Upstream v. Downstream CO_2 Trading in Electricity Markets: *What is the Cheapest Way to Sustainability?*

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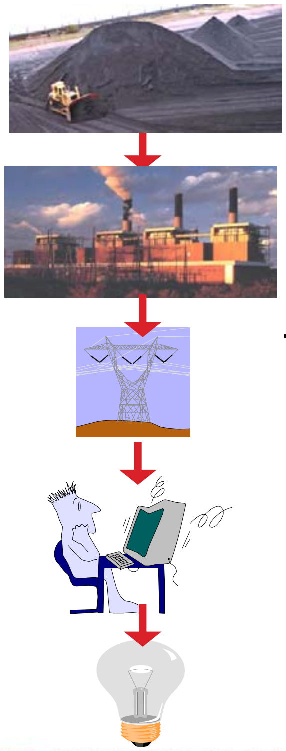
Outline

1. Who should be responsible for reducing carbon emissions?
   - *Three proposals for carbon markets*
   - *Which is cheaper? Provides more incentive for conservation?*
2. Method: Equilibrium models of electricity & carbon markets
3. Analytical results
4. Examples
   - *Simple*
   - *Western US*

www.wingas-uk.com

1. Who should be responsible for reducing CO_2?



Fuel extractors?

Oil producers/importers (US Waxman-Markey bill)

Power plants?

Power plants (EU Emissions Trading System)

US: Title IV SO_2; State greenhouse gas initiatives (RGGI)

Transmission grid/system operator?

In a single-buyer "POOLCO"-type power market

Retail suppliers/Load serving entities?

California, Western US "Load-Based" proposals

GEAC (Gillenwater & Breidenich 2009), CO_2RC (Michel & Nielson 2008)

Consumers?

Tradable Quotas, Personal Carbon Allowances (Fleming, 1997)

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Example: The California Debate

California AB32:

- *CO_2 to be reduced to 1990 levels by 2020*

Debate: "Point of Compliance" for CO_2

- *I.e., Who's responsible for "cap & trade"?*
  - *Power plants (sources)?*
  - *Load serving entities (LSEs) (for consumers)?*
- *Elsewhere, source-based dominates*
  - *Allocate allowances to power plants, & trade*
    - *Total emissions ≤ cap*
- *Load-based proposed for California*
  - *Mean emissions of LSE power purchases ≤ cap*
  - *Cheaper (Synapse Energy, 2007)?*
  - *Motivates more energy conservation (NRDC)?*
  - *Result in less CO_2 "leakage"?*
- *Concerns over effects on power trade motivated GEAC, CO_2RC*
  - *Generation Emission Attribute Certificates: Power plants sell power and emissions attributes separately to LSEs*
  - *CO_2 Reduction Credits: LSEs pay power plants to reduce emissions*

Gov. Schwarzenegger is joined by international leaders with a consistent record of addressing the global threat of climate change, New York Governor George Pataki and other environmental and industry leaders at a bill signing for AB 32 on Treasure Island in San Francisco on Tuesday, September 27, 2006.

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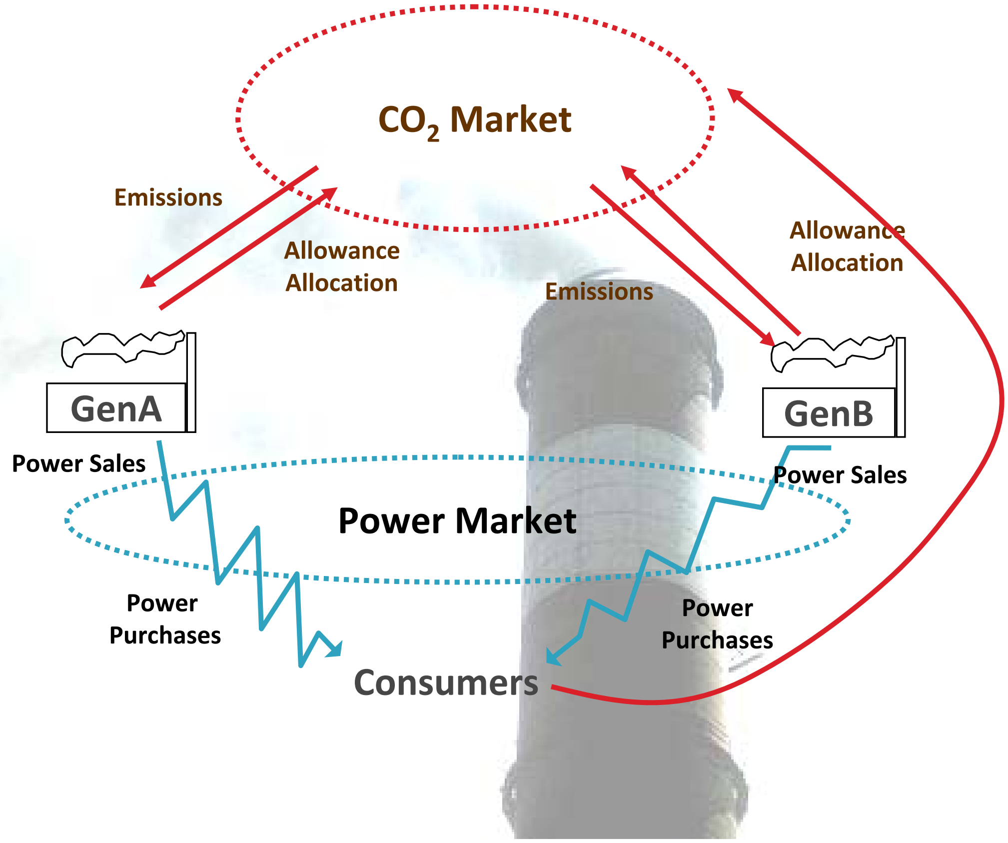
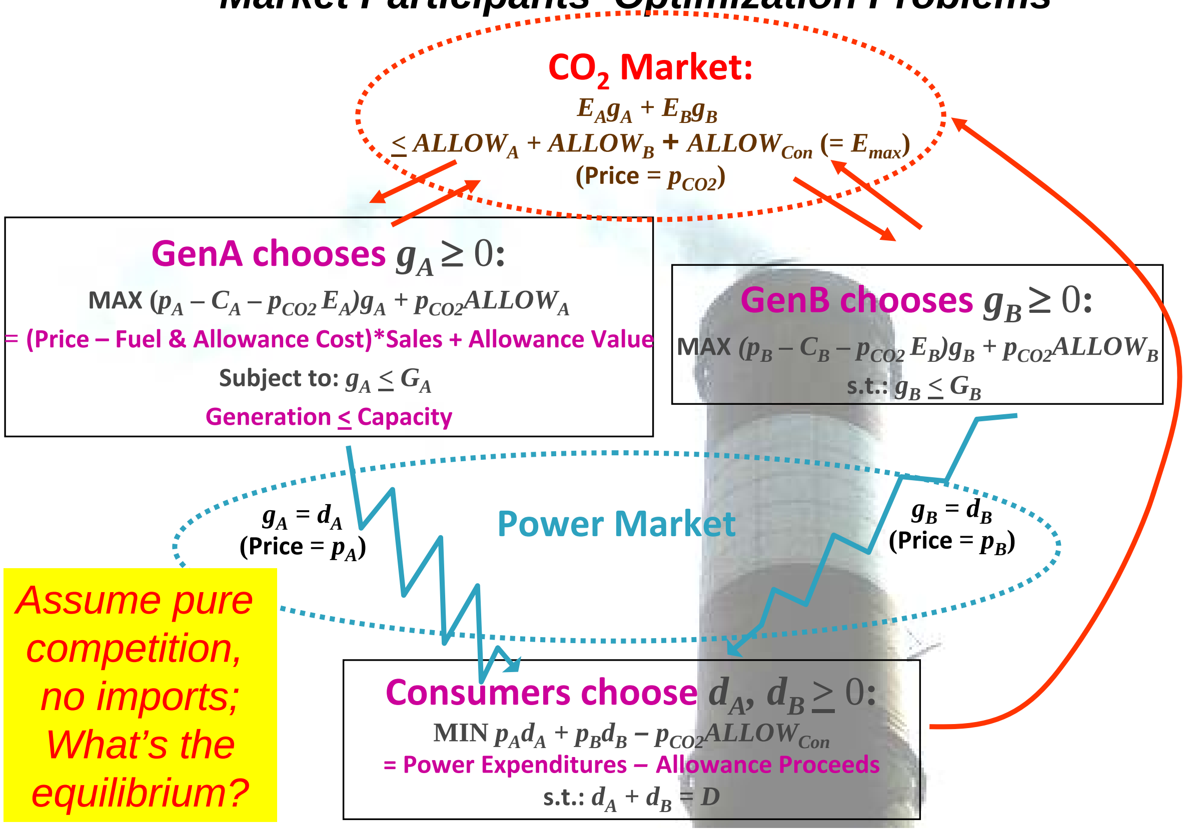
Source-Based Market Schematic



Source-Based (Competitive) Market:
Market Participants' Optimization Problems



Source-Based Market Equilibrium Problem:
Find $\{p_A, p_B, p_{CO2}; g_A, \mu_A; g_B, \mu_B; d_A, d_B, \lambda\}$ satisfying:

$E_A g_A + E_B g_B \le E_{max}$
(Price = p_{CO2})

$0 \le g_A \perp p_A - C_A - p_{CO2}E_A - \mu_A \le 0$
$0 \le \mu_A \perp g_A - G_A \le 0$

$0 \le g_B \perp p_B - C_B - p_{CO2}E_B - \mu_B \le 0$
$0 \le \mu_B \perp g_B - G_B \le 0$

$g_A = d_A$
(price = p_A)

$g_B = d_B$
(price = p_B)

$0 \le d_A \perp p_A - \lambda \le 0$
$0 \le d_B \perp p_B - \lambda \le 0$
$d_A + d_B = D \quad (\lambda)$

10 Conditions,
10 Unknowns

Load-Based Market:
Market Participant Optimization Problems

GenA chooses $g_A \ge 0$:
MAX $(p_A - C_A)g_A$
= (Price – Fuel Cost)*Sales
s.t.: $g_A \le G_A$

GenB chooses $g_B \ge 0$:
MAX $(p_B - C_B)g_B$
s.t.: $g_B \le G_B$

Power Market

$g_A = d_A$
(Price = p_A)

$g_B = d_B$
(Price = p_B)

Consumers choose $d_A, d_B \ge 0$:
MIN $p_A d_A + p_B d_B$
s.t.: $d_A + d_B = D$
$E_A d_A + E_B d_B \le D*ERate_{max} = E_{max}$ (dual = p_{CO2})
Emission weighted purchases ≤ Limit

Derive equilibrium conditions:
10 Conditions,
10 Unknowns

Analytical Conclusions

(B. Hobbs, J. Bushnell, & F. Wolak, *Energy Policy*, in press)

Power prices:

- *Uniform in <u>source</u>-based system: $p_A = p_B$*
- *Differentiated in <u>load</u>-based system*
  - Higher for cleaner generation
  - $p_i = p_0 - p_{CO2} * E_i$
    where p_0 = market price of zero-emissions power
- *Differentiation endangers efficiencies of PJM-like spot markets*
  - Single price markets chase clean power out to bilateral markets
  - Attract only dirty power, possibly a risk to reliability

All other variables identical:

- *Primal quantities (MWh, tons)*
- *Source-based p_{CO2} = LSE's shadow price of emissions*

Proof:

- *Source based $\{p_0 - p_{CO2} * E_i, p_{CO2}; g_A, \mu_A; g_B, \mu_B; d_A, d_B, \lambda\}$ satisfy equilibrium conditions of source-based (and vice versa)*

Analytical Conclusions

- "Load side carbon cap is likely to cost California consumers significantly less than supply side cap--Potentially billions of \$/yr."
  ("Exploration of Costs for Load Side and Supply Side Carbon Caps for California," R. Biewald, Synapse Energy, Inc., Aug. 2007)
  - By discriminating among suppliers and paying less for dirty power, LSEs can expropriate all profit increases due to emissions trading
  - Contrary to speculation, generator profits & net costs to consumers <u>same</u>

    … *If* allowances are auctioned to generators ($Allow_A = Allow_B = 0$), and consumers get proceeds ($Allow_{Con} = E_{max}$)

    …and *if* no damage to spot markets
- Two sources of emissions trading profits
  1. Emissions allowance rent = $E_{max} * P_{CO2}$
  2. Rents to clean generation occur if regulation increases gross margin on sales:

$$(p - C_i - p_{CO2} E_i) > (p^{NoReg} - C_i)$$

Load-based only transfers the first to consumers

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Example: Source-Based (Competitive) Market:
All Allowances Auctioned, Proceeds to Consumers

CO_2 Market:

$\underline{1}*g_A + \underline{0.5}*g_B \le \underline{0.75}$ tons

(Price = p_{CO2}) = $60/ton

Coal GenA:

MAX $(p_A - \underline{\$40/MWh} - p_{CO2}\,\underline{1\ t/MWh})g_A + p_{CO2}*\underline{0\ tons}$

= (Price – Fuel & Allowance Cost)*Sales + Allowance Value

s.t.: $g_A \le \underline{+\infty}$

Generation ≤ Capacity

Gas GenB:

MAX $(p_B - \underline{\$70} - p_{CO2}*\underline{0.5})g_B + p_{CO2}*\underline{0}$

s.t.: $g_B \le \underline{+\infty}$

Power Market

$g_A = d_A$ = 0.5 MWh

(Price = p_A) = $100/MWh

$g_B = d_B$ = 0.5 MWh

(Price = p_B) =$100/MWh

What's the equilibrium?

Consumers:

MIN $p_A d_A + p_B d_B - p_{CO2}*\underline{0.75\ tons}$

= Power Expenditures – Allowance Proce[eds]

=100(0.5+0.5)–60*0.75 = $55

s.t.: $d_A + d_B = \underline{1\ MWh}$

Dual = $100/MWh

Load-Based Market: Example

Coal GenA:

MAX $(p_A - \underline{\$40/MWh})g_A$

= (Price – Fuel Cost)*Sales

s.t.: $g_A \le \underline{+\infty}$

Gas GenB:

MAX $(p_B - \underline{70})g_B$

s.t.: $g_B \le \underline{+\infty}$

Power Market

$g_A = d_A$ = 0.5 MWh

(Price = p_A) = $40/MWh

$g_B = d_B$ = 0.5 MWh

(Price = p_B) =$70/MWh

What is the equilibrium?

Consumers:

MIN $p_A d_A + p_B d_B$ = 40*0.5+ 70*0.5 = $55

s.t.: $d_A + d_B = \underline{1\ MWh}$ (Dual = $100/MWh)

$E_A d_A + E_B d_B \le \underline{0.75\ tons}$ (Dual = p_{CO2} = $60/MWh)

Emission weighted purchases ≤ Limit

Incentives for Energy Efficiency

- Does Load-Based Trading give greater incentives for conserving energy?
  - *"Paint target on LSE's back"*
- *Not in California*
  - Utilities required to invest in energy efficiency if:
    Energy Efficiency Investment Cost
    *< Avoided Cost of Energy * Energy Savings*
  - In both load- and source-based systems, the "avoided cost of energy" (dual variable to the load constraint) is the <u>same</u>
    = p_0 in the load-based case = $100/MWh
- But if conservation also tightens LSE emissions constraint $E_A d_A + E_B d_B \leq D^* E_{Ratemax}$ then Load-Based *weakens* incentive
  - LSE saves $100/MWh in energy costs, but pays $60 more in CO_2 control costs
    - Conservation saves just $40/MWh

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Decoupling Proposal: CO_2 Reduction Credits

- Concern with differentiating power by emissions
  - *Harms spot-market type power market*
  - CO_2RCs and GEACs proposals to have consumers buy power & emissions separately
- CO_2RCs: Plants sell 2 commodities to consumers:
  - *Power* is metered
  - *CO_2RCs* are generated by power plants based on monitored emissions
    - Plant *i* generates $(K-E_i)g_i$
    - K is a high "default" emissions rate
    - LSEs/consumers must buy $(K- E_{ratemax})D$ CO_2RCs
- Variant: GEACs (sell MWh denominated GEACs, differentiated by emissions rate)

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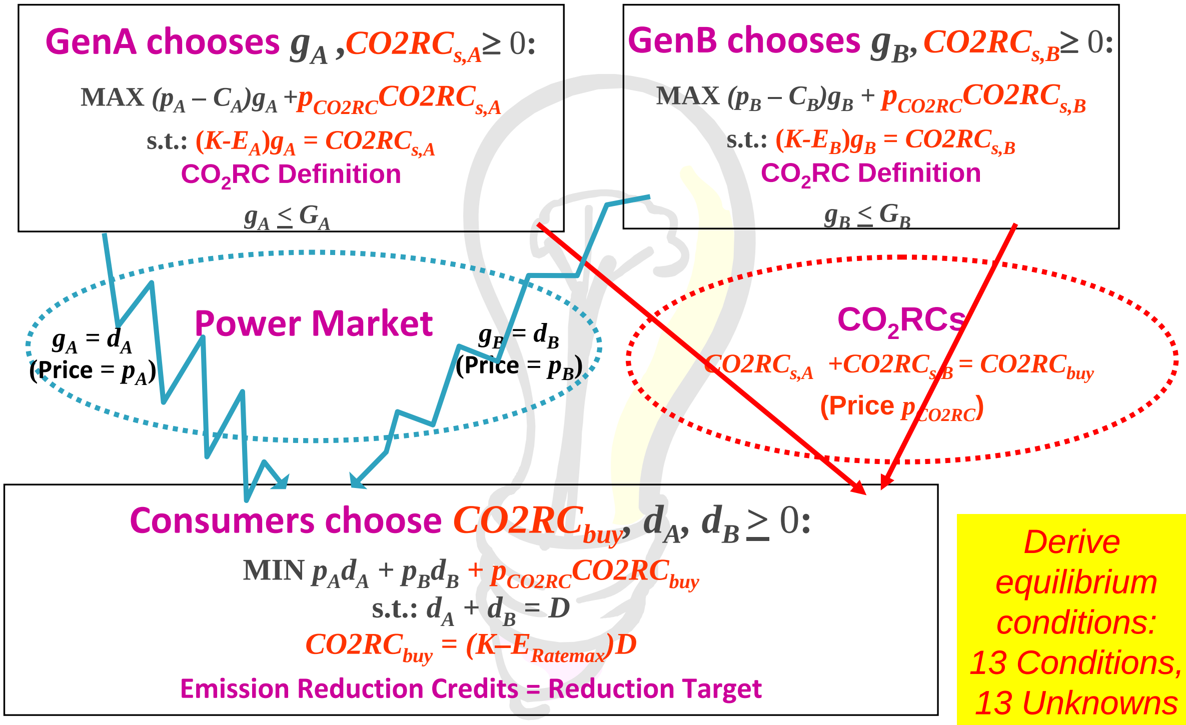
Generators Sell Power & CO_2RCs Separately



Analytical Conclusions: CO_2RC

- **CO_2RC is economically equivalent to source-based trading with the following (sometimes odd!) characteristics:**
  - *Uniform power price for all producers: $p_A = p_B$*
  - *Producer output is subsidized:*
    - For each MWh generated, get K free allowances
    - K is a high "default" emission rate > $E_{ratemax}$
    - Decreases MC of power production, causing price of power to fall
  - *Too many allowances: $\Sigma_i K g_i > \Sigma_i E_{ratemax} g_i = E_{ratemax} D$*
    - *.:. Consumers must pay generators for excess allowances, & "retire" them*
    - Consumers pay generators $(K\text{-}E_{ratemax})p_{CO2}D$
  - *Profits, Total consumer payments, amounts generated the same as original Source-Based*
    - Independent of default K
    - If zero price elasticity
- **Basic source-based trading simpler – avoid LSE transaction costs**

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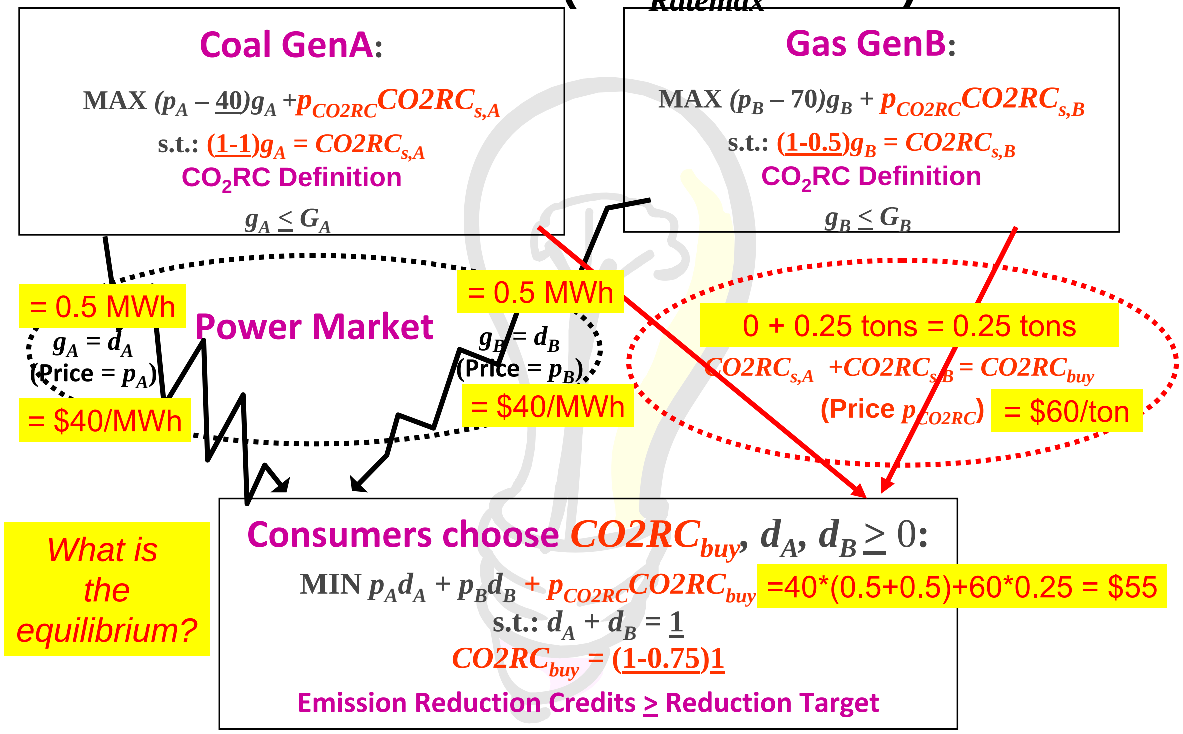
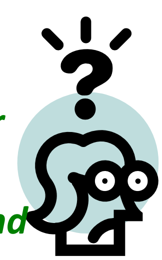
CO_2RCs Example: K = 1 ton/MWh (> $E_{Ratemax}$ = 0.75)



Numerical Simulation with Power Imports

Y.Chen, A. Liu, and B. Hobbs, "Economic & Emissions Implications of Load-based, Source-based and First-seller Emissions Trading Programs under AB32", *Operations Research*, in review)

- **California imports 20% of power…and 50% of its power-based CO_2 emissions**
- **3 California proposals (load, source, "first-seller"):**
  - ***Do they lead to different emissions permits and whole electricity prices?***
  - ***Do they yield different generator profits and consumer costs?***
  - ***How do they compare in terms of contract-shuffling and CO_2 leakage?***
- **Method: Mixed complementarity model of equilibria in energy, transmission, emissions markets**



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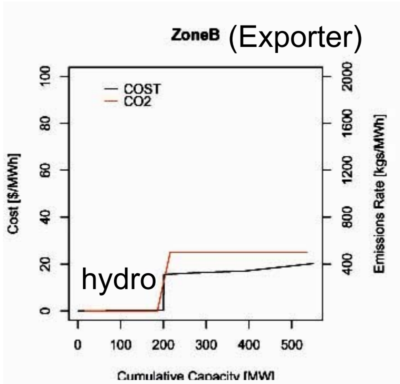
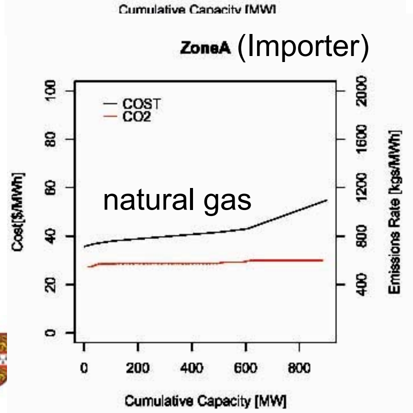
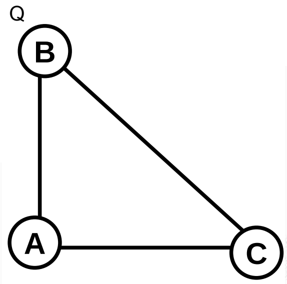
Example: Network, Gen Mix and CO_2 Emissions

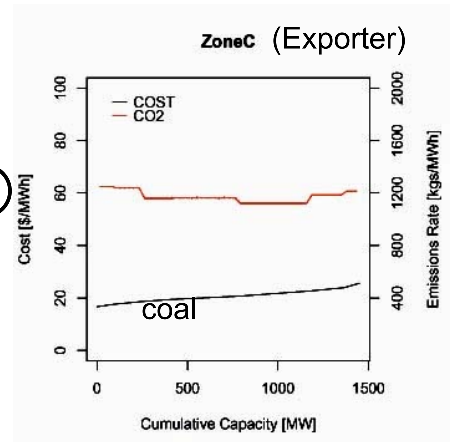




Zone A = Importer

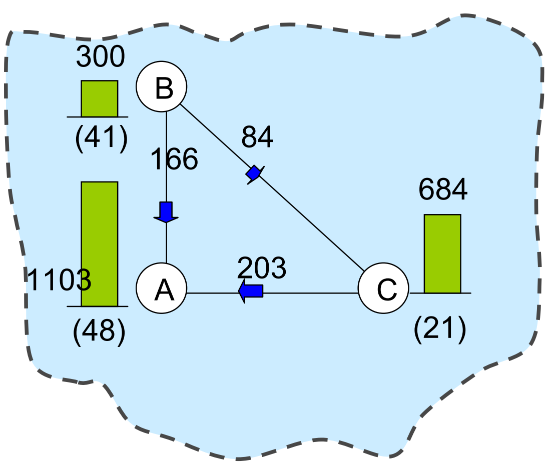
Policy for Zone A:
Target of 400 tons



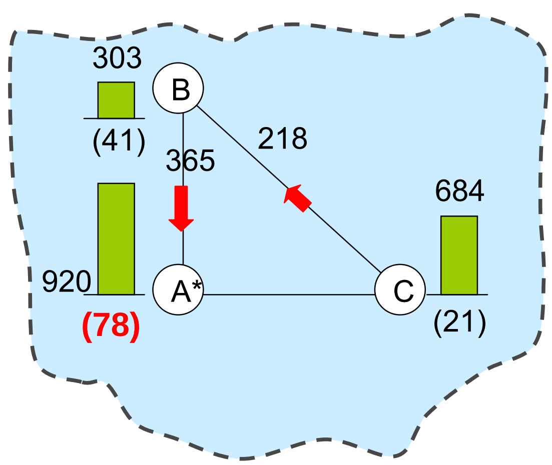


Results: Electricity Sales

net sales [MWh]
zonal sales [MWh]
( ) electricity price [$/MWh]

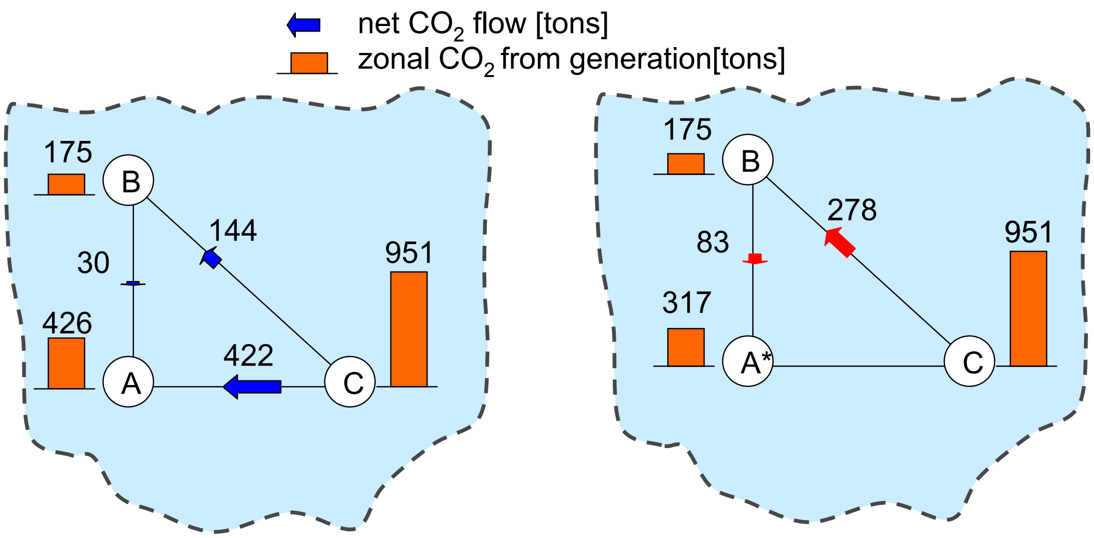


No Cap



All Three Policies

Results: CO_2 Emissions



No-cap **All Three Policies**

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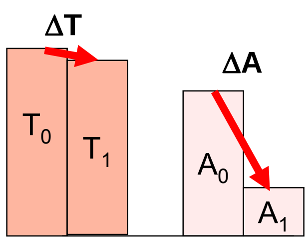
Results: CO_2 Leakage

***CO_2 leakage:* % of credited CO_2 reductions that are not real**



T_0: total emissions | *no cap*
T_1: total emissions | *policy*

A_0: A's "credited" emissions | *no cap*
A_1: A's "credited" emissions | *policy*

%leakage = 100%(1 - ΔT/ΔA)

	3 Approaches
%Leakage	85%

Occurs because "contract shuffling" results in large apparent reductions in import-associated emissions that are not real

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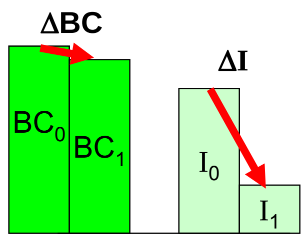
Results: Contract-shuffling

Contract shuffling: **re-arrangement of electricity imports contracts results in *apparent*, but not *real* emissions reductions**



BC_0: emissions of B & C | *no cap*
BC_1: emissions of B & C | *policy*

I_0: emissions import to A | *no cap*
I_1: emissions import to A | *policy*

$\%shuffling = 100\%(1 - \Delta BC / \Delta I)$

	3 Approaches
%Shuffling	100%

All emissions "reductions" associated with imports are imaginary

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Conclusion: Comparison of Systems

- ***If economic rent of allowances is retained by consumers, three proposals are economically equivalent (nodal prices, consumer costs, social welfare, etc)***
  - **E.g., auction allowances in Source-based system, proceeds go to consumers**
  - **Load-based more complex, can endanger spot power markets**
- ***All proposals subject to CO_2 leakage & contract shuffling***
- ***US Federal Legislation needed!***

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