Regulatory Uncertainty & Risk Aversion in a Market Equilibrium Model: Are Deterministic & Risk-Neutral Policy Models Biased?

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Motivation

- Future carbon regulations likely
  - Timing and form unknown
- Agents risk averse when investing
- Current investments will affect industry and social costs of carbon policy for decades
  - Consequences of incorrect understanding of these decisions will also persist
- Policy models have tended to abstract from risk in this setting, and policy is especially strongly linked to models for the energy sector
  - Deterministic policy models
  - Stochastic policy models with risk-neutral agents
- Are the resulting equilibria and policy conclusions biased?

Some Previous Work

- Evaluation of generation optionality under uncertain (exogenous) price processes
  - Investment: e.g., Fleten (2002)
  - Operations: e.g., Tseng (2004), Liu (2008)
- Stochastic market equilibrium models
  - Bottom-up modeling of investment under risk neutrality; e.g., Stochastic Markal (Loulou et al., 2000; Hu and Hobbs, 2006), MCP (Gabriel, 2008)
  - Equilibrium operations and financial hedging under risk aversion; e.g., Willems (2007)
  - Short-run equilibrium among risk-averse (CVar-constrained) generators (Ventosa et al., 2008)

Under uncertain carbon regulations

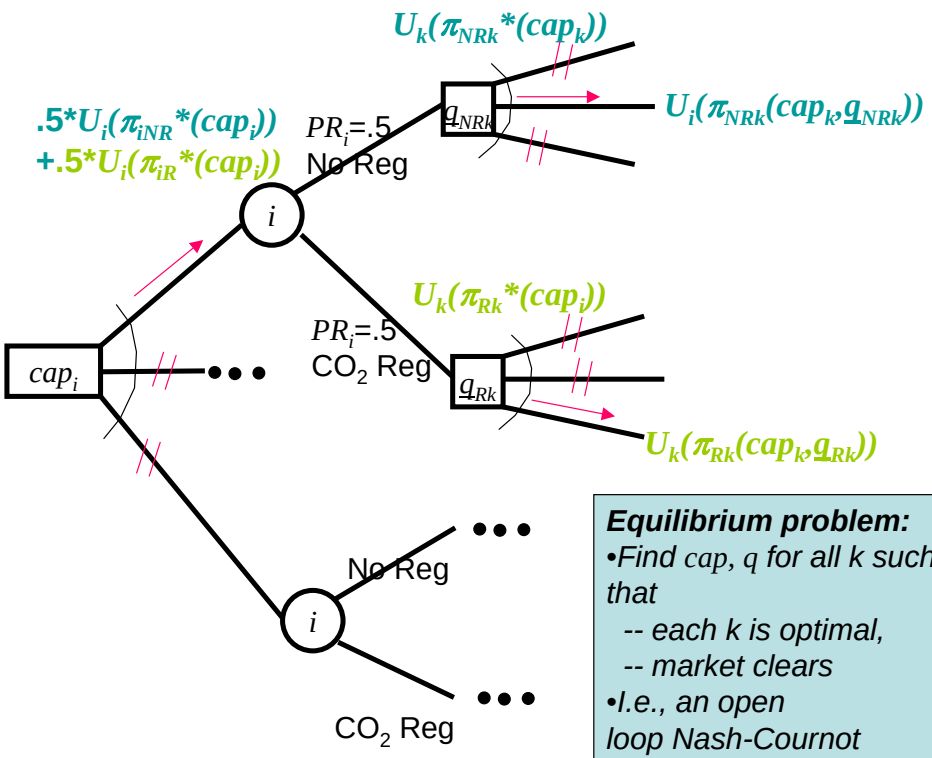
- How will investment differ if we model:
  - *risk averse* generators
  - under alternative regulatory *scenarios*?
- How do these results change with alternate policy instruments?
  - Tax vs. cap and trade?
  - Auction vs. grandfathering vs. contingent allocation of allowances?
- How do welfare impacts vary with the degree of risk aversion?

Model Formulation

- Two firms face a capacity expansion problem, with different technologies
  - coal-fired
  - gas-turbine
- Scenarios:
  - With regulation
    - Cap-and-Trade
      - Auctioned allowances
      - Freely allocated allowances ("contingent" on firm decisions)
    - Carbon Tax
  - Without regulation
- Two stage problem:
  - 1st stage: investment under uncertainty
  - 2nd stage:
    - regulation scenario revealed
    - plants are operated
    - profits realized

Model Formulation, cont'

Each firm k:
-- chooses its cap_i *and vector of operating variables* $\underline{q}_{ik}$ *under each regulatory scenario i,…*
-- to maximize its $E(U_k)$*,…*
-- subject to cap & q decisions by other firms



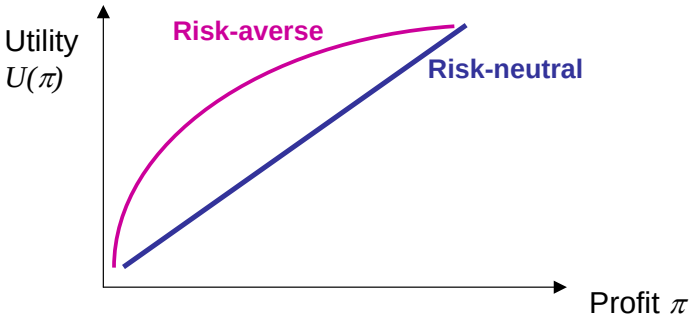
Equilibrium problem:
•Find cap, q *for all k such that*
-- each k is optimal,
-- market clears
•I.e., an open loop Nash-Cournot equilibrium

Model Formulation, cont'

- Agents make decisions to maximize expected utility
  - Constant relative risk aversion

$$U(\pi) = a - b \cdot e^{-r\pi} \quad b > 0, r > 0$$

  - Risk neutral: Profit as utility function



Model Formulation (Auctioned Emissions Case)

- Stochastic Equilibrium problem with:
  - KKTs for Operators' utility maximization problem:

$$\pi_{ik} = \sum_j HR_j \cdot q_{ijk} \cdot (p_{ij} - MC_{ik}) - CC_k \cdot cap_k - Z_i \cdot p^e_{reg} \cdot t_{reg,k}$$

$$U_{ik} = 1 - e^{-r\pi_{ik}}$$

$$Risk\ \ Neutral: Max \quad \pi_k = \sum_i PR_i \cdot \pi_{ik}$$

$$Risk\ \ Averse: Max \quad U_k = \sum_i PR_i \cdot U_{ik}$$

$$s.t. \quad q_{ijk} - cap_k \le 0 \qquad \forall\ i, j, k \qquad (\mu_{ijk})$$

$$\sum_j E_k \cdot HR_j \cdot q_{reg,jk} - t_{reg,k} - Allowance_k \le 0 \qquad (\lambda_{reg,k})$$

- E_k: emission rate;
- $Allowance_k$: free allowances allocated;
- q_{ijk}: generation variable;
- p_{ij}: electricity price variable;
- p^e: emission price variable;
- cap_k: capacity to be built;
- $t_{reg,k}$: net emission permit purchase.
- i: scenario index (Reg, NReg);
- j: time period index;
- k: firm index;
- HR_j: hours in the time period;
- MC_{ik}: marginal cost;
- CC_k: capacity cost;
- Z_i: scenario indicator: Z_i=1 for regulation, Z_i=0 otherwise;

Model Formulation, cont'

– KKTs for Consumers' problem:

$$Max \quad CS_i = \sum_j HR_j \cdot [(P_{0ij} \cdot d_{ij} - \frac{1}{2}\frac{P_{0ij}}{Q_{0ij}} \cdot d_{ij}^{\,2}) - p_{ij} \cdot d_{ij}]$$

$$s.t. \quad d_{ij} \geq 0 \qquad \forall\ i, j$$

– Market Clearing condition:

$$\sum_k q_{ijk} = d_{ij} \qquad \forall\ i, j \qquad (p_{ij})$$

$$\sum_k t_{reg,k} = E^{cap} \qquad (p^e_{reg})$$

- P_0, Q_0: inverse demand parameters;
- d: demand;
- E^{cap}: total emission cap.

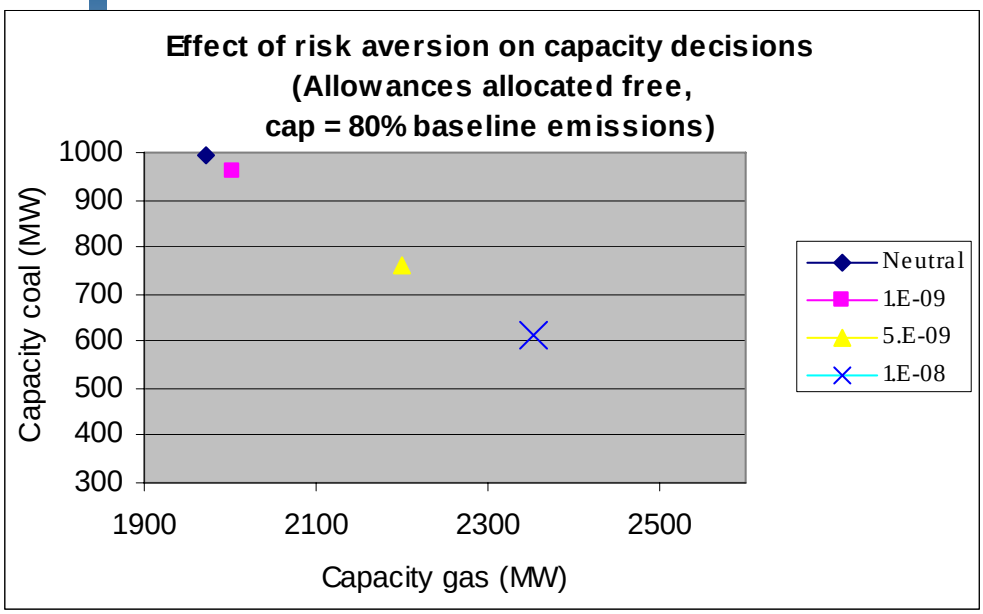
– Can also include allowance allocation rules

- dependent on sales
- dependent on investment

Solution

- Solve as a MCP (Mixed Complementarity Problem)
  - No analytical solution
  - Allows flexibility in the constraints
  - Commonly used in this policy setting
- Use PATH solver in GAMS
  - Successive linear approximation

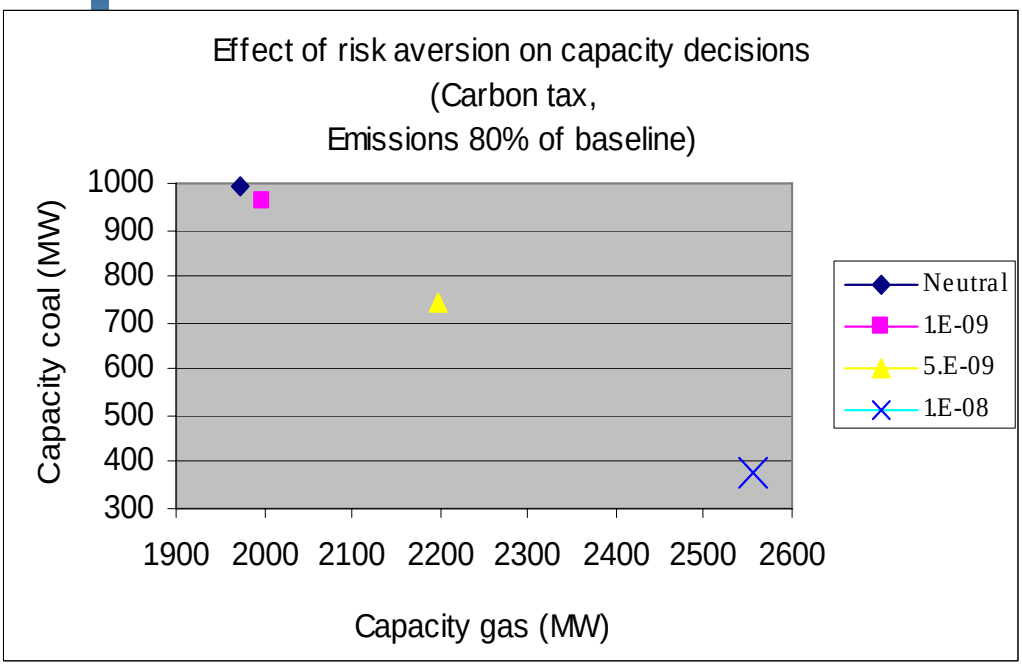
Capacity Changes with Risk Aversion: Free Allowance Allocation



Gas capacity increases and coal decreases as operators become more risk-averse.

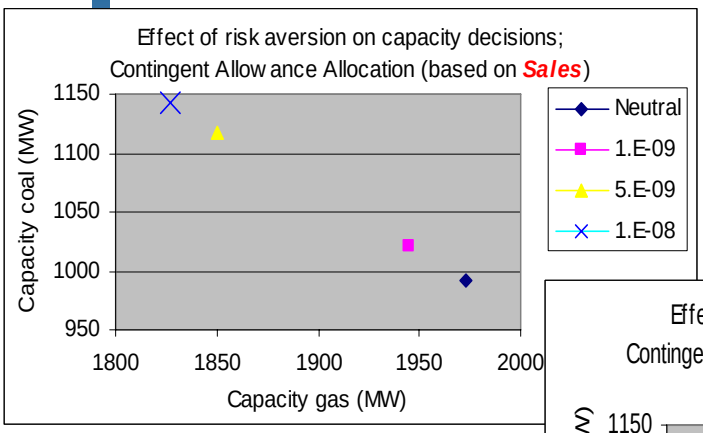
Risk aversion pushes solution towards worst case solution

Equivalent tax

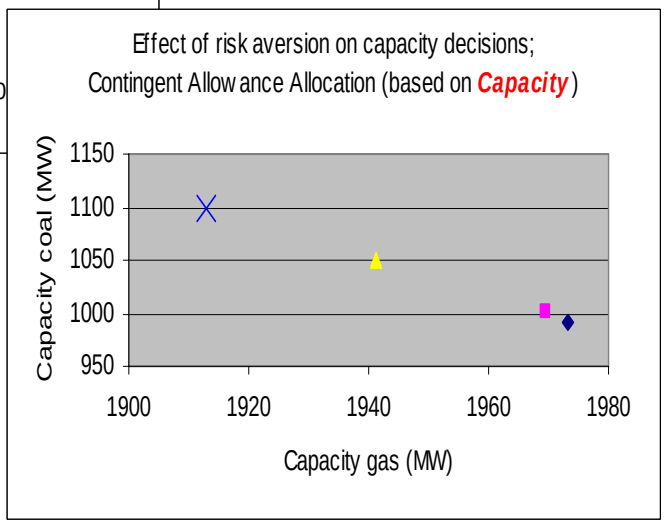


Effect of risk aversion magnified because no hedge from free allowances

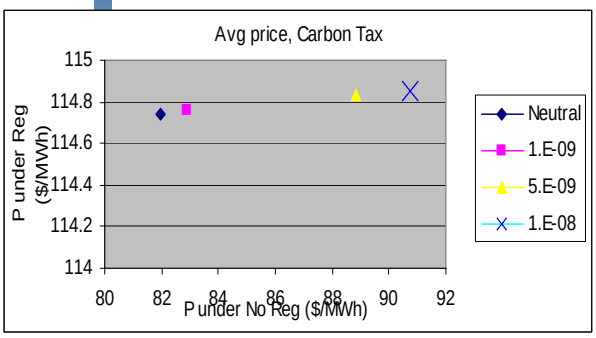
With contingent allocation of allowances: a reversal

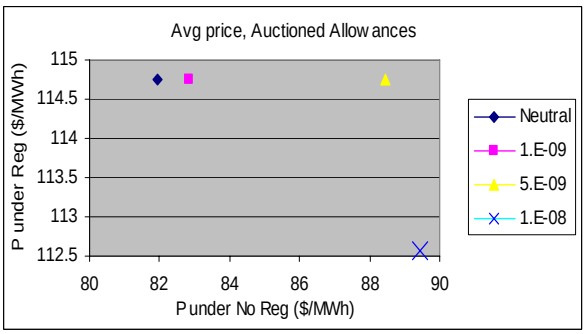


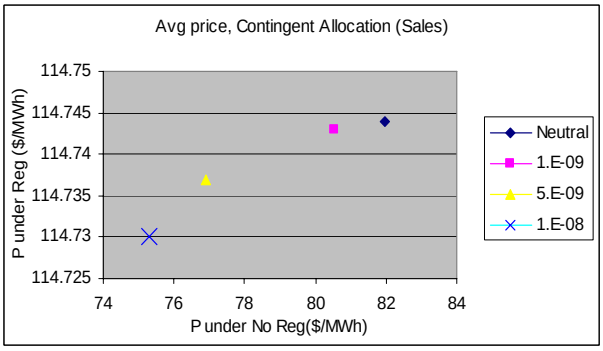
Risk aversion moves suppliers towards the certain regulation solution in the auction and tax cases;
away from it in the contingent allocation cases.

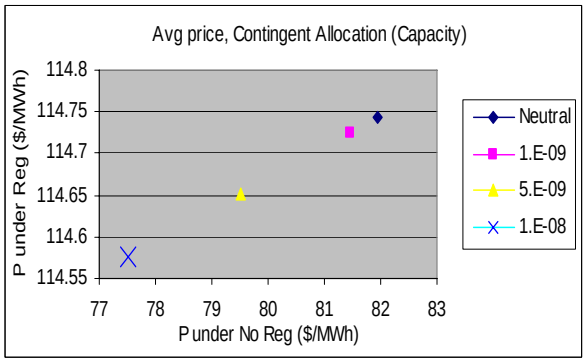


Average (demand weighted) Power Prices









Avg prices lowered by risk aversion under contingent allocation

Summary of Results

- Risk-neutral solutions (capacities, supplies, prices, demands) the same, regardless of how the emission allowances are distributed (grandfathering or auctioned) and initially allocated (different allocation rules)
  - But contingent allocation solutions differ
- Risk averse generators weight heavily profit under the least profitable scenario
  - This makes capacity and cost outcomes sensitive to the allocation scheme for allowances.
- Effects on capacity as operators become more risk-averse:
  - Under our assumptions, if carbon is taxed or allowances are auctioned
    - gas operator tends to build more capacity
    - coal operator tends to build less
    - Not a general result -- depends on initial allocation of allowances
  - If allowances are allocated for free by contingent rules, the reverse happens

Questions for Discussion

- Yes, risk aversion matters in simplified model
  - Are policy implications significantly different? (Welfare impacts of policy)
  - Will differences persist if there are many firms, more diverse set of technologies, and financial hedges?
- How might risk aversion be incorporated in large-scale policy models?
  - Defensible heuristics?
  - Estimating degree of risk aversion?