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VALUE OF SHORT-RUN DEMAND RESPONSE FOR INTEGRATING WIND: UNIT COMMITMENT & GENERATION EXPANSION MODELING WITH PRICE RESPONSIVE LOAD

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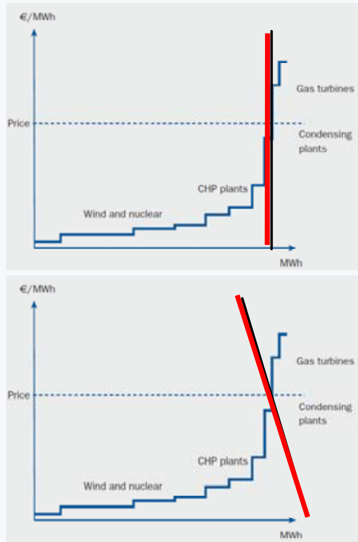
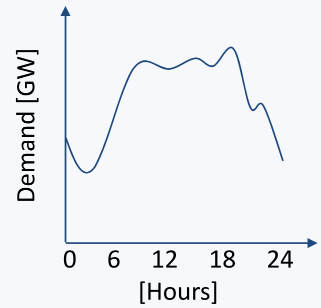
Overview

- *Problem:* Lack of demand response in operations & planning models
- Representing price responsive consumers
- *Operations*: Unit commitment
  - Effect of DR on dispatch
  - Effect of wind 'must take' requirements
    - Neither economically nor environmentally desirable
- *Investment*: Capacity expansion
  - Effect of DR on optimal wind investment
  - Effect of X-price elasticity

General context

“Supply follows demand”





“Demand follows supply”

What is the problem?

*Unit commitment & generation investment models assume **fixed short-run loads***

They neglect opportunities for:

- *improved dispatch & investment*
- *renewables integration*

What do we need?

Models accounting for price responsive consumers

We quantify:

- *changes in decisions*
- *efficiency benefits*

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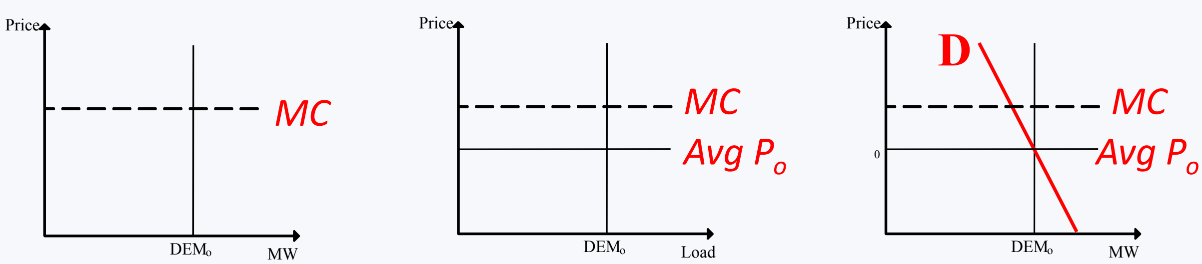
Representing behavior of price responsive consumers

Constructing an elastic short-term demand curve:

1. Solve cost minimizing model, given initial demand levels DEM_o
2. Obtain weighted average electricity price P_o
3. Add own-price elasticity to (P_o, DEM_o)
   - Direct response
4. Add X-price elasticity
   - Load shifting



Demand functions in optimization models

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If we have symmetry in X-effects:

Welfare maximization model

Objective: MAX welfare

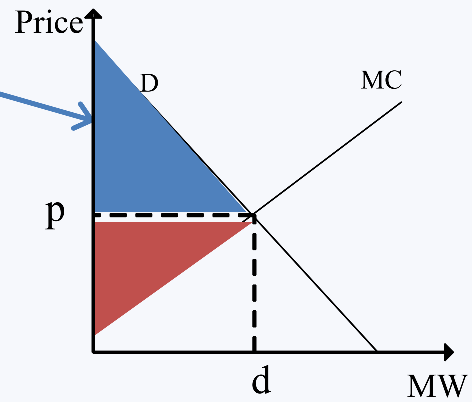
= **consumer** + **producer** surplus

= demand curve integral - cost

Subject to: system power balance

operational constraints

(installed reserve margin)



Three computational methods tested

1. Quadratic program (Samuelson, 1952)
   – Symmetry required of X-elasticity effects
2. Complementarity (Cottle, Pang, Stone, 1992)
   – Doesn't require symmetry
   – Cannot readily handle binary variables
3. PIES iterative piecewise linearization (Hogan, 1975)
   – Can handle asymmetry & binary variables

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Unit commitment model for wind dominated system

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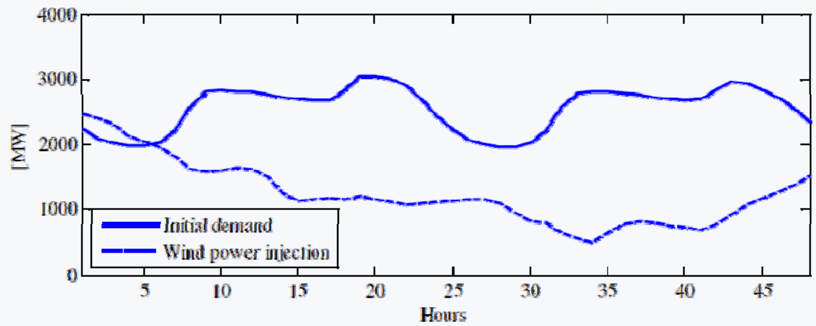

Min Cost = Cost of fuel + emissions + startups + wind curtailment

Or Max Welfare = Demand curve integral – Cost (own elasticity only)

s.t. System power balance

Ramping constraints

Capacity restrictions

Minimum run levels

Start-up

Minimum on- and down-time

Unit commitment results: Uniform price, fixed demand

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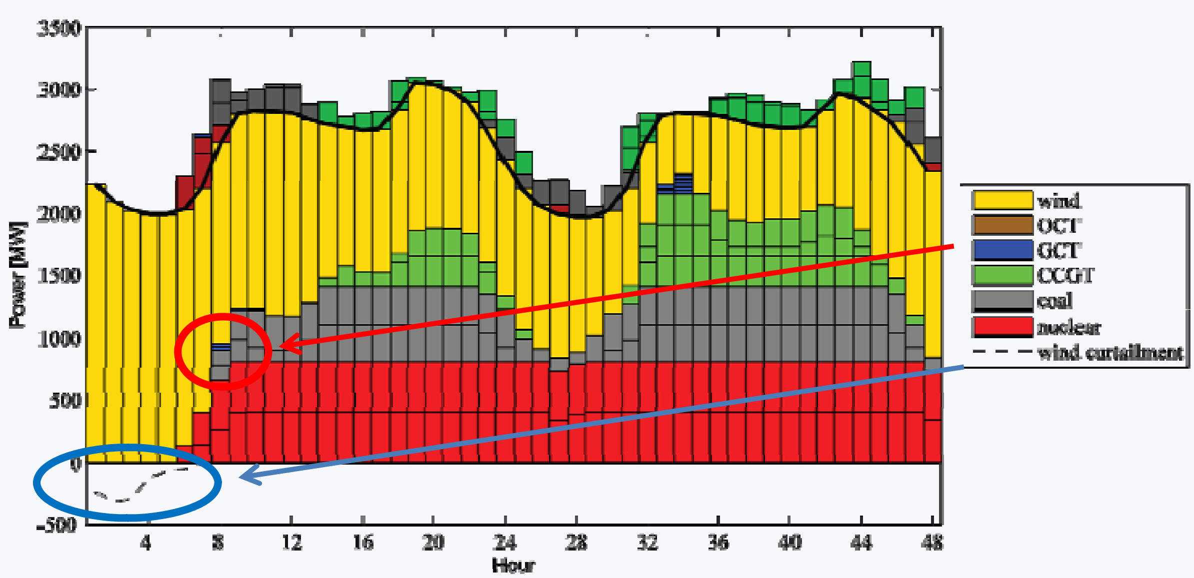

Unit commitment results: Demand response (own elasticity = -0.2)

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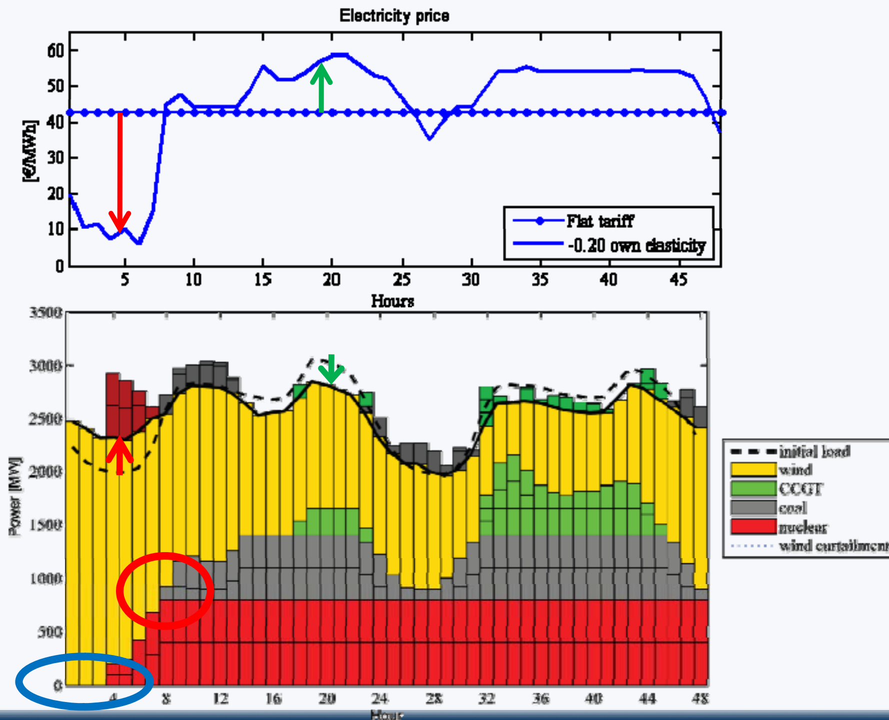

Net effect of demand response @ε=-0.2

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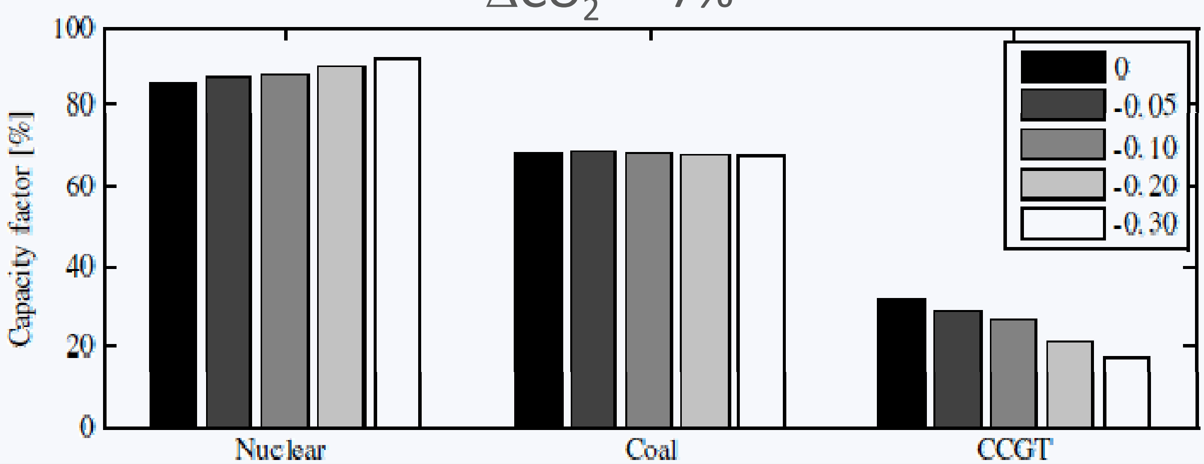
ΔCost = -14% (more if forecasts uncertain)

ΔWelfare = +1.4% (as fraction of cost)

ΔWind spill = -100%

ΔCO_2 = -7%



Giving wind absolute priority makes neither economic nor environmental sense

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- EU 'must take' rules; -$150 bids (or lower) likely in US CAISO
  - Can increase *both* costs and emissions
- Minimizing wind spill increases fuel costs & CO_2 (relative to dispatch under 0€/MWh wind bid)
  - 17% reduction in spill possible
  - Per MWh of spill reduction:
    - ➢ 0.71 ton CO_2 increase (+1.5% total CO_2)
    - ➢ 49 € cost increase (+1.3% total cost)
- Assumes:
  - No demand elasticity
  - Fuel dominates startup costs

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Generation capacity expansion

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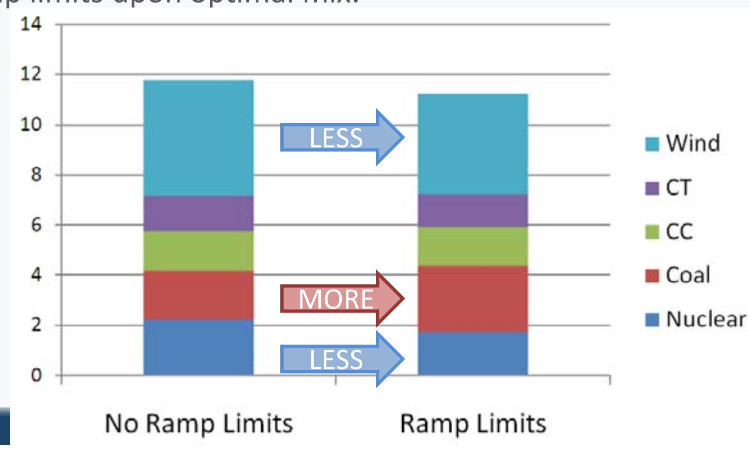
- Key tradeoffs:
  - More wind penetration requires more ramp capability
  - Baseload capacity less rampable
  - Demand response could provide
- Gen expansion models: often lack ramp and demand-response
  - Need these features to optimally integrate renewables
  - Effect of adding ramp limits upon optimal mix:



P & Q effects of own- and X-price elasticities

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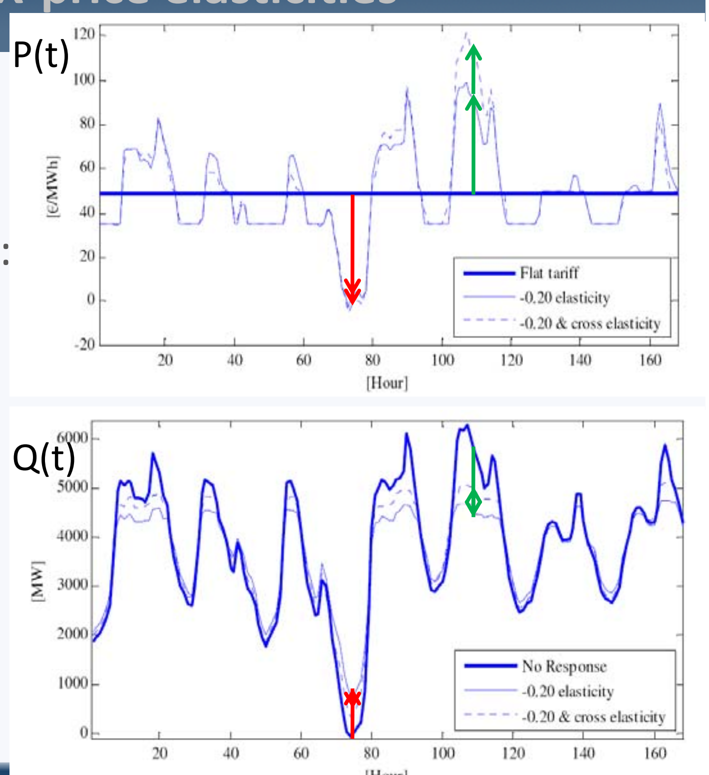
- Valley fill & peak reduction effects
- X-price elasticities yield:
  - less load response
  - more price volatility



Demand response in investment planning

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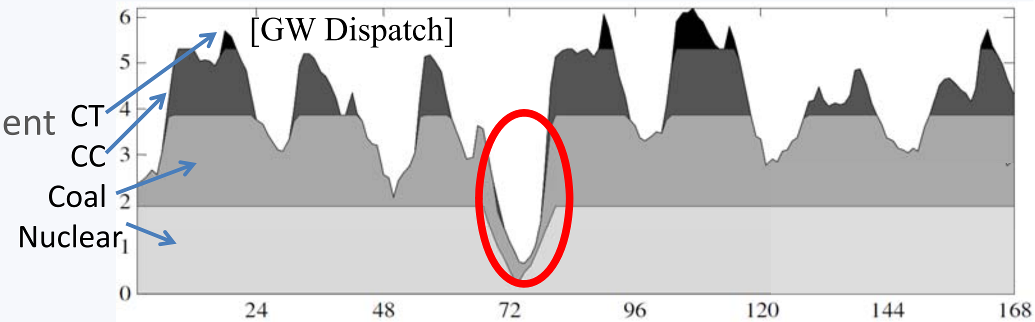
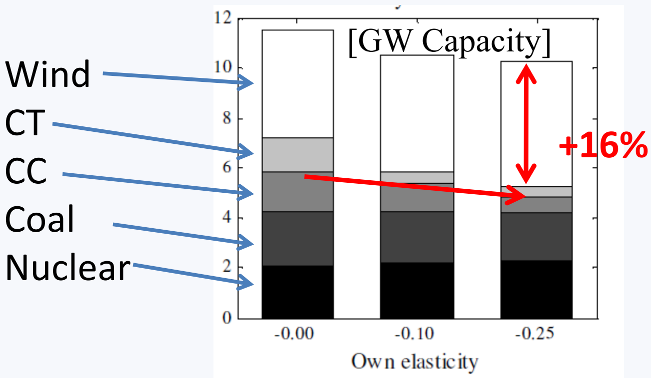
Example Dispatch & Investment Mix





Effect of elasticity on gen mix

- Less cycling capacity
- More wind

Welfare improvements:

- +1%/3% for ε = -0.1/-0.25
- Expressed as % of supply cost

Effect of X-elasticity upon investment mix

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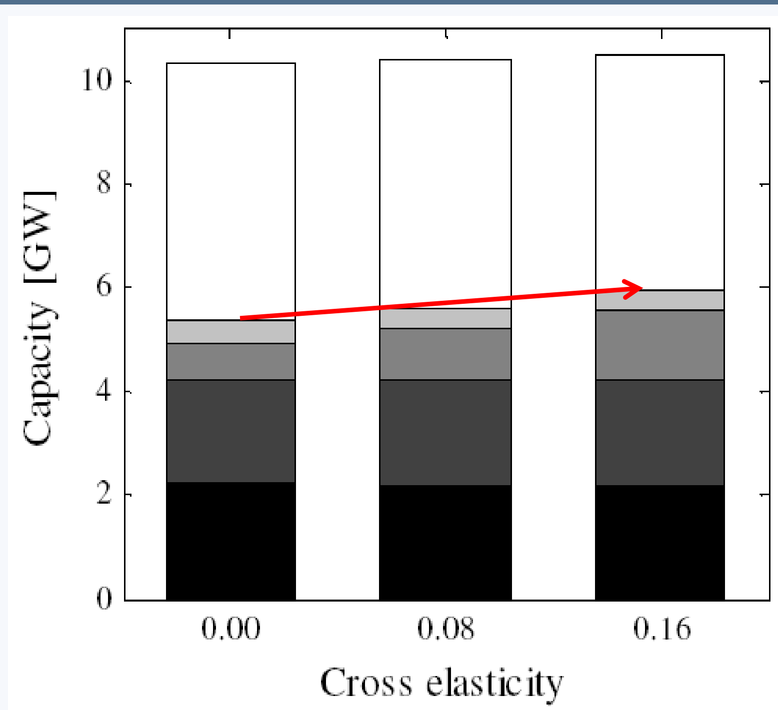

Conclusion

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- Models should account for responsive consumers
  - Ideally: both own- and X-elasticities
  - Welfare max or equilibrium calculation rather than cost minimization
- Short-term response yields
  - Reduced gen investment + operation costs
  - Enhanced value for variable wind power
- Future work:
  - Account for both long- and short-run elasticity
  - Account for uncertain forecasts, lags between commitments and outcomes

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