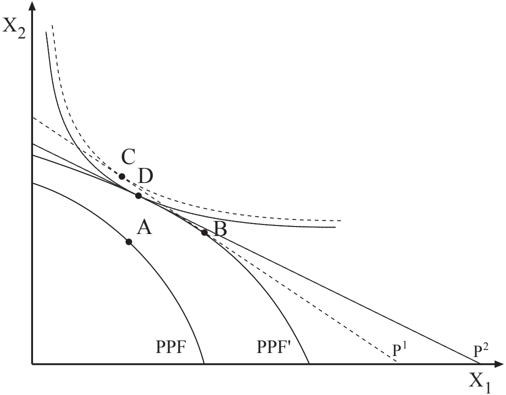


- The key step in each iteration k involves "re-calibrating" preferences of the representative agent based on partial equilibrium households' quantity choices:

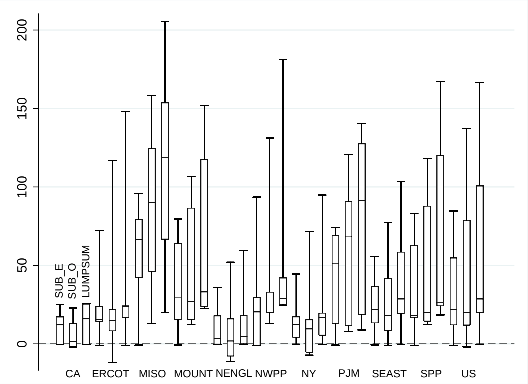
$$\bar{Q}_{n,i}^{k+1} = \sum_{h=1}^{H} q_{n,i}^{h,k}(\mathbf{p}^k, y^k)\,,$$

$$\Theta_{n,j}^{k+1} = \frac{\bar{p}_{n,j}^{k} \sum_{h=1}^{H} q_{n,j}^{h,k}(\mathbf{p}^k, y^k)}{\sum_{j' \in i} \bar{p}_{n,j'}^{k} \sum_{h=1}^{H} q_{n,j'}^{h,k}(\mathbf{p}^k, y^k)}\,.$$

Step 3: Iterative Procedure Reconciles Household Behavior with GE Model Response



Price impacts across markets (% of benchmark price, 20% cap)



- Substantial heterogeneity in price changes driven by CO_2 intensity
- Highest price impact under a LUMPSUM, prices fully reflect value of CO_2 emissions
- A subsidy reduces both the mean and variance of price impacts

Selected expenditure and income shares (%) by income decile

Income decile	Electricity	Natural Gas	Capital	Labor	Capital-labor ratio
1	4.7	1.8	27.4	23.5	1.17
2	3.7	1.3	26.1	43.1	0.61
3	3.2	1.1	23.4	55.7	0.42
4	2.8	1.0	19.2	67.5	0.28
5	2.4	0.9	18.3	71.0	0.26
6	2.5	0.8	16.8	75.6	0.22
7	2.2	0.8	15.5	79.1	0.20
8	1.9	0.7	14.7	80.9	0.18
9	1.8	0.7	19.7	77.7	0.25
10	1.5	0.6	28.7	69.7	0.41
All	2.6	1.0	20.9	64.7	0.32

Sensitivity analysis

	EV (%)	Carbon price (2006\$/tCO_2)	Abatement reg. ele. (%)	Standard deviation of EV	$\mu(EV)$ by region	ΔP_{ELE}	$\mu(\Delta P_{ELE})$ by region
Central case ($\sigma = 1$, $\sigma_{xELE} = 0.5$)							
SUM_E	-0.58	29.1	12.2	0.79	0.13	0.21	0.09
SUM_O	-0.59	26.8	15.1	0.79	0.15	0.34	0.12
Low market integration ($\sigma = 0$)							
SUM_E	-0.59	29.8	11.3	0.74	0.15	0.26	0.09
SUM_O	-0.61	28.4	12.3	0.77	0.17	0.65	0.12
High market integration ($\sigma = 10$)							
SUM_E	-0.55	28.6	12.0	0.73	0.12	0.21	0.09
SUM_O	-0.58	26.0	15.1	0.77	0.14	0.33	0.12
High market integration ($\sigma = 10$) and high electricity trade elasticity ($\sigma_{xELE} = 5$)							
SUM_E	-0.52	27.8	13.2	0.69	0.11	0.19	0.08
SUM_O	-0.55	25.4	16.4	0.73	0.13	0.30	0.10