The Complexity of Networked Resources: Lessons and Opportunities from the Service Sector

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Outline

- Common elements of service sector networks
- Regulated and deregulated markets
- Lessons from the electricity market
- Challenges for modelers

Networked Resources in the Service Sector

Industries:

- Finance
- Energy
- Communications
- Transportation
- Information
- Media
- Healthcare
- Public resources

Common Elements:

- Multiple agents
- Limited resources
- Complex interactions
- Increasing complexity
- Discontinuity in outcome
- Uncertainty in effect
- Individual needs

Results of Network Complexity

- Common failures
  - Financial - bubble, crashes, firm failures
  - Energy – blackouts, California crisis
  - Communications – regional losses
  - Health – epidemic spreads
  - Media – disinformation spreads
- Why?
  - Lack of central control
  - Lack of awareness, visibility
  - Interdependencies
- What to do?
  - New form of modeling
  - New analyses and computation

Complexity Increase Example: Regulated to Deregulated Markets

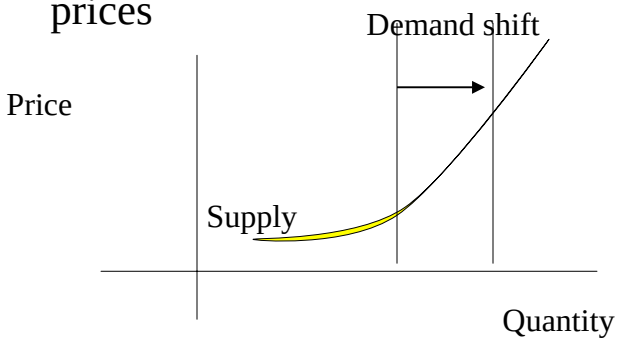
- Regulated
  - Single or few producers
  - Prices controlled by commission
  - Costs passed to consumers (eventually)
  - Little incentive for efficiency
- Deregulated
  - Multiple producers
  - Prices governed by market mechanism
  - Potential for market power (vary supply to manipulate price)
  - Questions about security (sufficient capacity)

Additional Issues in Electricity Markets

- Inelastic demand
- Variable demand
- Limited transmission capacity
- Limited (unavailable) storage capacity
- Rapid change – equilibrium appropriate representation?

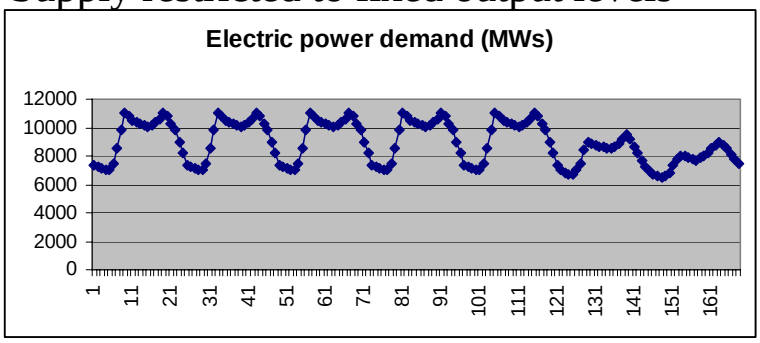
Inelastic Demand

- Demand increases can sharply increase prices



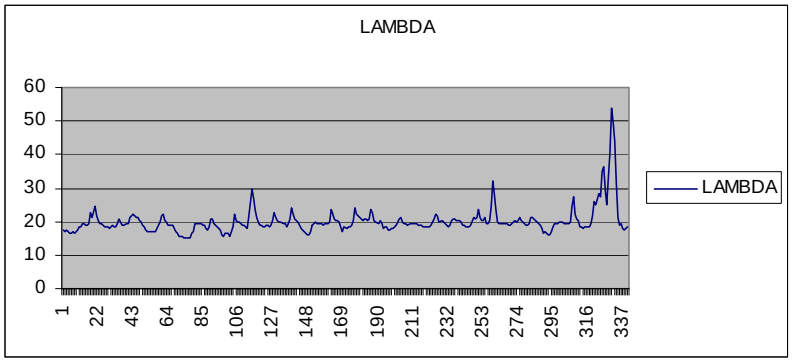
Supply/Demand Mismatch

- Demand varies continuously - often doubles (or more) during peak hours
- Supply restricted to fixed output levels



Result of Mismatch: Price Spikes

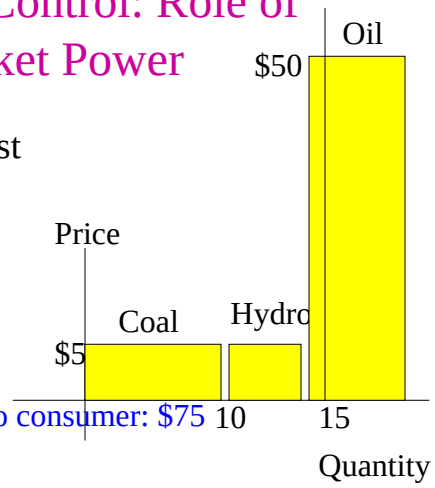
- California Power Exchange Data



Comparisons to Traditional Markets

- High Volatility
  - 10 to 100 times that of common stock
  - Prices from 0 to $10,000 per MWhr
- Difficulty in storage
  - Electricity close to un-storable
    - Difficulty substitution (liquidity)
  - Dynamics not consistent with previous models of prices

Change from Central Control: Role of Agents and Market Power



- Generators: Capacity, Cost
  - Coal, 10, $5
  - Oil, 10, $50
  - Hydro, 10, 0
- Demand: 15
- Cheapest dispatch
  - Hydro, 10; Coal, 5; Cost to consumer: $75
- Market power of hydro
  - Bid only 4 into market, now oil also used
  - Coal, 10; Hydro, 4; Oil, 1; Cost to consumer: $750

Change from Central Control: Anomalous Price Changes

Suppose 2 demand periods

Period 1 - demand=50

Period 2 - demand=100 or 200 equally likely

Capacities:

Hydro - 100 total

Coal - 60 at once

Oil - ∞

Costs:

Hydro – 0

Coal – 5

Oil - 50

Optimal Bids

Hydro - Bid only in Period 2, 100 at 5-ε

Coal - Bid 5

Oil - Bid 50

Result: Period 1 price=5; Period 2 price: 5-ε or 50

Lessons from Energy Market

- Must consider separate agents to find system behavior
- Multiple equilibria and lack of equilibria (dynamics)
- Uncertainty affect on observations, behavior
- Discontinuous effects
- Behavior may be counter-intuitive (so traditional controls have unintended consequences)
- Possibility for catastrophic failures

Modeling Needs

- Multiple agents
- Multiple "solutions"
- Combinations of discrete and continuous models
- Dynamic and transient behavior
- Uncertainty in observation and action – model of dynamics

Additional Challenges of Services

- Recognizing individual preferences
  - Examples: financial planning, health care planning, retail, education, entertainment
  - How to structure choices to find preferences?
  - How to do so implicitly?
  - How to accomplish on large scale?
  - How to incorporate into design of the service and pricing of the service?

Challenges (2)

- Interpreting data from large populations
  - Examples: Scanner data in retail, investor choices and tick-level price movements, medical procedures, monitor results and outcomes, learning in large organizations (and within individual)
  - How to use these datasets to design, improve decisions?
  - How to measure effects of different treatments, protocols, algorithms?

Challenges (3)

- Effects of organizational interactions
  - Examples: limited markets in finance, pricing in retail, multiple diseases in healthcare, limited audience attention in entertainment
  - How to incorporate many multiple agents with individual preferences (not necessarily observed) into decision system?
  - How to combine individual actions and choices on a large scale?

Challenges (4)

- Combining real-time, continuous actions with discrete changes in policies and preferences
  - Examples: Continuous trading in finance, continuous monitoring and control in healthcare
  - How to incorporate other techniques such as finite-element methods and continuous control with discrete preferences?
  - How to use learning in online processing?

Challenges (5)

- Nature of multiple interactions on model form: non-convexity and discontinuity
  - Examples: combinations of pricing and capacity decisions, multiple equilibria in markets, discontinuous learning outcomes, non-convex and complex physiological responses
  - How to optimize systems with multiple possible states?
  - How to model complex and chaotic transitions and responses (e.g., with gene mutations)?

Conclusions

- Modeling and controlling network resources requires:
  - Identifying preferences
  - Interpreting massive amounts of data
  - Incorporating organizational interactions
  - Combining continuous and discrete phenomena
  - Exploring multiple alternative states and complex interactions