Designing CO_2 Markets for the Power Sector:

Does It Matter Who Must Comply and Who Gets the Allowances?

Benjamin F. Hobbs

Theodore M. & Kay W. Schad Professor of Environmental Management
Whiting School of Engineering
The Johns Hopkins University

Member
California ISO Market Surveillance Committee

bhobbs@jhu.edu

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Outline

Background

Q1: Does It Matter Who Must Comply?

- **Load or Generators?**

Q2. Does It Matter How Allowances Are Allocated?

- **Grandfathered or free to new investment?**

Climate Warming Impacts: Example

- **The famous spaghetti farmers of Switzerland & Italy no longer raise the crop**

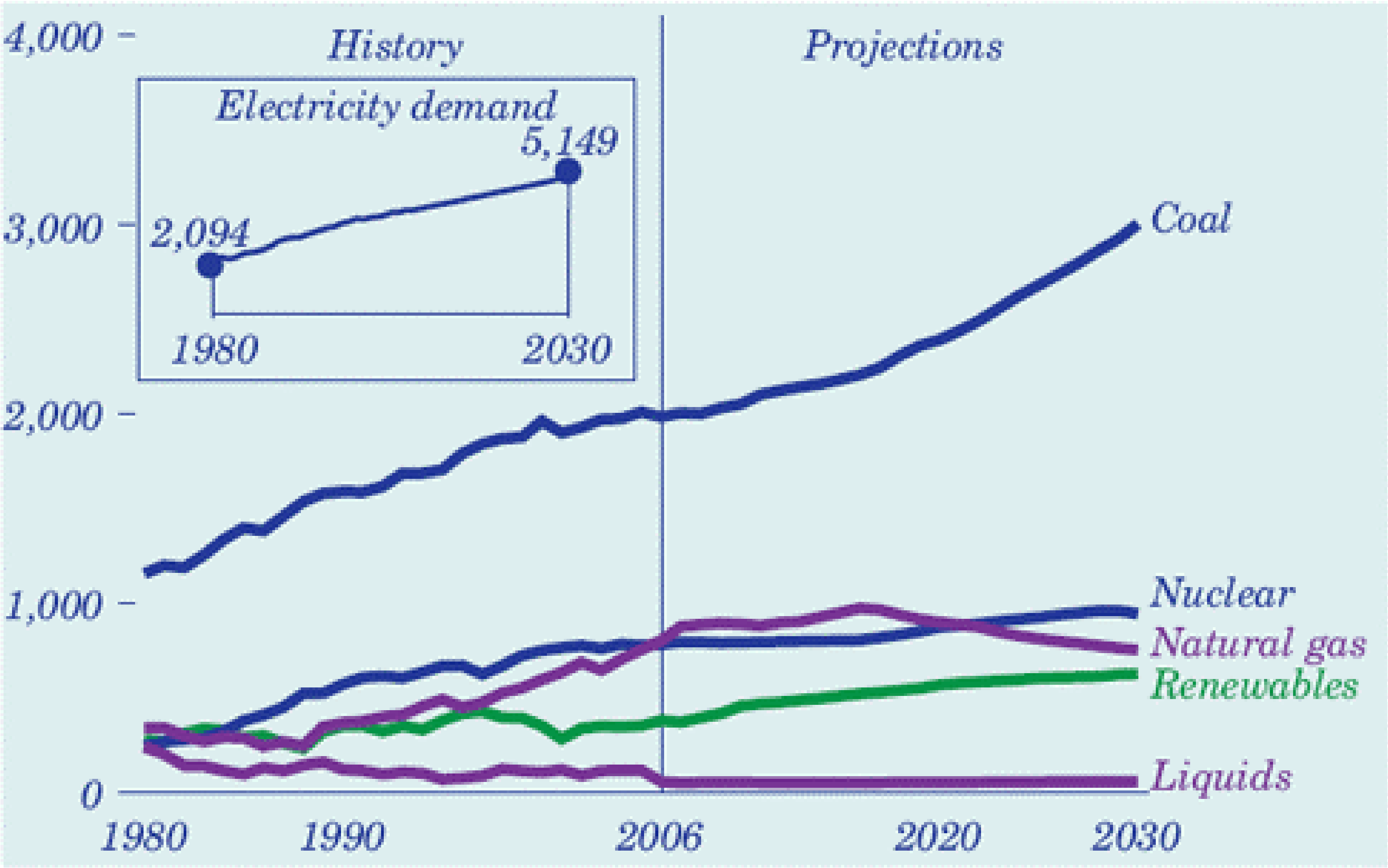
- **Speculation: Climate warming causing spread of the spaghetti weevil *(Marinarus meetbollus)***

Source: BBC, April 1, 1957

For more information,
see news.bbc.co.uk/onthisday/hi/dates/stories/april/1/newsid_2819000/2819261.stm

Power: 60% of U.S. Energy CO_2

Figure 4. Electricity generation by fuel, 1980-2030 (billion kilowatthours)



USDOE EIA, 2008 Annual Energy Outlook (draft)

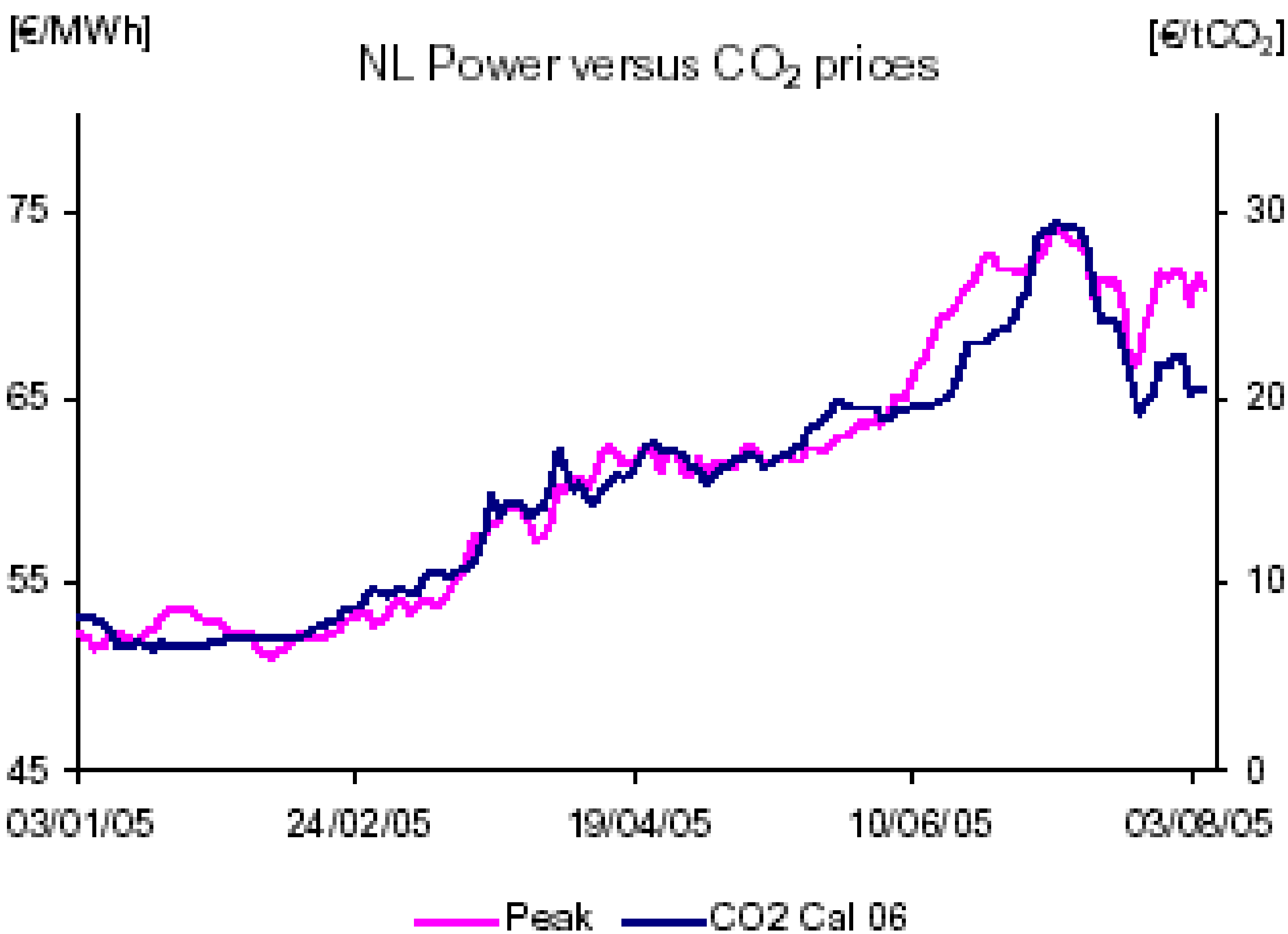
How to Incent CO_2 Reductions?

1. *Command-and-Control, e.g.,*
   - **Required fuels, equipment retrofits**
   - **Operating restrictions**
2. *Individual facility caps*
3. *Emissions taxes*
4. *Cap & trade*
   - **Overcompliers can sell excess permits to undercompliers**
   - **Permits allocated by auction or potlatch**
5. *Consumer choice*

- **Taxes, cap & trade create a "level playing field"**
  - **-- Preferred from an efficiency point of view (NAS/NRC, 2004)**
- **C&T easy to impose on utilities**
  - **--Taxes more appealing for other sectors**

EU Emissions Trading System

- **27 Countries: Phase I: 2005-07; Phase II: 2007-2012**
- **Each allocates allowances ("National Allocation Plans")**



Bulk Power Prices +50%

Source: J. Sijm, Netherlands Energy Research Centre, personal communication

State Programs in the U.S.

Goals:

- **RGGI: -10% by 2019**
- **CA: 1990 levels by 2020**

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.

Design Issues:

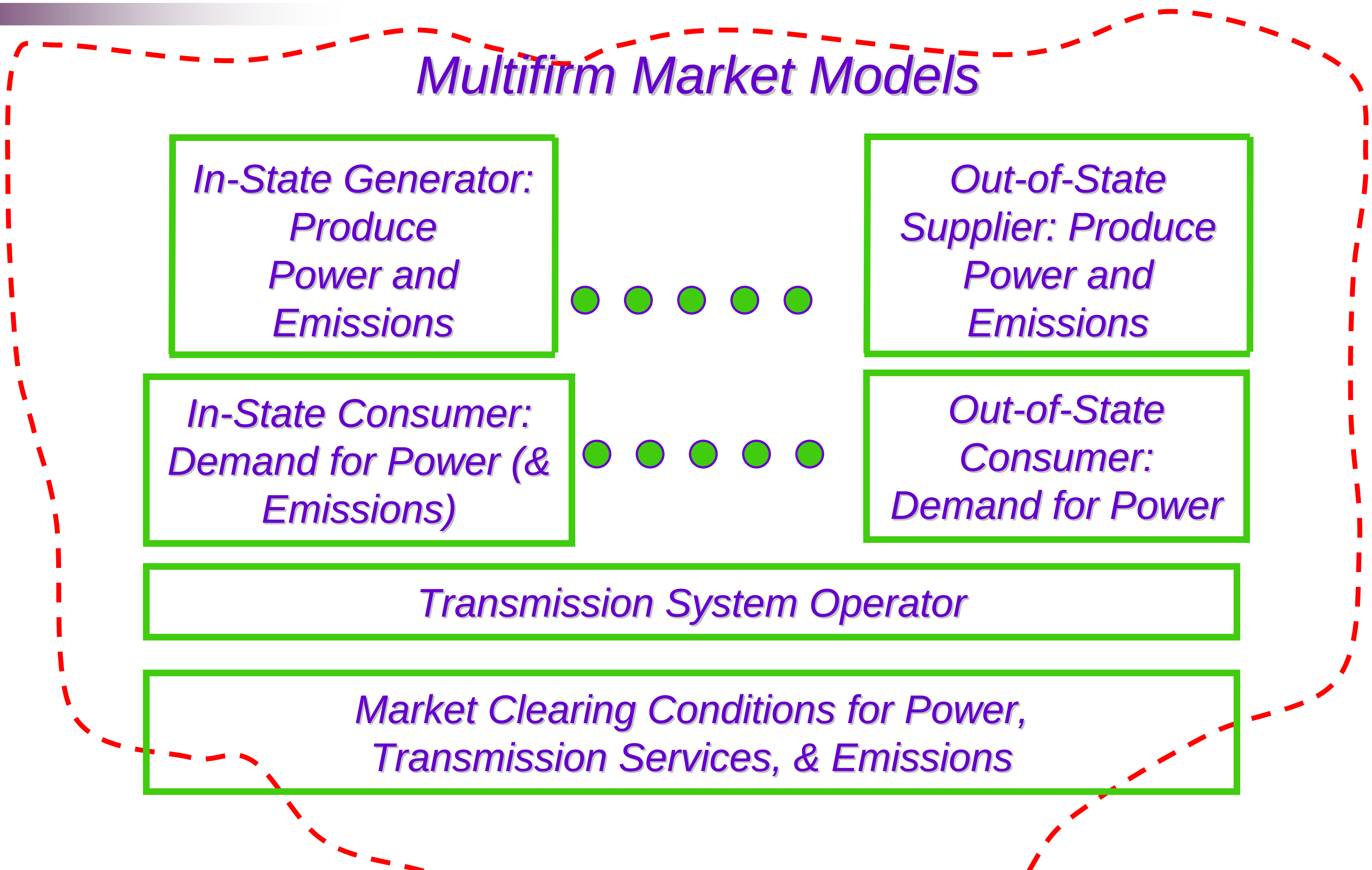
- **Who should be responsible for emissions?**
- **Who should be given the allowances?**
  ("rent seeking")
- **Effectiveness**
  ("leakage," "contract shuffle")
- **Cost**

Q1: Who should be responsible for CO_2 compliance?

- **California AB32 Challenges:**
  - Power only responsible for 20% of CO_2 there
  - Large amounts of imports

- **Focus of policy debate: "Point of Compliance" for CO_2 allowance "cap and trade" system** http://docs.cpuc.ca.gov/efile/PD/78643.pdf
  - Load serving entities (LSEs) or power plants (sources)?
  - Elsewhere, source-based dominates
    - Allocate allowances to power plants, and then trade
      - Total emissions can't exceed cap
    - E.g., Title IV SO_2 program, RGGI
  - Load-based proposed for California
    - Mean emissions of LSE power purchases $\leq$ cap
    - Cheaper (Synapse Energy, 2007)?
    - Provide more motivation for energy efficiency (NRDC) ?

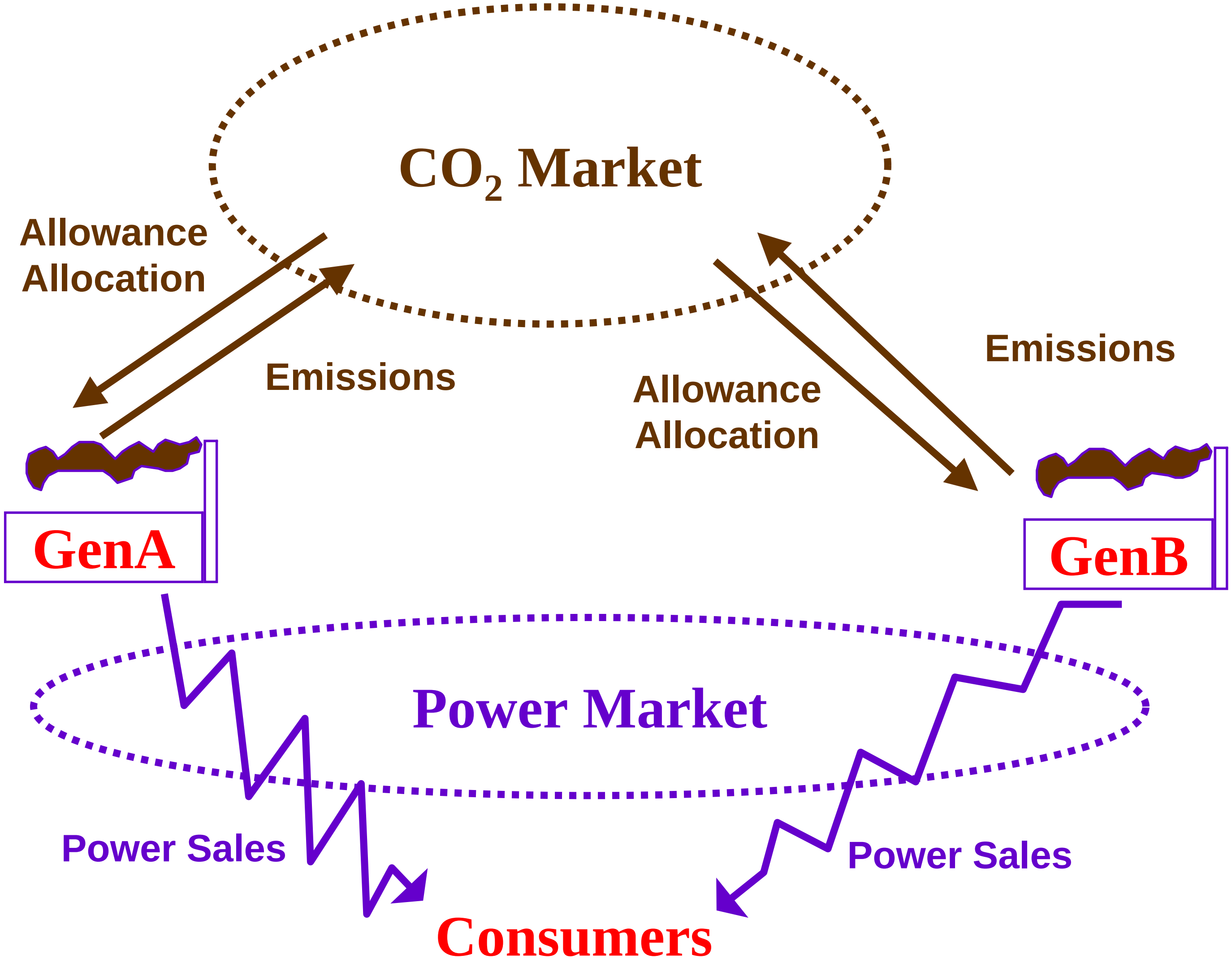
Model Structure: “Complementarity Models”



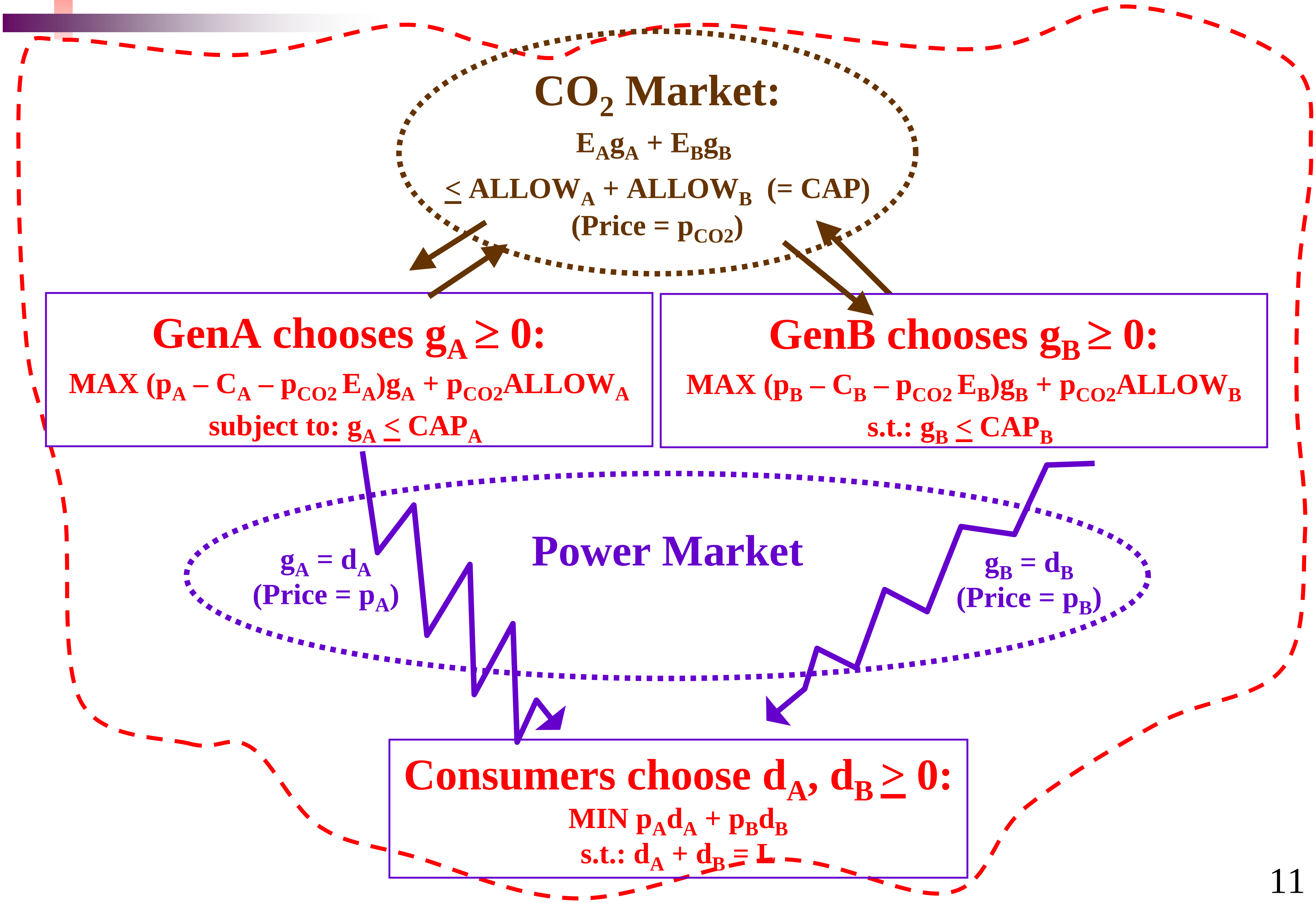
Equilibrium calculation:

- **Derive 1st order conditions for each market participant**
- **Add market clearing conditions**
- **Solve *n* conditions for *n* unknowns**

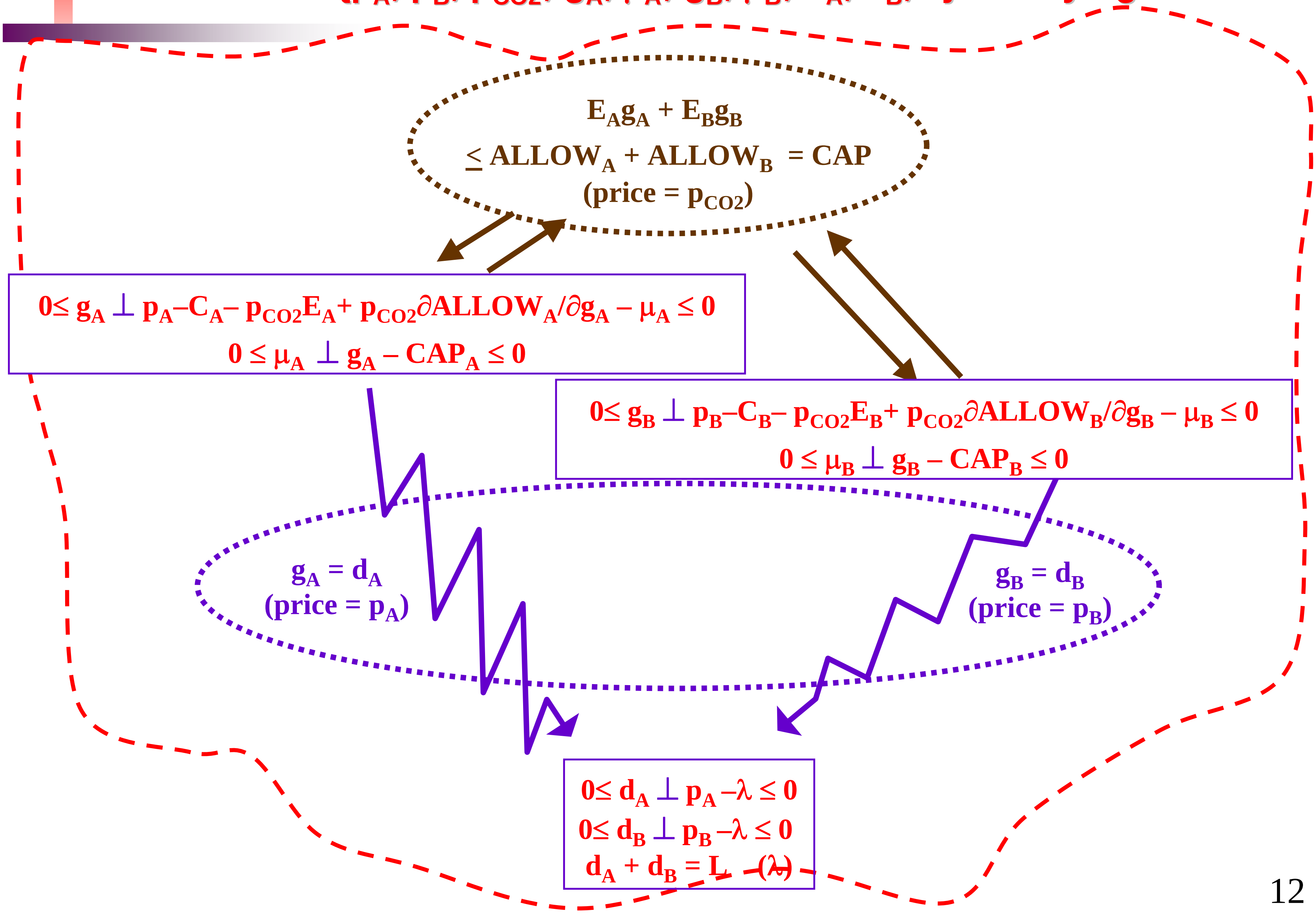
Source-Based Market Schematic



Source-Based Market: Market Participant 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:



***Load*-Based Market: Market Participant Optimization Problems**

GenA chooses $g_A \geq 0$:

MAX $(p_A - C_A)g_A$

subject to: $g_A \leq CAP_A$

GenB chooses $g_B \geq 0$:

MAX $(p_B - C_B)g_B$

s.t.: $g_B \leq CAP_B$

Power Market

$g_A = d_A$
(Price = p_A)

$g_B = d_B$
(Price = p_B)

Consumers choose $d_A, d_B \geq 0$:

MIN $p_A d_A + p_B d_B$

s.t.: $d_A + d_B = L$

$E_A d_A + E_B d_B \leq L{*}Rate = CAP$

Analytical Conclusions

(Market Surveillance Committee, California ISO, “Opinion on Load-Based and Source-Based Trading of Carbon Dioxide in California,” Nov. 27, 2007 http://www.caiso.com/1cab/1cabe03d6e190.pdf ; Y.Chen, A. Liu, and B. Hobbs, “Economic & Emissions Implications of Load-based, Source-based and First-seller Emissions Trading Programs under AB32”, POWER Conference, UCEI, UC Berkeley, March, 2008 http://www.ucei.berkeley.edu/power_conf.html)

- **For single jurisdiction (no power imports), power prices:**
  - **Same for all sources in source-based system**
  - **Differentiated in load-based system**
    - **higher for cleaner generation**
    - **endangers efficiencies of PJM-like spot market**

- **Allowance prices the same under load- and source-based**

- **“Load ~~side carbon cap is likely to cost California~~ consumers signifi~~cantly less than supply side cap--Potentially billions of~~ $/yr.”**
  (“Exploration of Costs for Load Side and Supply Side Carbon Caps for California," B. Biewald, Synapse Energy, Inc., Aug. 2007)
  - **Contrary to speculation, net costs to consumers <u>same</u>**
  - **… If allowances are auctioned to generators, and consumers get proceeds**
    - **… if no damage to spot markets**

Analytical Conclusions

- Above conclusions also apply when CO_2-constrained states trade power with non-constrained states (under certain conditions)
  - Load- and source-based equally prone to "leakage"/"contract shuffling"
  - Assumes consistent treatment of imports to/exports from constrained state:
    - Imports' "emissions" come under the constraint
    - Exported generation must obtain allowances

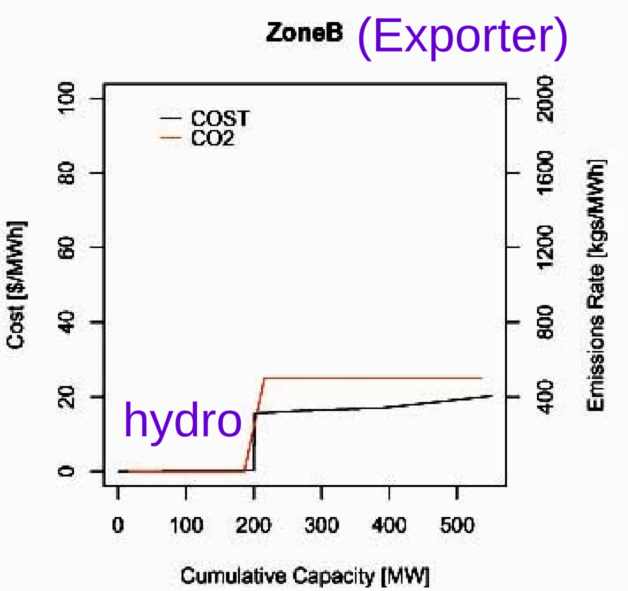
Simulation Questions

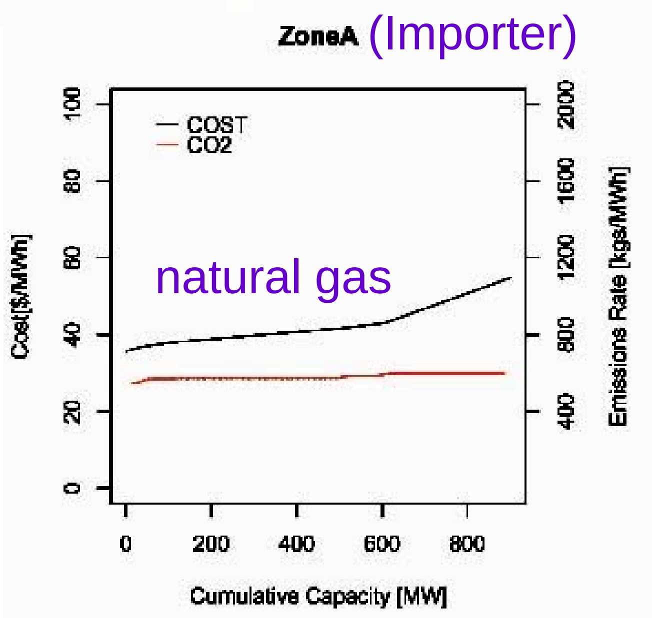
Three California proposals (load-, source, "first-seller"):

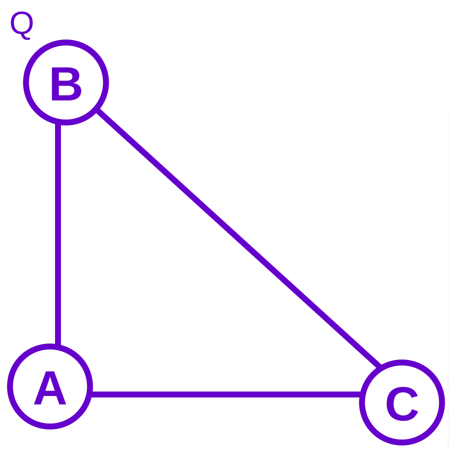
- ***Do they lead to different emissions permits and whole electricity prices?***
- ***Do they yield different generator profits and consumer costs?***
- ***How do they compare in terms of contract-shuffling and CO_2 leakage?***

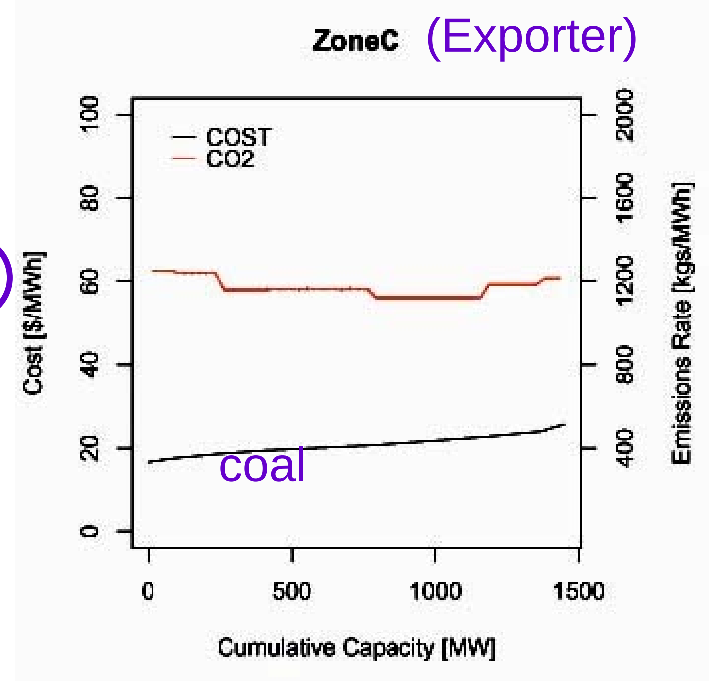
Numeric Example:
Network, Gen Mix and CO_2 Emissions

Policy for Zone A:
Target of 400 tons

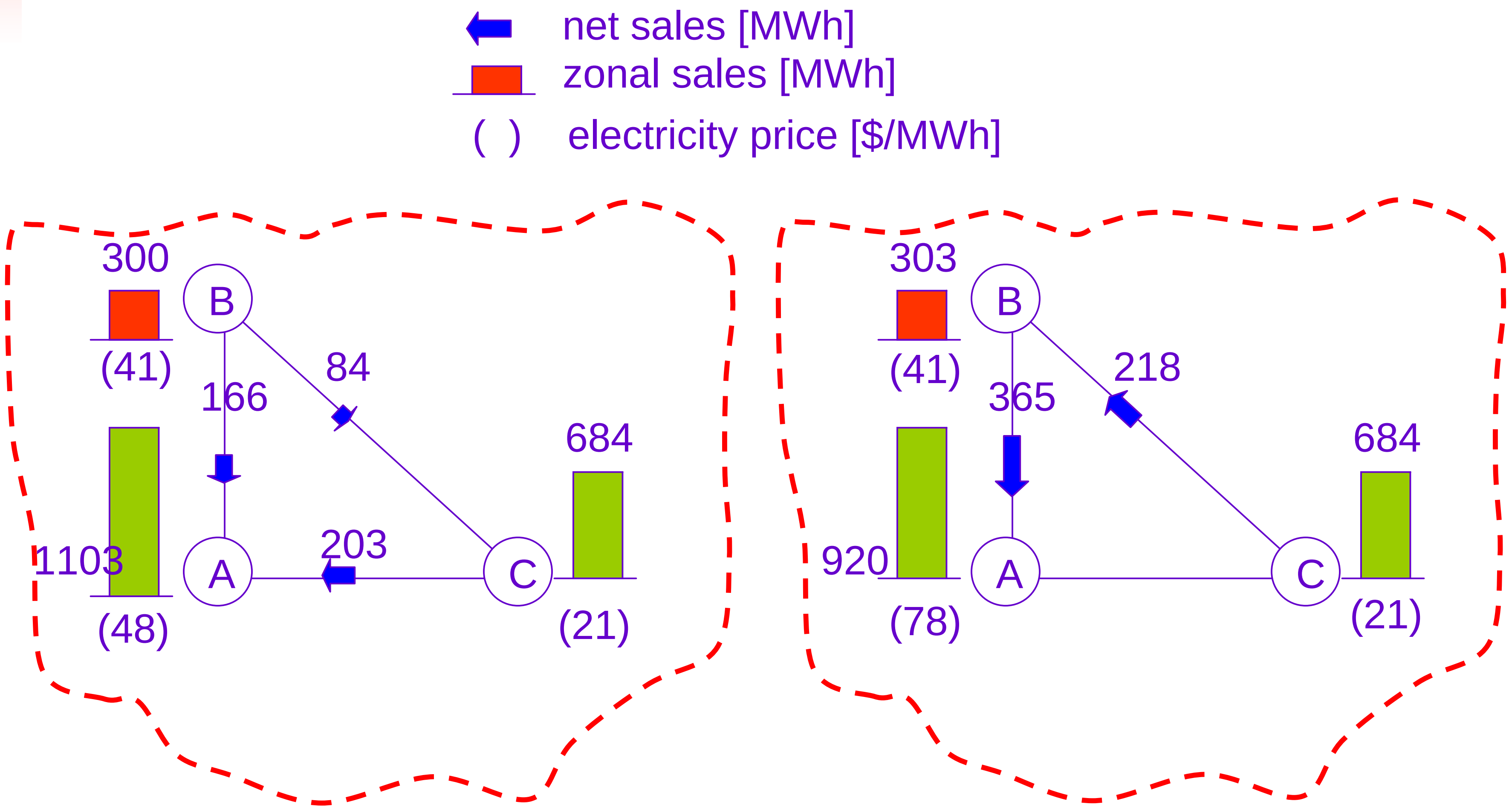






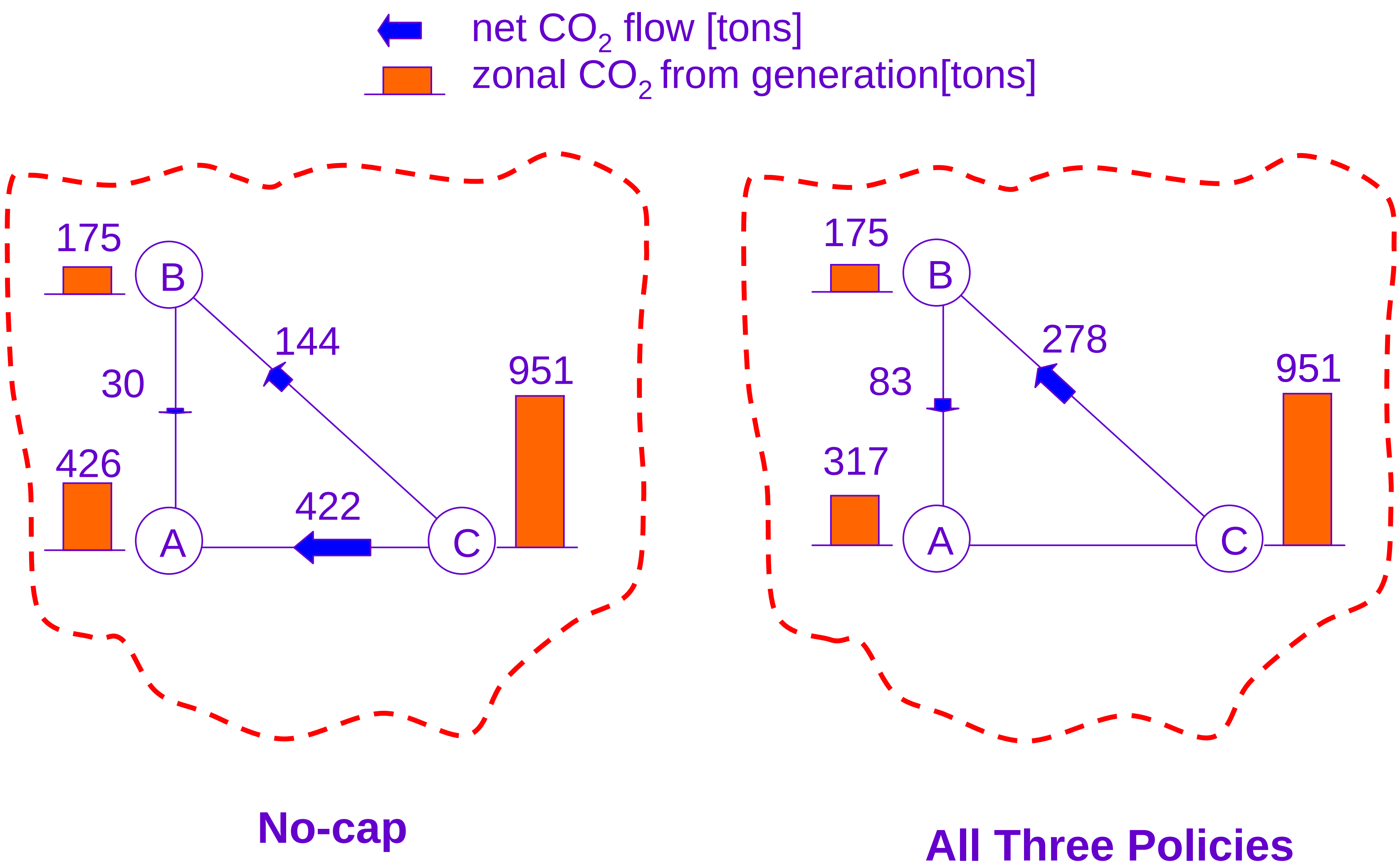


Results: Electricity Sales



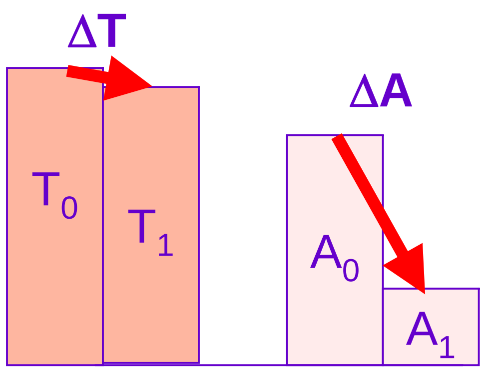
No Cap **All Three Policies**

Results: CO_2 Emissions



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*

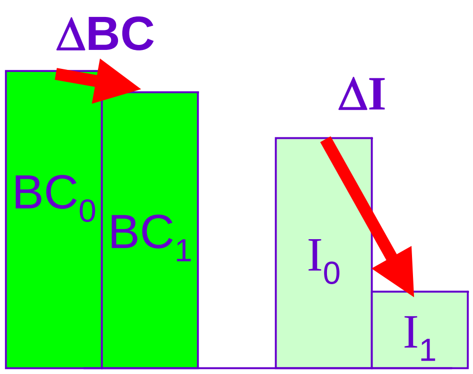
$\%leakage = 100\%(1 - \Delta T/\Delta A)$

	3 Approaches
%Leakage	85%

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

Results: Contract-shuffling

Contract shuffling: **re-arrangement of electricity imports contracts shrinks actual 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- ΔBC/ ΔI)

	3 Approaches
%Shuffling	100%

All emissions "reductions" associated with imports are imaginary

Q2. How Does Allowance Allocation Affect the Efficiency & Cost of CO_2 Trading?

- ***Huge rents at stake***

- ***Allocation methods:***
  1. **Auction (proceeds to government or consumers)**
  2. **"Grandfather" (free to producers, based on past decisions)**
  3. **"Contingent Allocation"/"Updating": Free allocation to producers based on either investments or sales**

- ***How might alternative allocation rules affect outcomes?***
  - **Generation mix**
  - **Costs & welfare**
  - **Consumer expenditures**

Is Allocating Allowances to New Investment Good For Consumers?

- ~~"However, if the expansion of the generation park (by incumbents or newcomers) is associated with a free allocation of emission allowances, then players will base their long-term investment decisions on the long-term marginal costs, including the costs of the CO_2 allowances, but by subtracting the subsidy that lowers the required mark-up for the fixed costs … On balance, the power price will not be increased (ceteris paribus)."~~

  "Explanation of CPB Vision on Relationship Emissions Trading - Power Prices," Aug. 2005, Netherlands Bureau for Economic Policy Analysis, Ministry of Economic Affairs

- ***Is this true in an industry with time varying demand, no storage, and a mix of technologies?***
  - ***Will the least-cost generation mix still result, and all the allowances rent returned to consumers?***

Literature: Divided Opinions

- ***Grandfathering / auctioning efficient (in closed economy)***
- ***Sales-based subsidizes consumption, raises costs*** *(Fischer, 2001)*
  - **But may be 2^{nd} best if commodity traded with non-regulated countries** (Demailly & Quiron, 2006)
- ***No distortion from allocating to new investment*** *(NL CPB, 2005)*
  - **New entry results in lower prices, transfer of rents back to consumers**
  - ***If* single technology, zero price elasticity** (Zhang et al., 2007)
- ***Allocation to new investment can distort mix of new generation, invert dispatch orders, inflate costs*** *(Ibid.)*
  - **Generation may be built to get free allowances**
  - **Distortion can be greater for milder emissions reduction**
  - **Depends on how discriminate among generation types**
- ***But such allocation can correct capacity market failures*** *(Smeers, 2007)*

Multiarea Complications

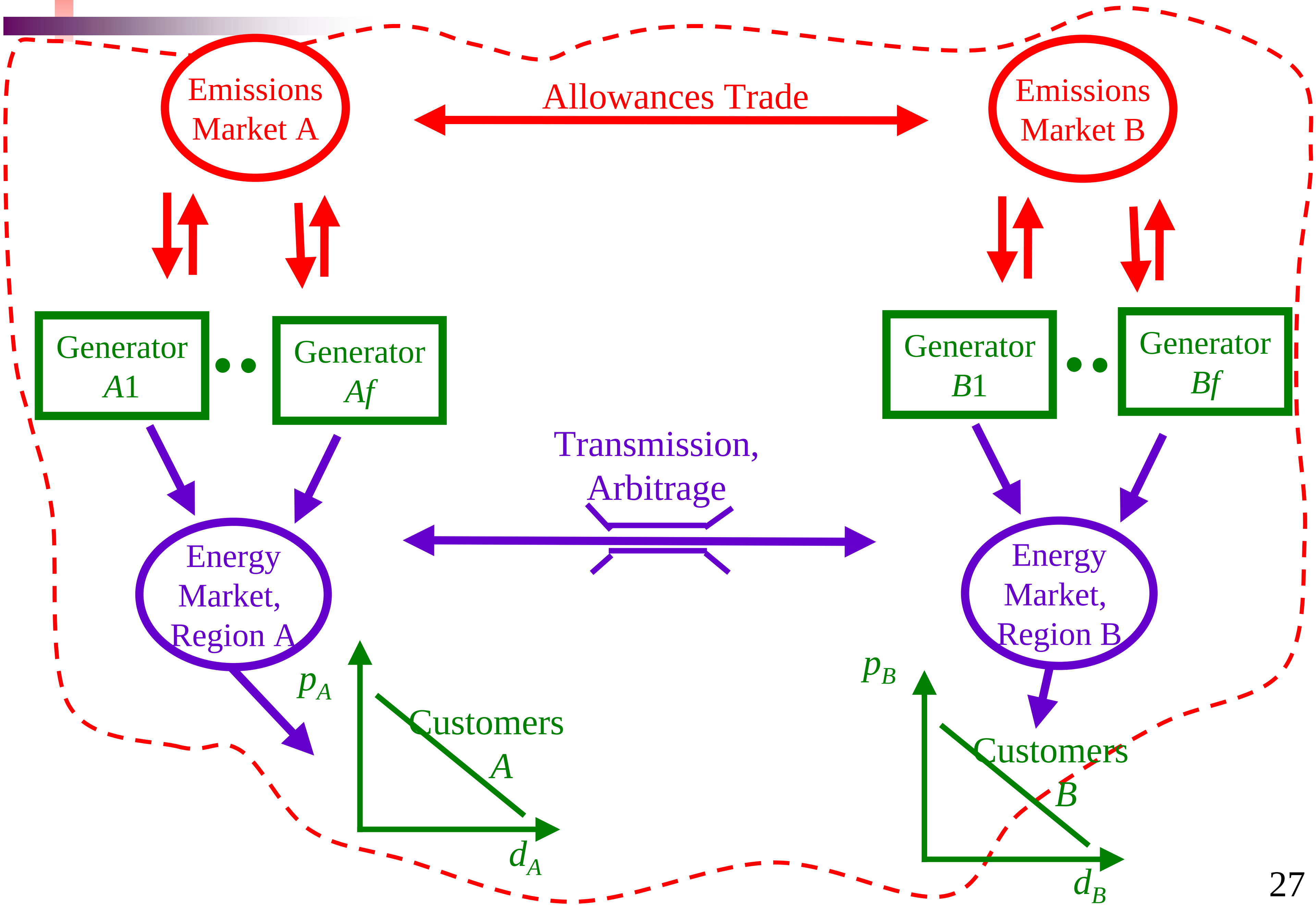
- ***Regulated regions trade power with unregulated***
  - **Which allocation schemes 2nd best?**
- ***Separately regulated regions trade with each other***
  - **Distort siting/energy trade if different allocation rules?**
  - **Artificial differences in allowances prices?**
- ***Multiple trading regions under single allowances cap, but with different allocation rules***
  - **Distort trade?**
  - **Raise compliance costs?**
  - **Which combinations of rules are least compatible?**

Model of Long Run Multiregion Energy & Emissions Markets

(Zhao, Hobbs, & Pang, http://ideas.repec.org/p/cam/camdae/0748.html)

- ***Compare:***
  - Complete grandfathering (or auction)
  - Mix of grandfathering & contingent allocation (sales, investment)
    - Various combinations of rules for different regions
    - Regions in same emissions trading system, or different ones
- ***Assume:***
  - Free entry long run equilibrium
  - No market power, continuous capacity investments, no outages
  - Transmission limitation between systems
    - Transmission capacity rationed efficiently

Model Structure



Long Run Equilibrium for Energy/Transmission/Capacity/Emissions

Find {prices , allocations, gen/sales, capacity, transmission} solving:

Profit Maximization, Generator *f* in region *n:*

Given {prices , allocation rules}:

MAX **Revenue – Costs of Capacity, Allowances, Fuel**

Market clearing, Market *n*:

Energy Supply = Demand

Emissions Supply = Demand

Allowances Allocated = Allowances Available,

subject to "ratio rules"

Capacity Supply = Demand

ISO:

Given {power p}:

MAX **value of**

transmission

services provided

Long Run Equilibrium for Energy/Transmission/Capacity/Emissions

Find $\{p_{nt}^*, pe_n^*, pcap_n^*, \alpha_{nf}^*, \beta_{nf}^*, a_{nt}, s_{nft}, cap_{nf}\}$ *solving:*

Profit Maximization, Generator *nf*:

Given $\{p_{nt}^*, pe_n^*, pcap_n^*, \alpha_{nf}^*, \beta_{nf}^*\}$:

$$MAX \quad \Sigma_t [p_{nt}^* - MC_{nf} - pe_n^*(E_{nf} - \beta_f^*)] s_{nft} + (pcap_n^* + \alpha_f^* pe_n^* - F_{nf})\, cap_{nf}$$

s.t.: $0 \le s_{nft} \le cap_{nf}, \ \forall t$

Market clearing, Market *n*:

Energy Market: $\Sigma_f s_{nft} + a_{nt} = d_{nt}(p_{nt}^*), \ \forall t$

Emissions Market: $0 \ge \Sigma_{f,t} E_{nf} s_{nft} - \bar{E}_n \ \perp \ pe_n^* \ge 0$

Contingent Allowances Allocation: Either:

$\Sigma_f \alpha_{nf}^* cap_{nf} + E_{GFn} = \bar{E}_n; \ \alpha_{nf}^*/\alpha_{n1}^* = R_{nf}, \ \forall f \ne 1$ (entry)

$\Sigma_{f,t} \beta_{nf}^* s_{nft} + E_{GFn} = \bar{E}_n; \ \beta_{nf}^* / \beta_{n1}^* = R_{nf}, \ \forall f \ne 1$ (sales)

Capacity Market: $\underline{CAP}_n \le \Sigma_f cap_{nf} \ \perp \ pcap_n^* \ge 0$

ISO:

Given $\{p_{nt}^*\}$:

$$MAX \quad \Sigma_{n,t} p_{nt}^* a_{nt}$$

s.t.: $\Sigma_n a_{nt} = 0$

$\Sigma_n PTDF_{nk} a_{nt} \le T_k, \ \forall k,t$

Model Properties and Solution

- ***Under mild conditions, a solution exists***
  - **for single region versions**
  - **multiple region versions in process**

- ***Computation***
  - **Rearrange and linearize nonlinear complementarity problem to obtain (a provably feasible) linear problem**

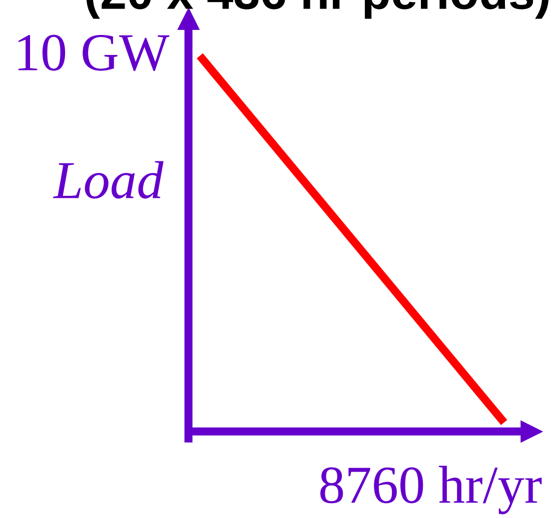
  - **Iterate until convergence; converged solution solves the original problem**

Example. 3 Gen Types, 2 Regions

- ***Emissions limit: 40 MT/yr in each***
  - *94% of unconstrained emissions*
- ***Elastic demand***
  - *Price intercept of € 1000/MWh*

    $\Rightarrow \varepsilon = -0.11$ @ P= € 100/MWh
- ***1 GW transmission limit***
- ***Generator assumptions:***
  - Same in each region

Load Distribution
@*p* = €0/MWh
(20 x 436 hr periods)

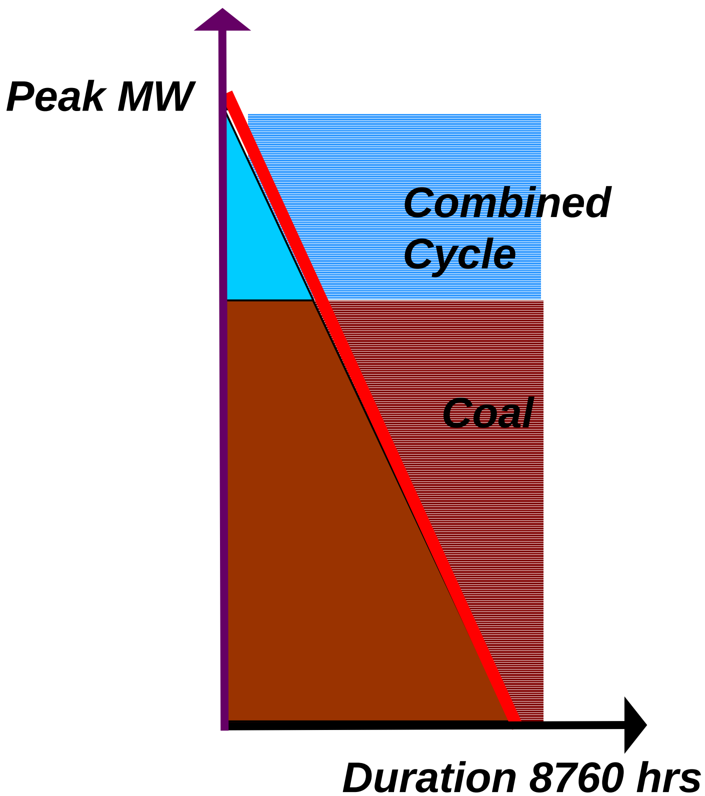


Technology	Fixed Cost (€/kW)	MC (€/ MWh)	CO_2 (Ton/ MWh)	Allowances to Investment (relative) (1/MW)
Combustion Turbine	50	80	0.6	0.6
Combined Cycle (Gas)	75	40	0.35	0.35
Pulverized Coal	120	20	1	1

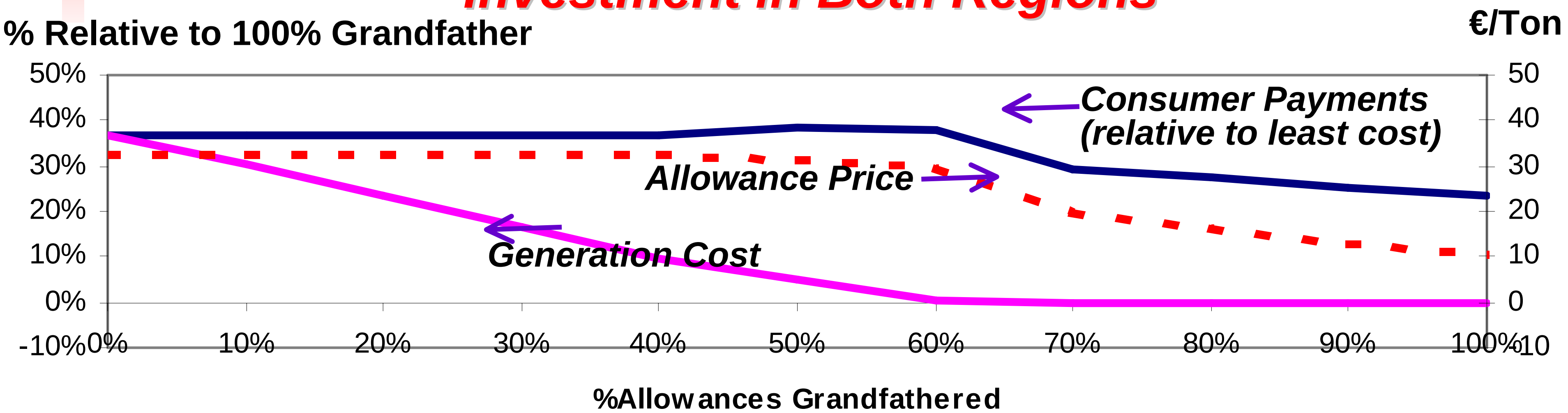
Results: Least Cost Emissions Reduction

6% CO_2 Reduction

ΔCost = 0.4 €/MWh (0.8%)
pe = 11 €/ton



Results: 6% Emission Reduction
Same Mix of Grandfathering & Free Allocation to New Investment in Both Regions



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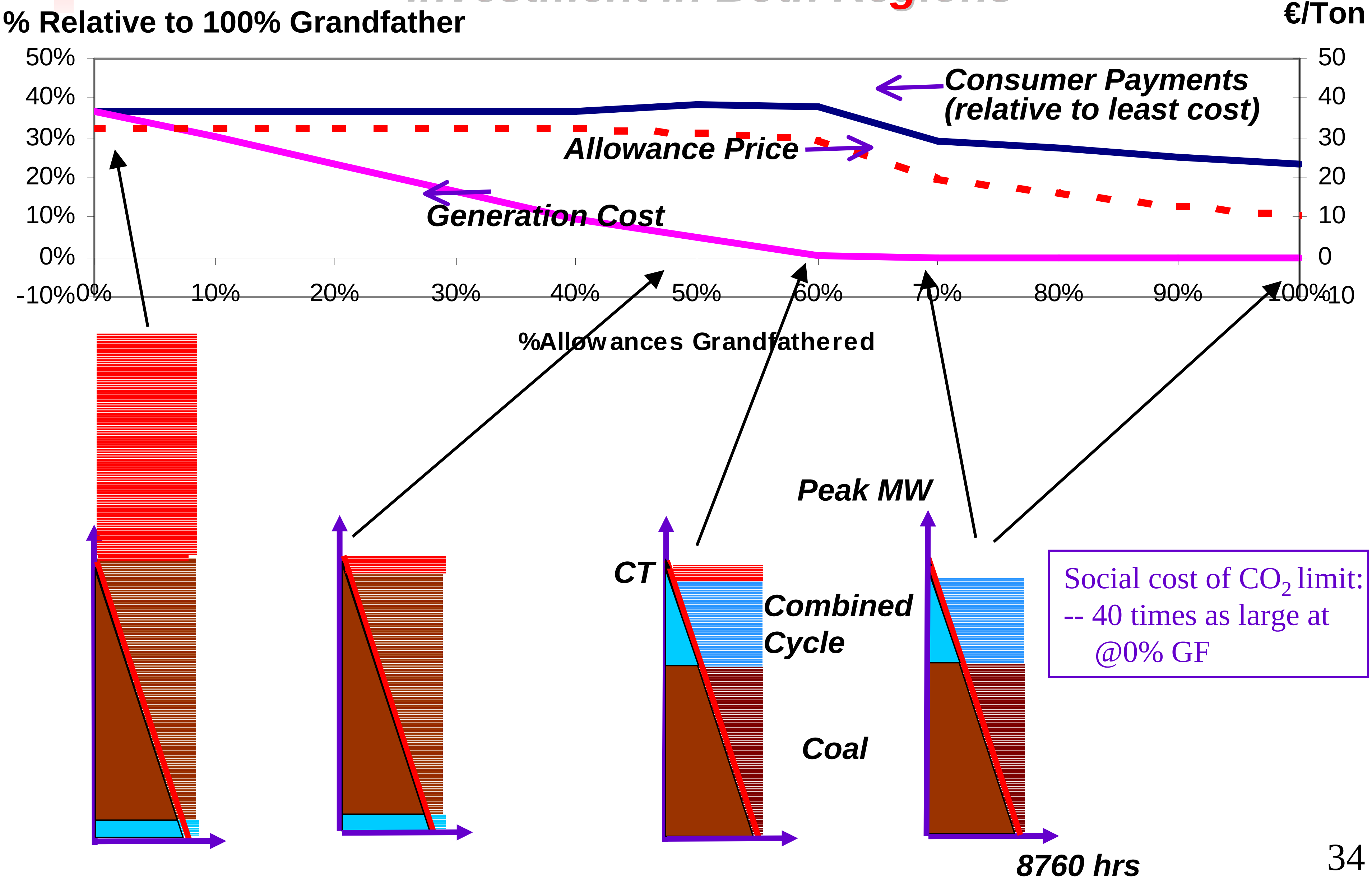


Social cost of CO_2 limit:
-- 40 times as large at @0% GF

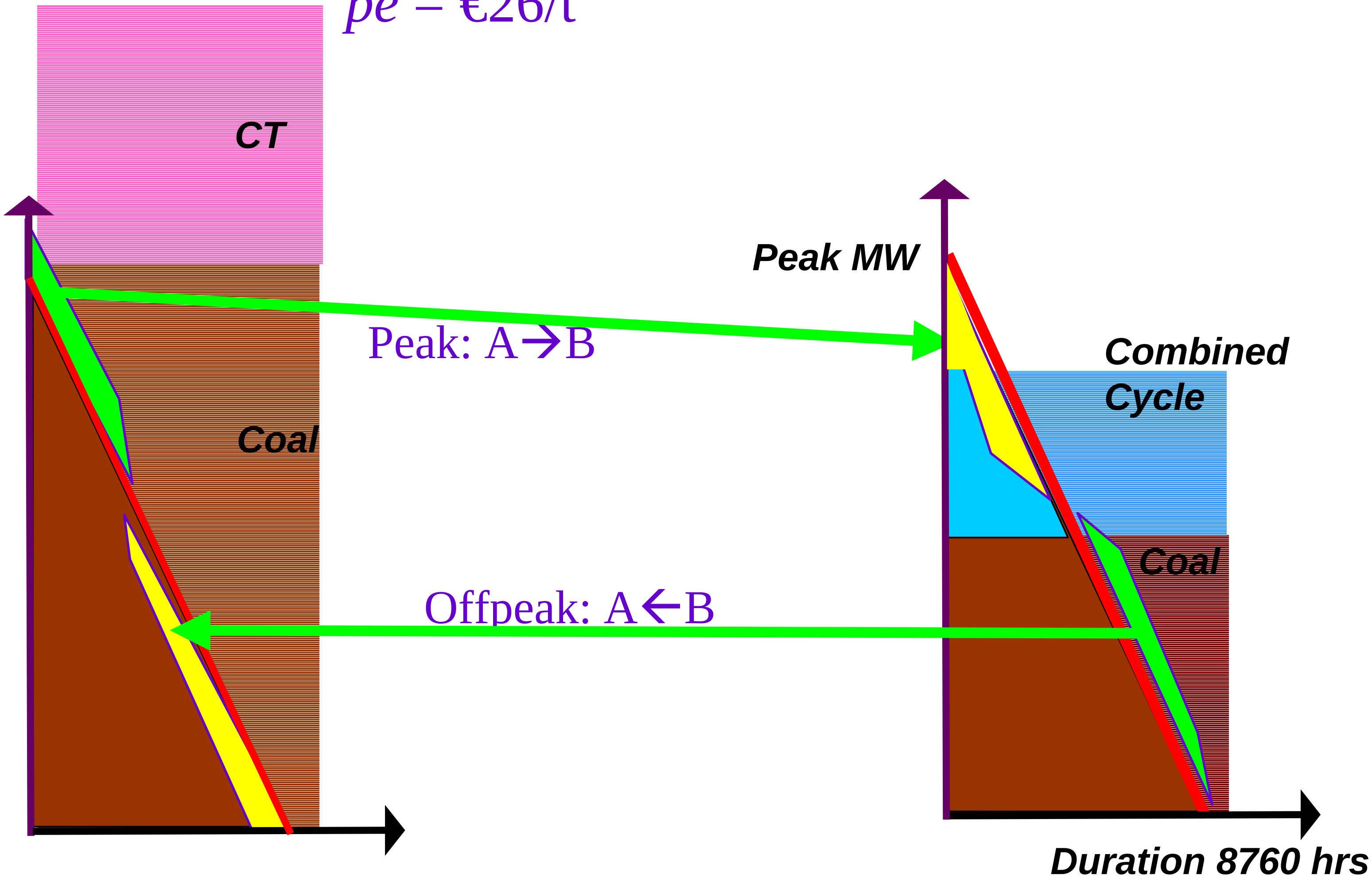
Effects of Giving Away Allowances to New Investment

- ***Can affect allowance prices***
  - **distorting dispatch order**
- ***Investment distortion***
  - **For %GF < 50%: *major* (overinvest--generation built to get allowances)**
- ***Increases social cost of CO_2 control***
  - **At least doubles (under %GF = 0)**
  - **Distortion worse at *smaller* levels of CO_2 reduction**
  - **Power prices may not change; instead most of cost is loss of government allowance rent**

Different Allocation Rules in Different Regions

Region A:
Contingent: 100% Allowances to investment
pe = €26/t

Region B:
100% Auctioned
pe = €18/t



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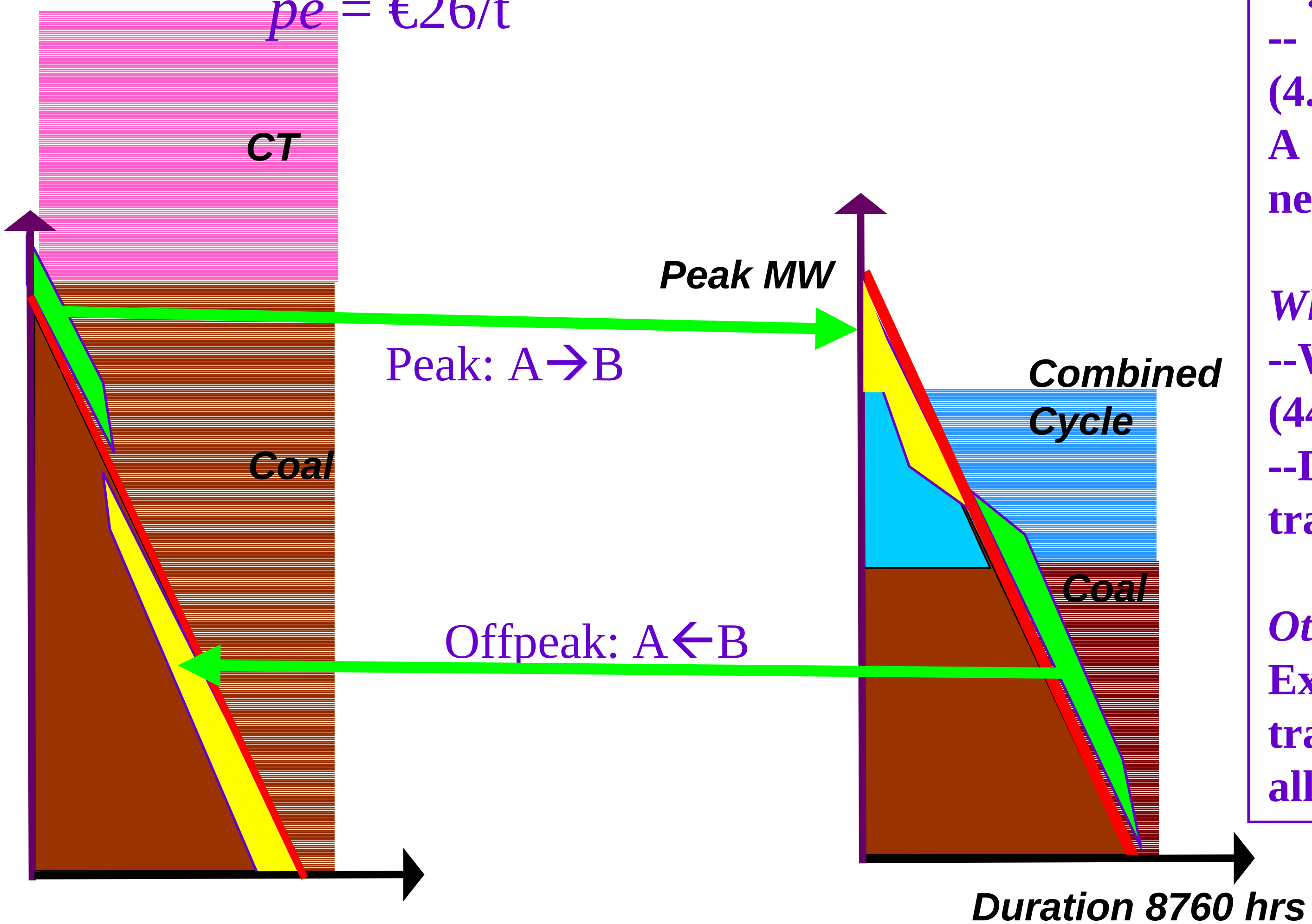

***Social cost of CO_2 limit*:**
-- 0.9% (0.4€/MWh) of no-limit cost if both regions grandfather
-- 10 times larger (4.2€/MWh) if Region A gives allowances to new investment

Why?
--Wasted investment (4400 MW CT)
--Distorted dispatch, trade

Other effect:
Exaggerated value of transmission, allowance arbitrage

Example of Distortion from Mixed Rules at A and B

-6% CO_2 case: congestion price @1000 MW limit

60,833 €/MW/yr

However, welfare decreases if more transmission

If add 2300 MW …

…welfare decreases by 210 M €/yr or …

… -89,000 €/MW/yr

Compare "efficient" (all auction/grandfather) rule:

No congestion

Conclusion

- Equilibrium models provide general insights on relationships of proposed policies
- Q1: Under some conditions, load-, source-, & “first-seller” based CO_2 trading are economically equivalent
  - In terms of consumer costs, generation, emissions, efficiency
  - All proposals are subject to contract shuffling and CO_2 leakage
  - Assumes: consumers own allowances; no undermining of ISO markets
- Q2: Allocating allowances to new investment can distort:
  - Dispatch
  - Investment in both generation & transmission