The Regional Greenhouse Gas Initiative: Emission Leakage and the Effectiveness of Interstate Border Adjustments

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Outline of Talk

Emission Leakage

The problem

- Multiple regions emitting greenhouse gases (GHGs) + limits on GHGs in a subset of jurisdictions ⇒ emissions from unconstrained regions increase, offsetting abatement
  - **Output-shifting/"pollution haven" effect**: abating regions import more GHG-intensive goods manufactured by unconstrained trade partners, who, in the face of increased demand for their products, expand production, emissions
  - **Input substitution/"rebound" effect**: contraction in abating regions' energy demand depresses the traded price of fossil fuels in unconstrained jurisdictions, inducing substitution of FF's for other inputs, increasing emission intensity of production

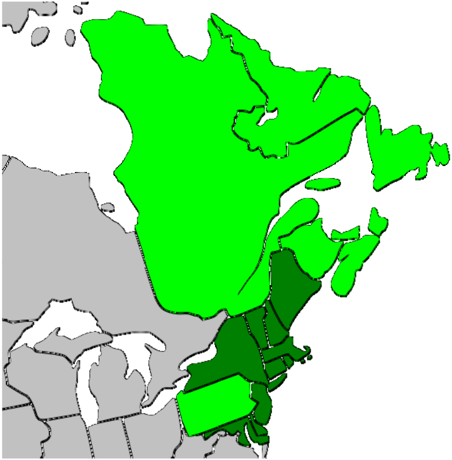
Policy context

- Prior work focused exclusively at international level (Kyoto Protocol), where developed countries have binding GHG targets, developing countries don't
- Recent developments in U.S. climate change policy mirror this "in-out" structure
  - California's Global Warming Solutions Act (2006)
  - Regional Greenhouse Gas Initiative (RGGI)

RGGI

Program highlights

- Supply-side cap-and-trade scheme to cut carbon dioxide (CO_2) emissions from electric power plants
- 10 New England + Mid-Atlantic states (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York and Vermont)
- Pennsylvania, Washington DC + Canada's Atlantic provinces participating as observers w/. no formal abatement commitments
- Objective: return generators' CO_2 to 2002-2004 average emission levels by 2009-2014, reduce emissions by a further 10% in 2015-2019
- Emission control costs moderated by a "safety valve" provision (at $10/ton CO_2)



Issues and Research Questions

Issues

- Inter-regional electricity price differentials arbitraged by bulk power flows on a near real-time basis
- Higher electricity generating costs/power prices in RGGI states ⇒ electricity imports from unconstrained states ⇒ more coal-fired generation, CO_2 emissions
- Concern that utilities in RGGI states with outside generation assets will import power (Burtraw et al., 2006) ⇒ proposals for technical measures to neutralize leakage (Farnsworth et al., 2007)
- Implicit assumption: leakage confined to electric power sector!
- Focus mirrors use of partial equilibrium capacity expansion models (IPM, HAIKU) to analyze RGGI

Questions

- Need to understand how much leakage likely to occur, and why
- Precise amount of leakage debated (Farnsworth et al.: 18-25% of abatement in 2015 vs. American Council for an Energy-Efficient Economy: 60-90%)
- Our contribution: shrink range of estimates, characterize their dependence on key uncertain economic variables
- General equilibrium approach utilizing an interregional CGE (ICGE) model

A Simple Theoretical Model

Setup: the pollution haven effect

- Adapt Gerlagh-Kuik's (2007) model w/. 2 regions: $r \in$ abaters (A) non-abaters (N)
- Regions use CO_2-emitting fossil energy (ε_r) to produce electricity (q_r), latter traded
- Examine how
  - Reduction in ε_A + electricity imports (t) $\Rightarrow$ increase in ε_N
  - Countervailing tariff on electricity use (τ_A^q) alleviates leakage
- Carbon-energy = non-traded good w/. region-specific prices (ξ_r); electricity = perfectly homogeneous good w/. a single market-clearing price (π)
- Identical upward-sloping isoelastic carbon-energy supply curves (elasticity η); downward-sloping isoelastic electricity demand curves (elasticity δ).
- Identical generation technology: inputs of generic composite factor (ζ_r, w/. price ψ) + ε_r w/. cost share $\alpha \in (0,1)$
- Carbon-energy a necessary input $\Rightarrow \sigma \in (0,1]$ = elasticity of substitution b/w. ε and ζ
- Production and cost functions and energy demands:
  $$q_r = F(\varepsilon_r, \zeta_r; \sigma), \quad \pi = G(\xi_r, \psi; \sigma) \quad \text{and} \quad \varepsilon_r = H(\xi_r, \pi, q_r; \sigma)$$
- Simplifying assumption 1: ψ unaffected by emission limit. Allows us to hold generic factor offstage, focus on CO_2!

Theoretical Model: Setup (Continued)

Inter-regional power trade

- Electricity demand > supply in A, supply > demand in $N \Rightarrow A$ generates power for domestic use, N exports t units of power to A
- Simplifying assumption 2: identical electricity demand in both regions ⇒ trade makes up the same share of consumption (β)
  $t/(q_A + t) = t/(q_N - t) = \beta \in (0,1) \quad \Rightarrow \quad q_A = t(1-\beta)/\beta$ and $q_N = t(1+\beta)/\beta$
- Simplifying assumption 3: initially identical thermodynamic efficiencies in generation
  $\varepsilon_N/\varepsilon_A = q_N/q_A = (1+\beta)/(1-\beta) > 1$
- A has cleaner production but dirtier consumption (characteristic of RGGI states)

Border adjustments

- A's preferred instrument to neutralize leakage: tariff on foreign electricity
- BUT fundamental limitation of being unable to discriminate between domestically produced and imported power (intentionally discriminatory character of instrument violates commerce clause—Bolster, 2006; Farnsworth, 2007; Weiner, 2007)
- A imposes a tax τ_A^q on *all* electricity consumed within its borders ⇒ producers + consumers see gross-of-ad-valorem-tariff price $(1+\tau_A^q)\pi$

Theoretical Model: Algebraic Summary

Model solved in terms of "hat algebra" (Fullerton-Metcalf, 2001)

Regional carbon-energy supplies:

$$\widehat{\varepsilon}_A = \eta\widehat{\xi}_A, \tag{1a}$$

$$\widehat{\varepsilon}_N = \eta\widehat{\xi}_N, \tag{1b}$$

Regional electricity demands:

$$(1-\beta)\widehat{q}_A + \beta\widehat{t} = -\delta(\widehat{\pi} + \widehat{\tau}_A^q), \tag{2a}$$

$$(1+\beta)\widehat{q}_N - \beta\widehat{t} = -\delta\widehat{\pi}. \tag{2b}$$

Cost function incorporating A's electricity tax:

$$\widehat{\pi} + \widehat{\tau}_A^q = \alpha\widehat{\xi}_A, \tag{3a}$$

$$\widehat{\pi} = \alpha\widehat{\xi}_N. \tag{3b}$$

Regional carbon-energy demands:

$$\widehat{\varepsilon}_A = \widehat{q}_A + \sigma(\widehat{\pi} + \widehat{\tau}_A^q - \widehat{\xi}_A), \tag{4a}$$

$$\widehat{\varepsilon}_N = \widehat{q}_N + \sigma(\widehat{\pi} - \widehat{\xi}_N). \tag{4b}$$

We treat $\widehat{\varepsilon}_A < 0$ as a policy variable, drop (1a), solve remaining 7 eqs. in as many unknowns.
Also examine effects of tax alone, solving full model for unknowns as f'ns of parameters, $\widehat{\tau}_A^q$

Theoretical Model: Key Results

- Emission limit ↓ A's generation, tariff has opposite effect ⇒ overall sign ambiguous
$$\widehat{q}_A, \widehat{\xi}_A \downarrow \text{ in } -\widehat{\varepsilon}_A, \uparrow \text{ in } \widehat{\tau}_A^q$$
- Effects on N's electricity exports, generation, emissions and energy price qualitatively similar to one another, but opposite in sign to above:
$$\widehat{\pi}, \widehat{t}, \widehat{q}_N, \widehat{\varepsilon}_N, \widehat{\xi}_N \uparrow \text{ in } -\widehat{\varepsilon}_A, \downarrow \text{ in } \widehat{\tau}_A^q$$
- Leakage is inevitable unless emission cap accompanied by restraint on electricity trade:
$$\text{Leakage rate:} \quad \Lambda = -\frac{d\varepsilon_N}{d\varepsilon_A} \propto 1 + \frac{[\alpha\delta + \sigma(1-\alpha)(1-\beta)]\widehat{\tau}_A^q}{\alpha(1-\beta)\widehat{\varepsilon}_A} < 1$$
- $\widehat{\tau}_A^q = 0 \Rightarrow \Lambda > 0$, independent of $\widehat{\varepsilon}_A$, ↑ in A's import share of electricity consumption, elasticity of N's carbon-energy supply; ↓ in the price elasticity of electricity demand, carbon-energy cost share in generation
- Leakage can never cause overall emissions ($\mathscr{E}$) to ↑ above baseline levels (cf. Babiker, 2005)
- Tariff limits leakage by stimulating import substitution via an increase in A's domestic electricity supply, while simultaneously attenuating demand.
- Λ decreasing in $\widehat{\tau}_A^q$, which neutralizes leakage if $\widehat{\tau}_{A,0}^q = -\dfrac{\alpha(1-\beta)}{\alpha\delta + \sigma(1-\alpha)(1-\beta)}\widehat{\varepsilon}_A > 0$
- Zero-leakage tariff increasing in electricity demand elasticity; decreasing in A's electricity import intensity, generators' carbon-energy cost share, substitution elasticity
- For any $\widehat{\varepsilon}_A$, sufficiently high electricity tariff can reverse leakage by limiting demand for N's exports to the point where its generation falls, inducing *de facto* abatement

Theoretical model: Insights from Numerical Parameterization

Numerical Results ($\alpha = 0.3$, $\beta = 0.03$, $\delta = 0.5$, $\eta = 1$, $\sigma = 0.8$)

		RGGI Only ($\hat{\tau}^q_A = 0$)	RGGI With Border Measures ($\hat{\tau}^q_A = \hat{\tau}^q_{A,0}$)	Border Measures Only ($\hat{\tau}^q_A = \hat{\tau}^q_{A,0}$)
1. Carbon-energy	$\hat{\xi}_A$	0.030	0.107	0.055
price	$\hat{\xi}_N$	0.030	–	-0.052
2. Electricity	$\hat{q}_A$	-0.059	-0.017	0.086
output	$\hat{q}_N$	0.047	–	-0.081
3. Electricity price	$\hat{\pi}$	0.009	–	-0.016
4. Electricity trade	$\hat{t}$	1.768	–	-3.040
5. Carbon-	$\hat{\varepsilon}_A$	-0.076[a]	-0.076[a]	0.055
energy	$\hat{\varepsilon}_N$	0.030	–	-0.052
demand	$\hat{\mathcal{E}}$	-0.021	-0.037	–
6. Emission	$\hat{\varepsilon}_A - \hat{q}_A$	-0.017	-0.060	-0.031
intensity	$\hat{\varepsilon}_N - \hat{q}_N$	-0.017	–	0.029
7. Leakage	Λ	0.420	–	1.005
8. No-leakage tax	$\hat{\tau}^q_{A,0}$	0.032	0.032[a]	0.032[a]

[a] Exogenously imposed values.

A simple ICGE model (updated version of Sue Wing, 2007)

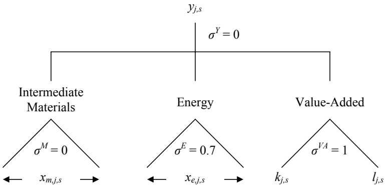
Model structure

- In contrast to prior sub-national CGE studies (Partridge-Rickman 1998), present model resolves 50 states + DC simultaneously
- 10 industry sectors: bi-level CES prod'n f'n of fuel and non-fuel intermediate inputs, value-added; imperfect interstate labor + capital mobility
- Simplified interstate trade using Armington structure: each good has single aggregate consumer price = CES aggregate of state-level producer prices
- Simplified tax structure: representative state agents, no gov't, lump-rum revenue recycling to hholds in state where tax levied

Industries

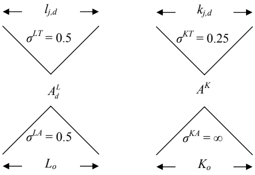
A. Fossil Fuels	*C. Non-Energy Goods/Sectors*
1. Coal	6. Energy-intensive sectors (Stone, clay & glass + Chemicals + Metals + Pulp & Paper)
2. Petroleum	7. Durable goods manufacturing
3. Gas	8. Non-Durable goods manufacturing
B. Non-Fossil Energy Goods/Sectors	9. Transportation
4. Electric power	10. Rest of the economy (Agriculture + Mining + Construction + Services + Government)
5. Crude oil & gas	

Representation of Production and Imperfect Factor Mobility in the Model



σ^M = Elasticity of substitution among intermediate material inputs ($x_{m,j,s}$); σ^E = Elasticity of substitution among intermediate energy inputs ($x_{e,j,s}$); σ^{VA} = Elasticity of substitution between labor ($l_{j,s}$) and capital ($k_{j,s}$); σ^Y = Elasticity of substitution among energy, materials and value-added.

(a) Industries' nested production functions



A^L_d = aggregate labor supply in destination state d; σ^{LA} = Elasticity of substitution among labor endowments of origin states o (K_o); σ^{LT} = Elasticity of transformation between aggregate and sector-specific labor at d ($l_{j,d}$); A^K = aggregate capital supply; σ^{KA} = Elasticity of substitution among origin states' capital endowments (K_o); σ^{KT} = Elasticity of transformation between aggregate and sector-specific capital ($k_{j,d}$).

(b) Imperfect interstate and intersectoral factor mobility

Data Development

- BLS social accounting matrix (SAM) for 2004, adjustments to intermediate energy demand using EIA data
- SAM regionalized using BEA data: column disaggregation of value-added using state GDP components, commodity × state disaggregation of total final use using ASPI
- Column disaggregation of non-energy intermediates: value shares of goods in given sector the same for all states = share in aggregate SAM
- Intermediate + final demands for energy imputed from EIA state energy data
- Factor supply acc't: derive value of states labor endowments using agg. demand from GSP, 2000 census county-to-county worker flow files, capital remuneration computed as residual ASPI
- Caveats: no interstate trade matrices (creating need for Armington assumption), no data on components of final demand ⇒ only crude esimates of terms-of-trade effects, welfare calculations based on *income* not consumption

Model Calibration and Policy Experiments

Calibration

- Model formulation as MCP, benchmark numerical calibration + replication w/. MPSGE
- simulate year 2015 as target date for proposals to regulate CO_2
- Scale benchmark state factor endowments at historical state GDP growth rates
- Estimate elasticity of energy intensity w.r.t. state GDP (cf. Metcalf, 2007), compute energy-intensity decline factors, scale energy coeffs. in cost, expenditure f'ns

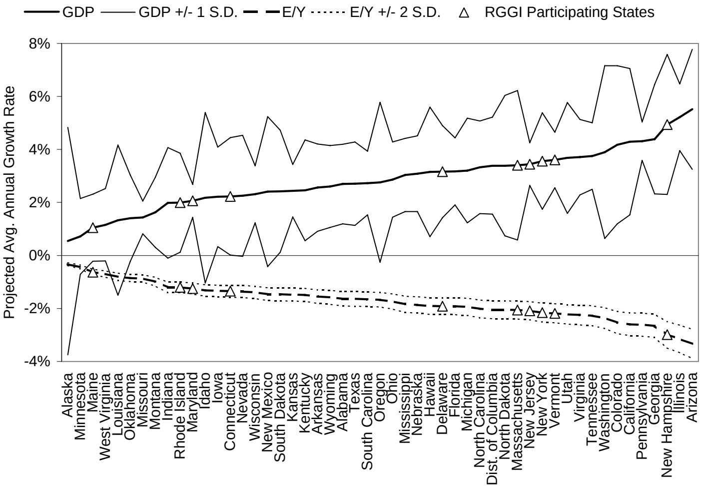
$$\log\left(\frac{E}{Y}\right)_s = \underset{(0.0004)}{0.0001} + \underbrace{\underset{(0.016)}{0.605}}_{\omega_1} \log\left(\frac{E}{Y}\right)_{s,-1} \underbrace{\underset{(0.013)}{-0.240}}_{\omega_2} \log Y_s \underset{(0.005)}{-0.066} \log P^E_s + \underset{(0.011)}{0.109} \log HDD_s.$$

- LR E/Y income elasticity $\Omega = \omega_2/(1-\omega_1)$= -0.61, S.E. 0.05

Policy experiments

- Intra-state allowance trading under individual RGGI emission targets (autarkic state abatement)
- Inter-state allowance trading under aggregate RGGI cap
- Harmonized tariffs on electricity consumption in RGGI states: search over values to find leakage-neutralizing tax

Average Annual Growth Rates of State GDP and Energy Intensity, 2005-2015



Overview of Results and Sensitivity Cases

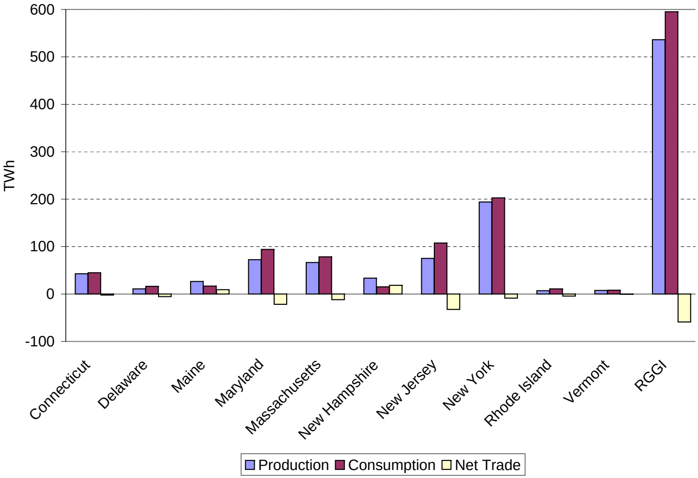
Base Case Results

- Allowance price: \$2.70 / ton CO_2
- Increase in elec. imports: 3.3%
- Leakage rate: 49%
- Aggregate U.S. net abatement: 3.3 $MTCO_2$
- Leakage-neutralizing electricity tax: 2.5%
- RGGI abatement after elec. tax imposed: 6.7 $MTCO_2$
- RGGI-wide change in per capita ASPI (with recycled tax revenues): +\$5

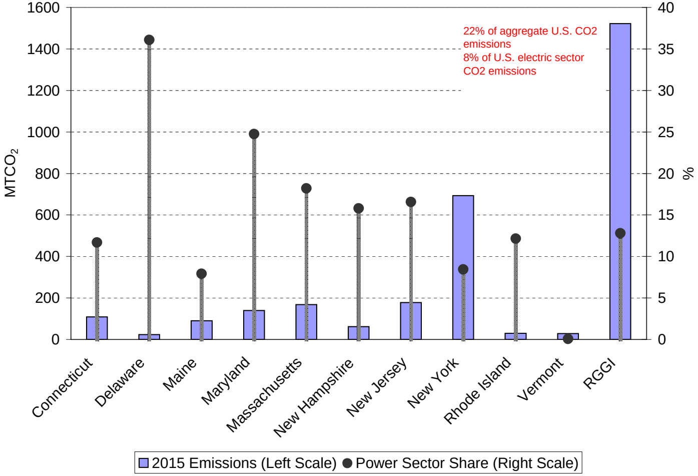
Sensitivity Cases

- Income elasticity of E/GDP ± 2 S.D.
- Autonomous energy efficiency improvement (AEEI) at 1% and 0.5% per annum
- GDP growth rate $\pm$ 1 SD
- 2/0.5 $\times$ interfuel substitution elasticity
- 2/0.5 $\times$ Armington elasticity of substitution for electricity
- 2/0.5 $\times$ Armington elasticity of substitution for coal, oil, gas

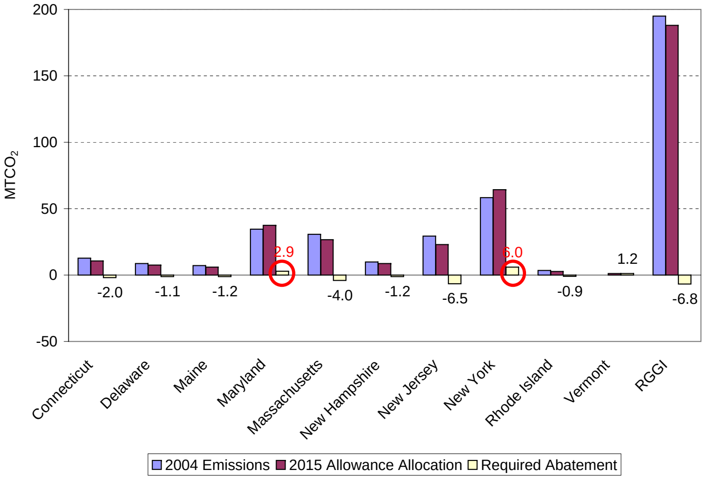
BAU Scenario: Interstate Electricity Market Disposition



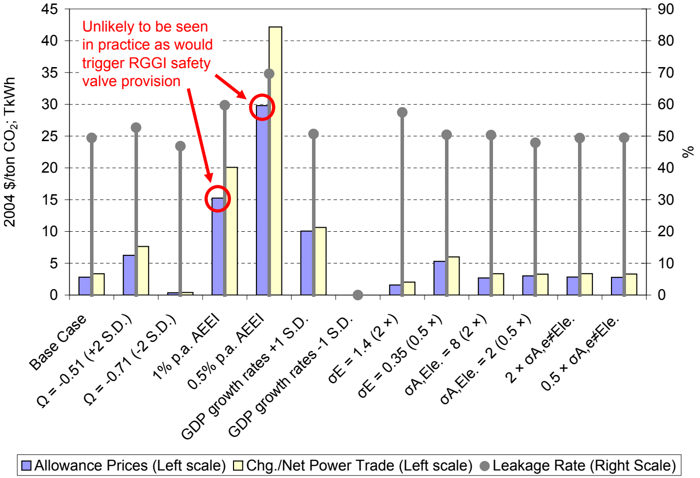
BAU Scenario: Importance of Electric Power for CO_2 Emissions



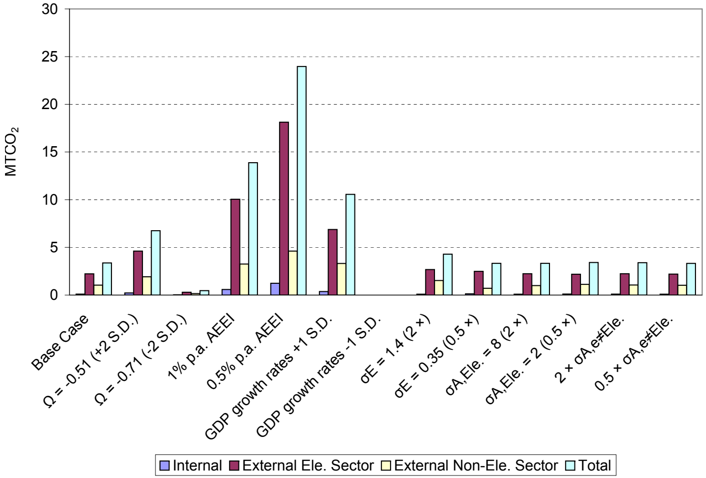
RGGI Interstate Emission Trading: “Hot Air”



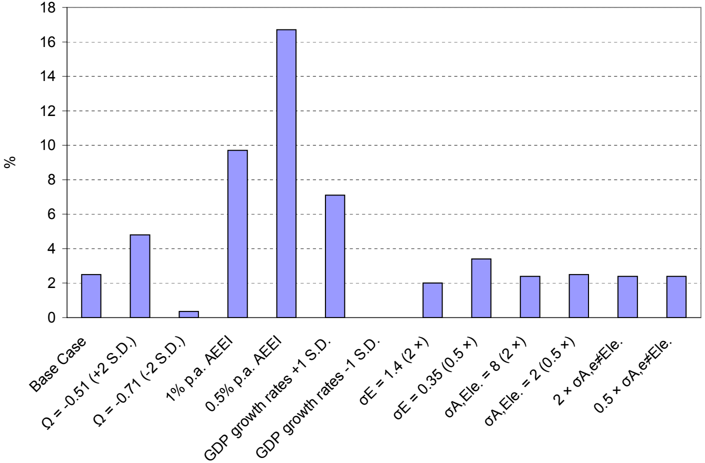
Sensitivity: Impacts on Allowance Prices, Electricity Trade and Leakage



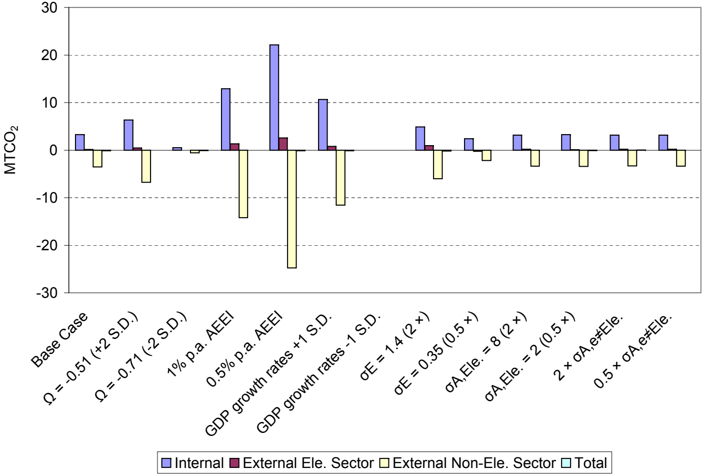
Sensitivity: Leakage Disposition and Importance of Non-Electric Sectors



Sensitivity: Leakage-Neutralizing Electricity Tariffs



Sensitivity: Leakage Disposition in the Presence of Electricity Tariffs



Conclusions

RGGI caps bind lightly on participating statesŠ economies

- Substantial "hot air" introduced by non-binding targets in New York, Maryland
- Allowance prices typically in $2-7 range, only exceed $10 safety valve threshold if state energy intensities decline much more slowly than historically
- Small primary abatement burden + recycled permit revenues = slight increases in per capita income
- Total net abatement of RGGI is small: < 4 MT in base case

Substantial induced CO_2 leakage

- Modest inflows of electric power to RGGI states
- Leakage rates fairly tightly clustered in 47-57% range
- Non-electric sectors in unconstrained states responsible for 1/3 of the problem

Countervailing electricity taxes

- Tax rate on electricity use in RGGI states of 2.5% neutralizes leakage in base case
- Taxes strongly attenuate RGGI states' demand for imported power
- Induce substantial *internal* leakage, but w/. smaller offsetting effect on primary abatement

Bottom Line

The import substitution response induced by unilateral electricity taxes is effective in attenuating power inflows and leakage

Consequent increases in electricity prices are associated with an inward shift in the economy-wide demand curve for electricity

Result: smaller generation response outside RGGI, substitution of electricity for fossil fuels, and lower emissions there.