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

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<tr>
<th>Price</th>
<th>Supply</th>
<th>Quantity</th>
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Supply/Demand Mismatch

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

Electric power demand (MWs)

11/10/2003 “Understanding Complexity” Workshop, Princeton University
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