

Analyzing strategic interaction in multi-settlement electricity markets: A closed-loop supply function equilibrium model

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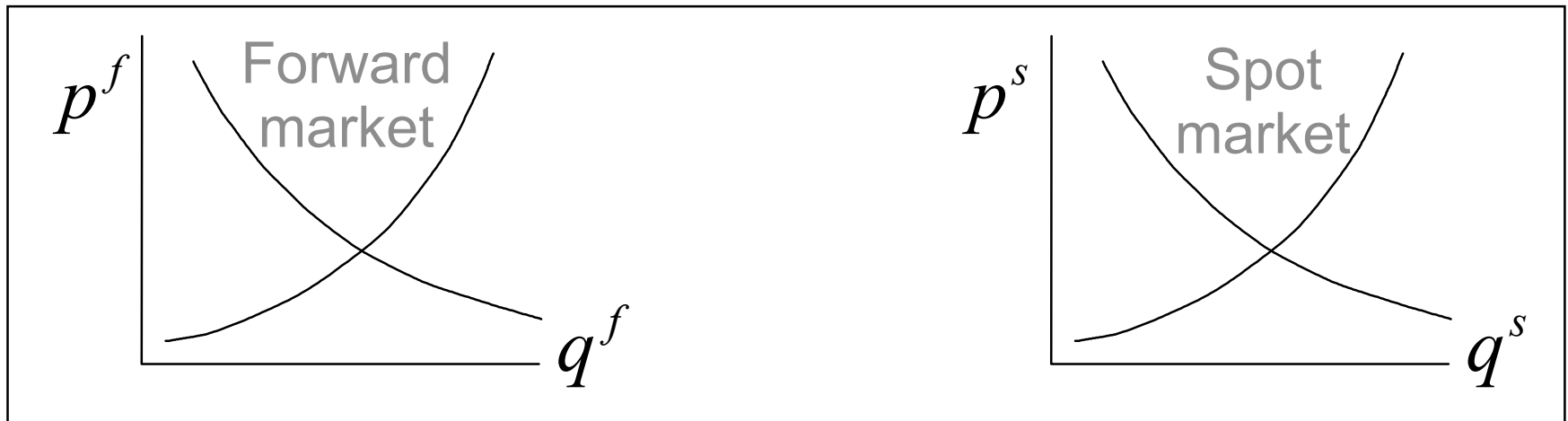
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The big picture

- Greater reliance on market incentives to guide economic activity--"Deregulation"
- Since ~1990, "restructuring" of many countries' electricity sectors
- **Market structure:** Potential for inefficient pricing with too few competitors
- **Market architecture:** Development of (inter alia) centralized *forward markets*, and *supply function (SF) bids*: $q_i \equiv S_i(p)$
 - "Multi-settlement market"
= *spot market* + (one or more) *forward markets*

Motivation

- At a (very high!) level of abstraction, a multi-settlement electricity market looks like this:



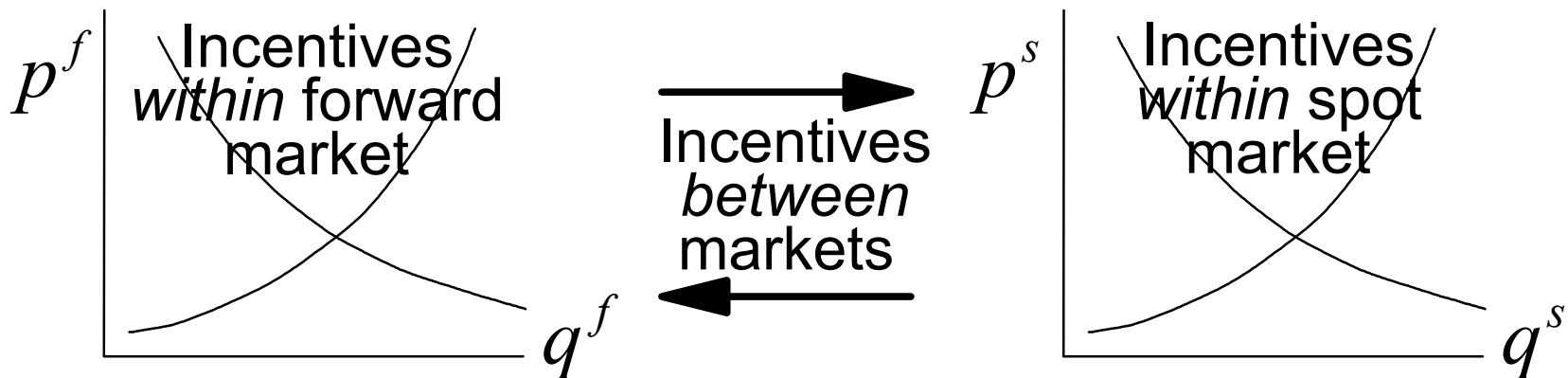
- California's forward market (PX) is defunct, but many other regional electricity markets feature a multi-settlement design

Motivation, cont'd

- I develop a model of supplier and consumer behavior that generates endogenously the outcomes we observe in such markets, namely,
 - *upward-sloping supply functions and*
 - *downward-sloping demand functions,*under uncertainty, in both forward and spot markets
- Provides necessary "machinery" to draw coherent distinctions between *market power*, *market manipulation*, and *opportunity cost pricing* in a multi-settlement market

The Problem

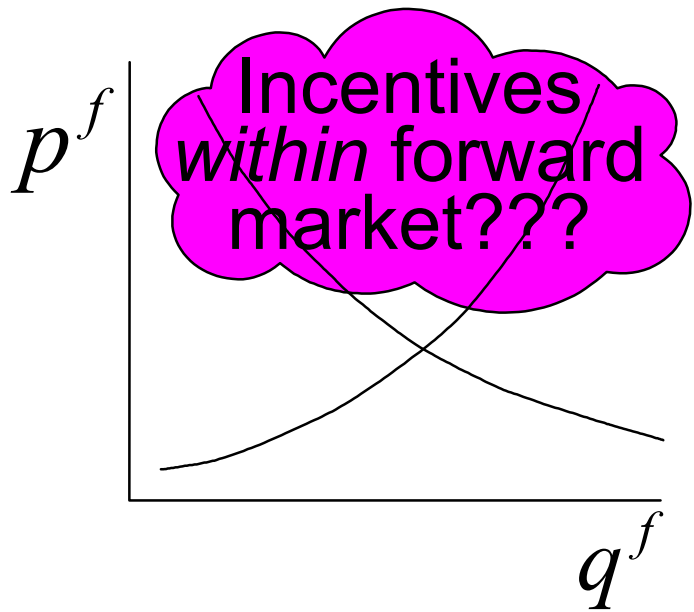
- In general terms:
 - *What should we consider "workable competition," given this **market structure** and **market architecture**?*
 - *Empirically, how would we recognize it?*
- In particular:
 - ***What incentives** do market participants face in competitive multi-settlement electricity markets, and on what do these incentives depend?*



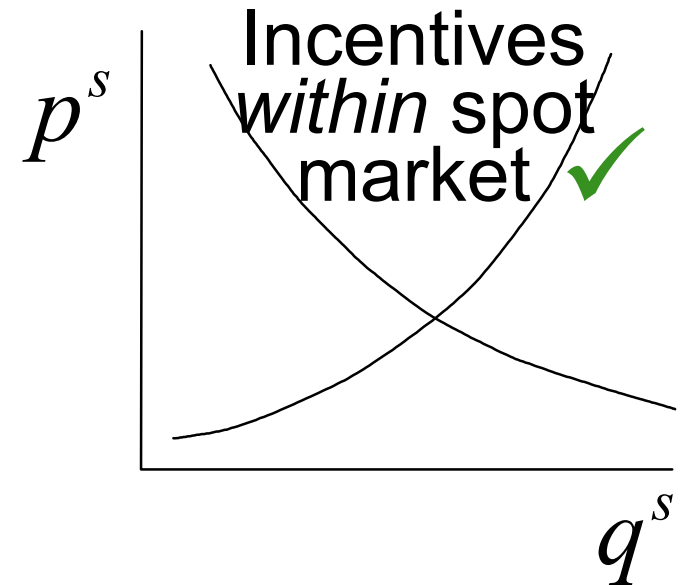
The Problem, cont'd

- Specifically:
 - *What is "the" **optimal forward market bid** for a supplier in this setting, and on what does it depend?*

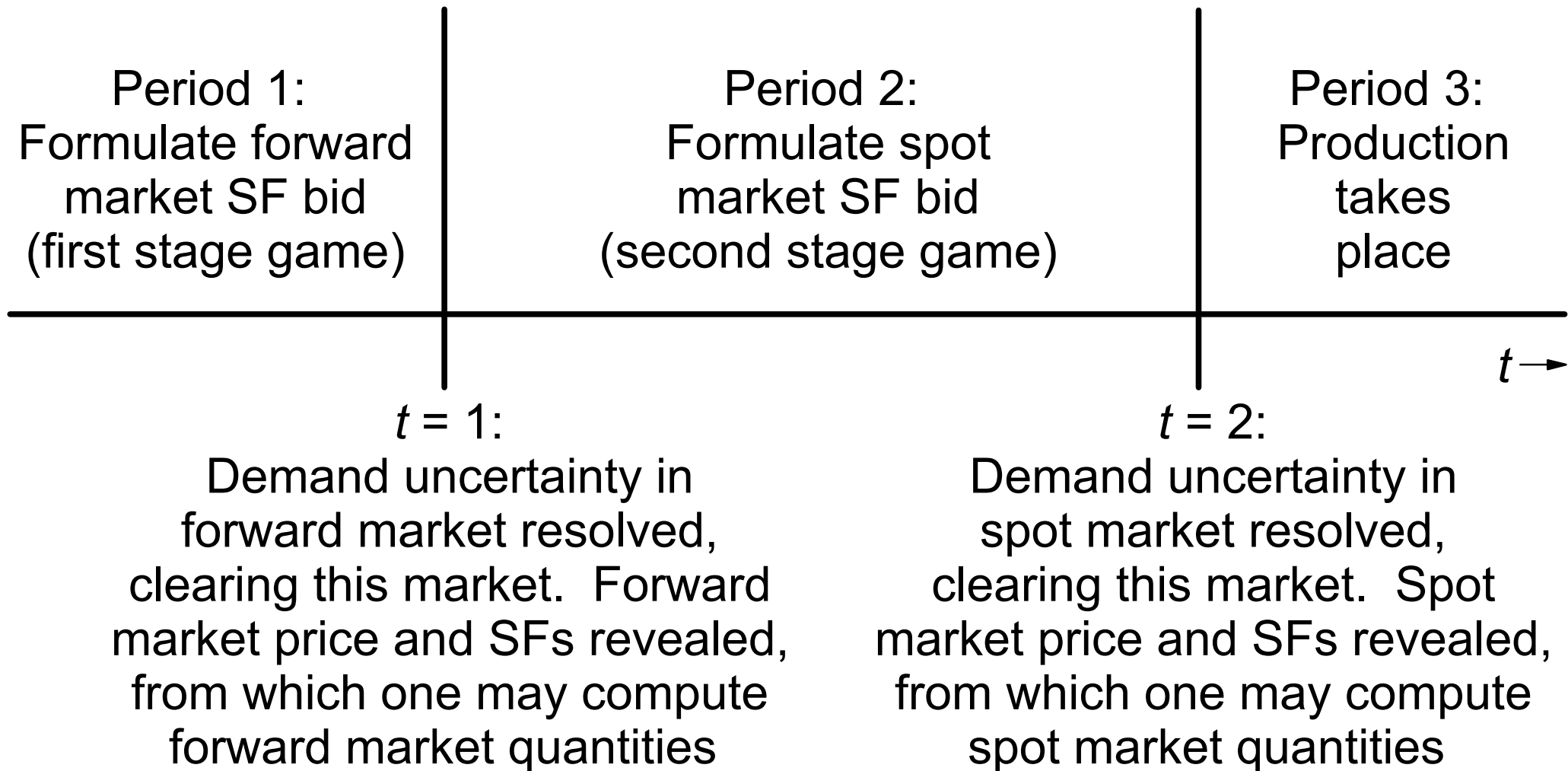
Summary of what is **known** and **unknown** from previous work



✓
→ Incentives *between* markets
←
???



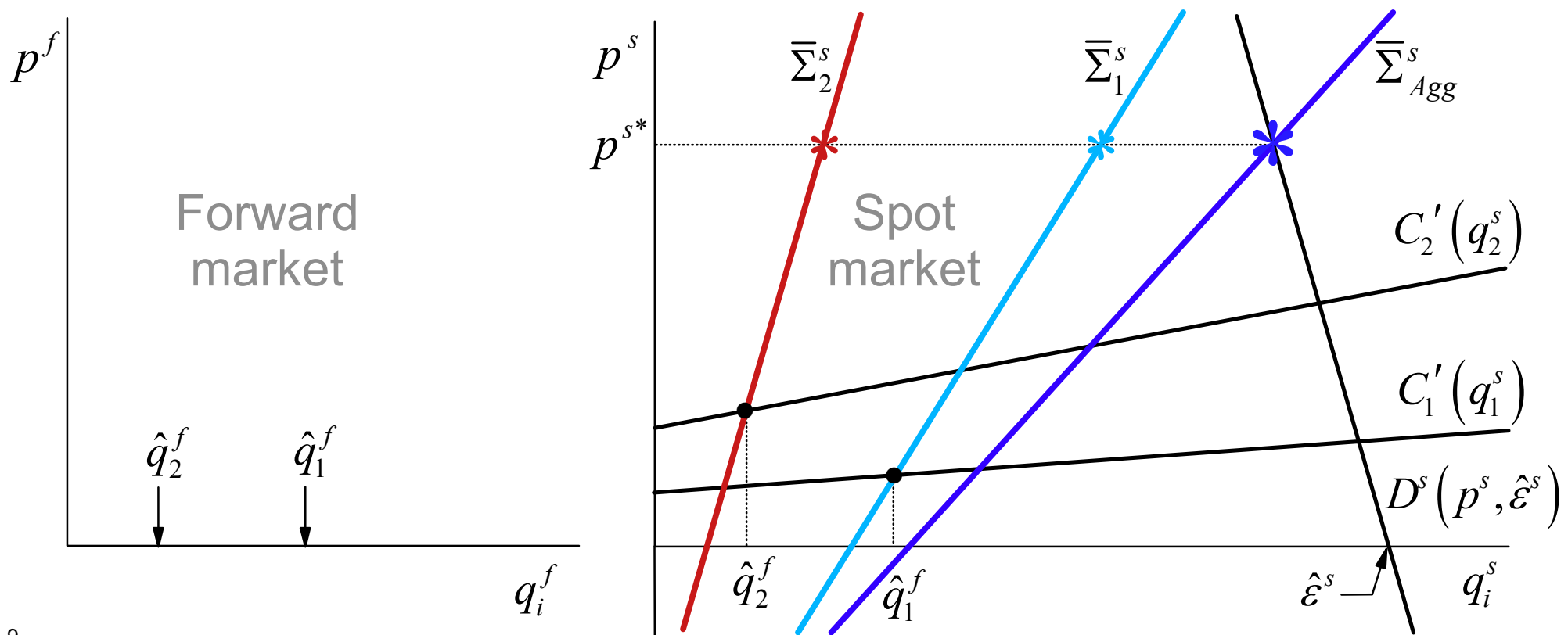
The multi-settlement market game



Solution algorithm: Backward induction

Spot market results - simplified affine example

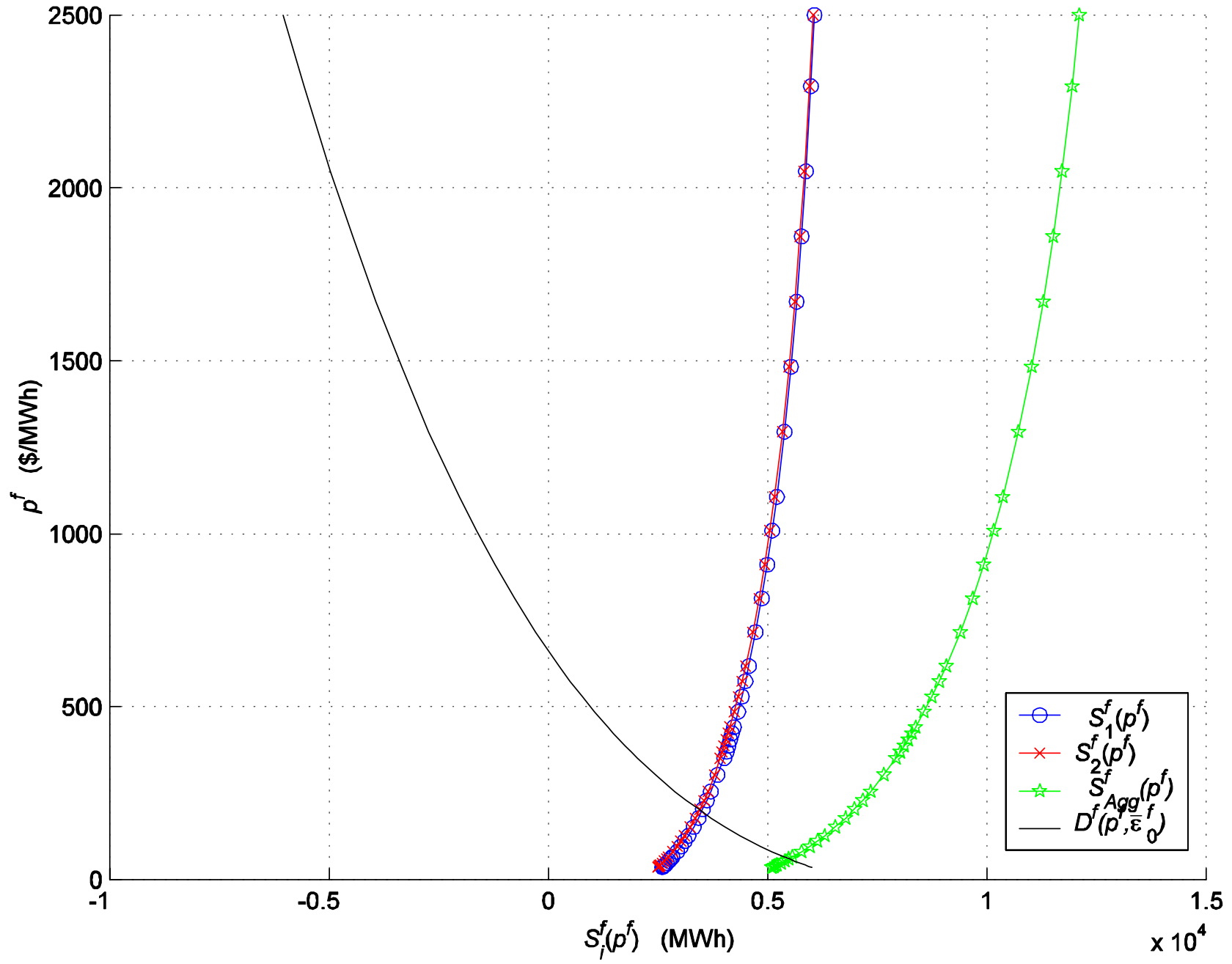
- Assume *affine* demand, marginal cost, and spot market SF $\bar{\Sigma}_i^s \left(p^s; \hat{q}_i^f, \cancel{\hat{q}_j^f} \right)$
- For realized forward quantities \hat{q}_i^f and spot market demand shock $\hat{\varepsilon}^s$, we find:



Demand specification

- A nested optimization problem produces endogenous spot and forward market demand by end-use consumers. . .
- Spot market optimization:
 - *Maximize consumer surplus from consumption of "amenities," produced by consumer using electricity*
- Forward market optimization:
 - *Maximize a risk-averse mean-variance utility function over consumer surplus and forward market cashflows*

Equilibrium in the forward market



Numerical welfare results

- Three models studied are ranked as theory would predict. Namely, from lowest to highest expected welfare, we have
 - *Single-market SFE*
 - *Multi-settlement market SFE*
 - *Perfect competition (single market - efficient solution)*

Decomposing suppliers' incentives for forward market activity

- Incentive for forward market activity
 - = Direct effect
 - + Settlement effect
 - + Strategic effect

Interpreting forward market behavior

- A "*prisoner's dilemma*": Both firms have an incentive to sell forward, but when both do so, both end up worse off
- Result is a *battle over (expected) market share* (in both markets)
- Forward market activity (up to a point) increases own profits and results suggest that an increase in one firm's forward market activity decreases its rival's profit

Other Findings

- Assessing competitiveness of the *forward* market requires evaluating behavior in *both* forward and spot markets
- Forward market positions (whether due to SF or quantity competition) create *strategic commitments* that influence rivals' later actions and hence spot market outcomes
- Perfect inter-market price arbitrage is not a necessary implication of profit maximization
- Price caps on forward contracts could be counterproductive, in welfare terms

Potential future extensions

- Inter-market price arbitrage
- Market power: Perfectly competitive behavioral benchmark (PCBB) in forward market
- >2 strategic firms
- Disclosure / observability of forward contract positions
- Market manipulation: could operationalize via distributional parameters
- Robustness of results under more realistic modeling assumptions