Sequential Markets, Market Power and Arbitrage

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Sequential Markets

- Many goods are sold in a sequence of markets or auctions.
  - Agricultural products, treasury auctions, wine auctions, etc.
  - Often called "forward" and "spot" markets.

- **Key:** same good at same delivery date, several opportunities to buy or sell before delivery.

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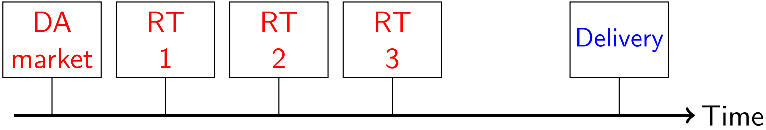

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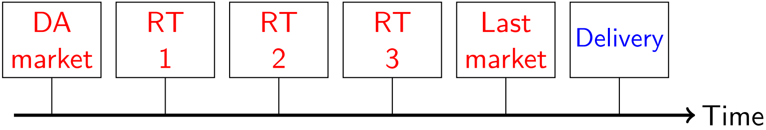
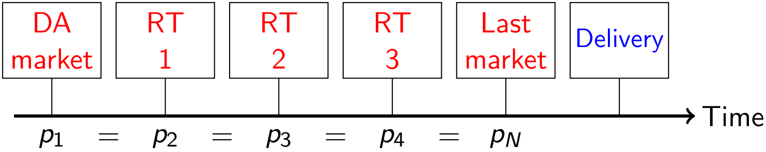
- Subsequent markets open to re-allocate production and re-optimize hourly plans.
- Supply and demand need to be balanced at the delivery.



Price Differences in Sequential Markets

- In a stylized setting, price differences should go away
- However, empirically, we do not see it in many markets



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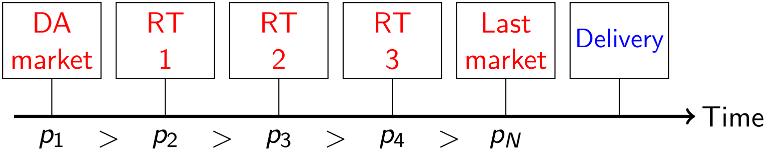
- However, empirically, we do not see it in many markets
- Most electricity markets exhibit systematic price differences
  - PJM, NY, New England, Midwest, CA, Iberian etc.



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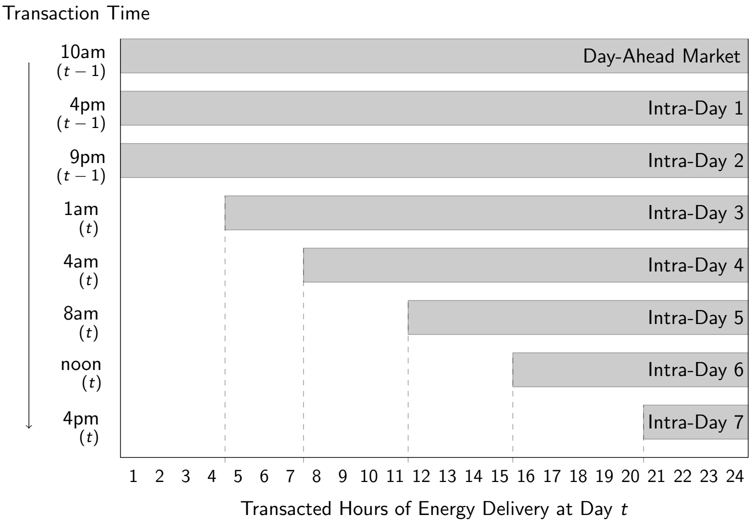
- **Empirics:** We examine firms' strategic behavior by using data from the Iberian electricity market
  - Hourly bids and production data at the power plant unit level
  - We also exploit the unique market structure

Sequential Markets in the Iberian Market



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- Moreover, full arbitrage is not necessarily welfare enhancing
  - True even if the transaction costs of arbitrage are zero
- **Empirics:** We use welfare counterfactual analysis to show it

Related Literature

Sequential Markets and Arbitrage

- Lazear (1986); Allaz and Vila (1993); Salant (2011); Coutinho (2013).
- Saravia (2003); Borenstein, Bushnell, Knittel and Wolfram (2008); Jha and Wolak (2013); Birge, Hortacsu et al. (2013).

Market Power

- Borenstein, Bushnell and Wolak (2002); Kim and Knittel (2006); Puller (2007); McRae and Wolak (2014).

Contributions

1. **Theory:** Develop a framework to explain systematic price differences due to market power and limits to arbitrage.
2. **Empirics:** Use high-frequency micro-level data in electricity markets to test theoretical predictions.
3. **Welfare counterfactual:** Examine welfare implications of relaxing limits to arbitrage with a structural model.

Part 1: Basic Setup

A Model of Sequential Markets

- Consider two sequential markets.
- Consider a large supplier with cost c.
- All energy is allocated in the first market (day-ahead).
- The second market is for re-shuffling (real-time).
- Residual monopolist faces demands,

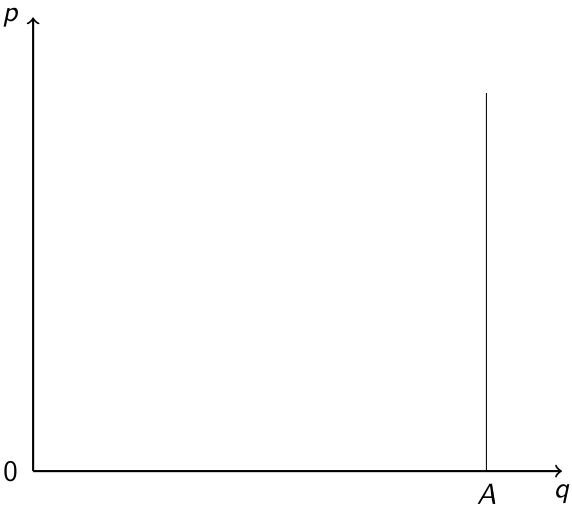
$$D_1(p_1) = A - b_1 p_1, \quad D_2(p_1, p_2) = b_2(p_1 - p_2).$$

Interpretation of Residual Demand

$$D_1(p_1) = A - b_1 p_1, \quad D_2(p_1, p_2) = b_2(p_1 - p_2).$$

- Residual demand at day-ahead can be interpreted as inelastic demand A minus supply curve by other firms, $b_1 p_1$.
- Interpret $b_1 p_1$ as fringe suppliers pricing at marginal cost.
- In second market, production can re-adjust along the marginal cost curve.
- Note: typically, real-time market less responsive, $b_2 < b_1$.

Intuition as Dynamic Monopolist, $b_1 = b_2$



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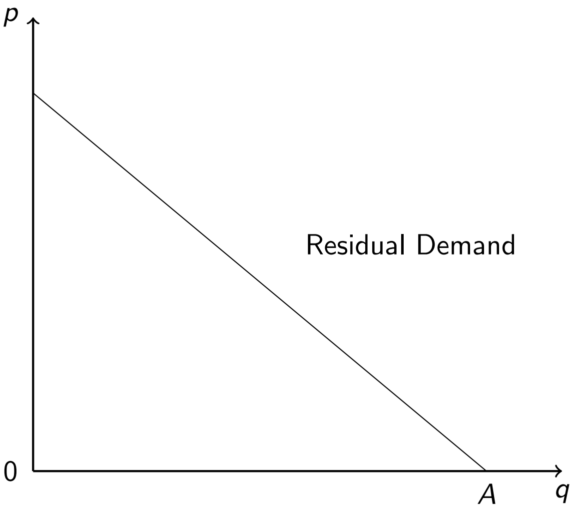

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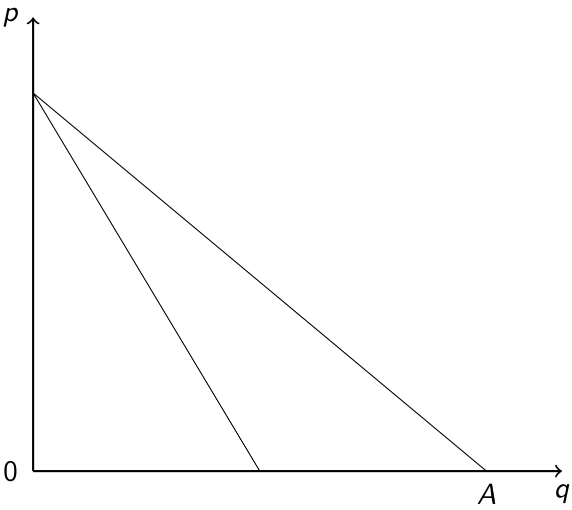

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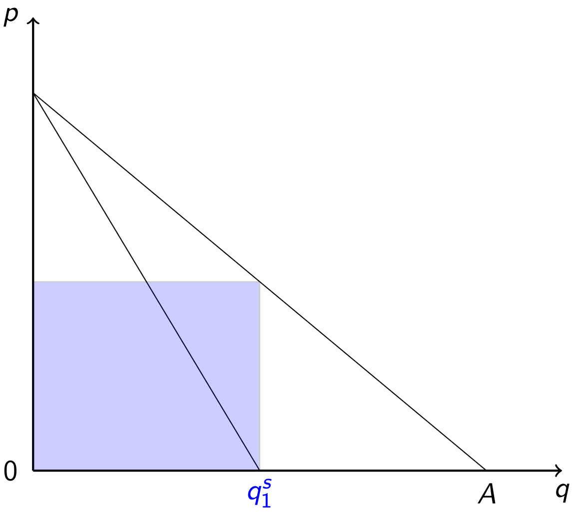

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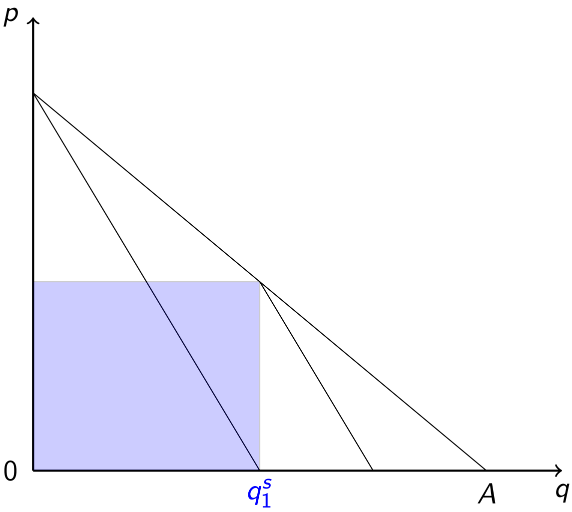

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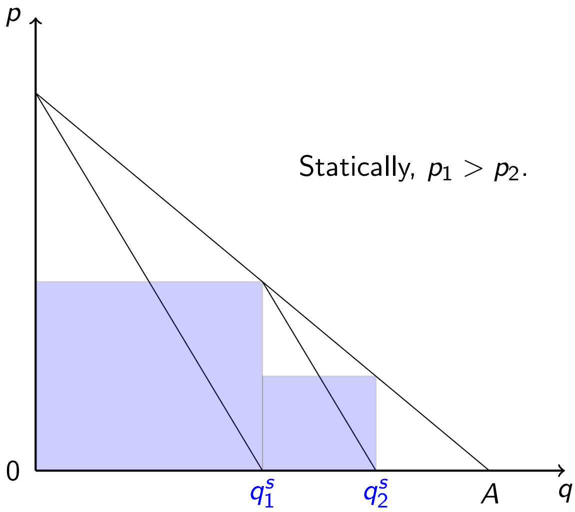

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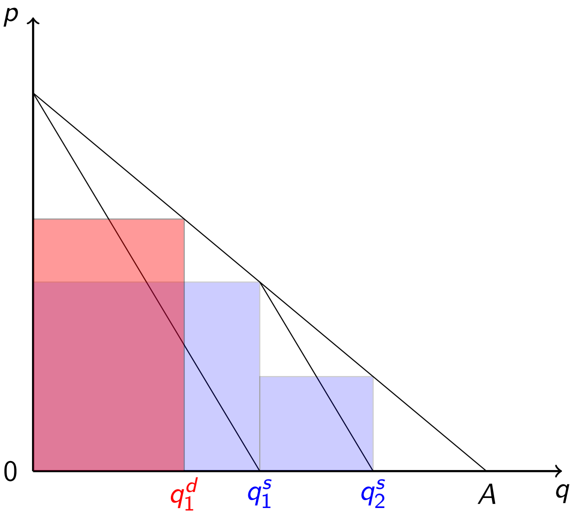

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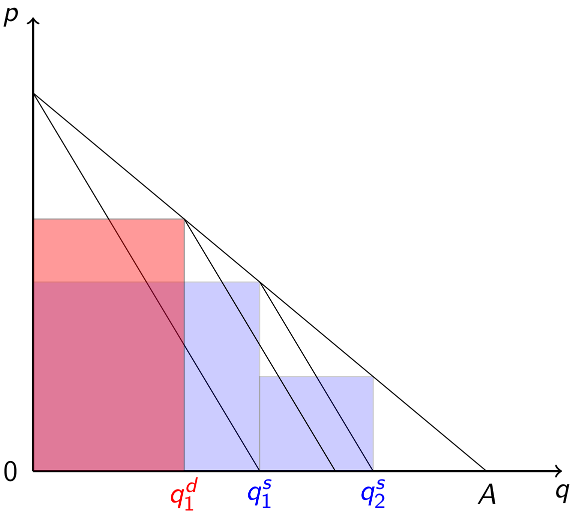

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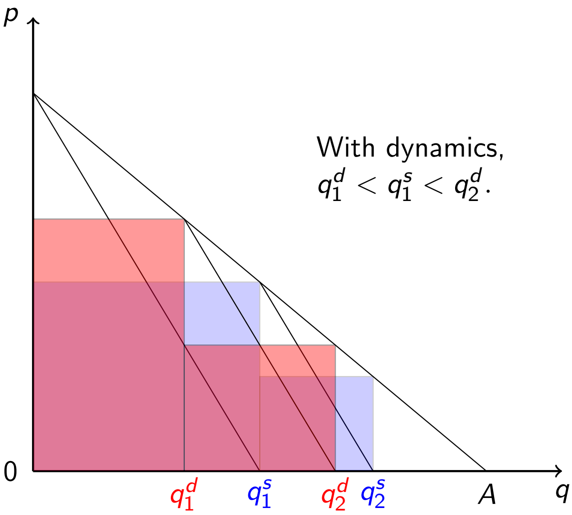

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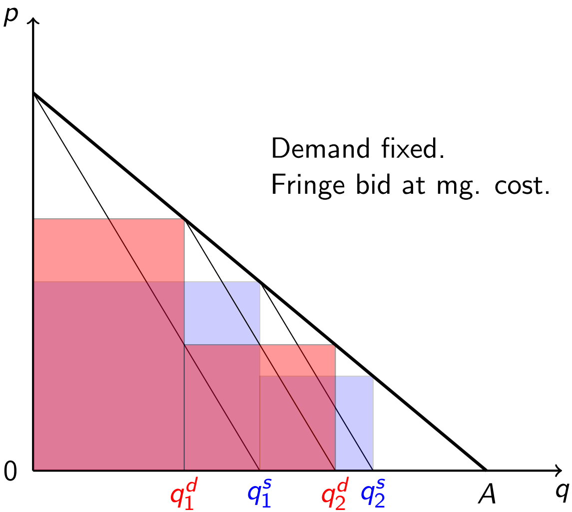

What could prevent arbitrage from demand?

- Day-ahead market plans for all expected demand.
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  - Some demand agents can arbitrage, but in a limited fashion.

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- Day-ahead market plans for all expected demand.
  - Electricity cannot be stored economically in large amounts.
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- Equivalent to procurement auction in which auctioneer commits to allocating all quantity in a first market, and allows for secondary trade (e.g. Treasury auctions).

What could prevent arbitrage from suppliers?

- A key assumption in the simple model is that competitive producers just offer marginal cost curve.
- In practice, firms can (and *do*) engage in arbitrage.
- However, subject to limitations:
  1. Bidders need to have a physical asset to back their offers to generate (no virtual trading)—cannot bid larger than capacity.
  2. Large swings in physical schedule discouraged by the regulator.

Arbitrage by wind farms

- Wind is a technology particularly suited for arbitrage, even in the presence of institutional constraints.

- *Ability* to arbitrage:
  1. Capacity constraints are almost never binding.
  2. Less regulatory scrutiny, due to the inherent uncertain nature of its production (up to a certain limit).

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- *Incentives* to arbitrage: if competitive.

In the Paper

- Theoretical predictions under different scenarios:
  - No arbitrage (baseline).
  - Full arbitrage.
  - Limited arbitrage (physical/regulatory constraints).
  - Strategic arbitrage (endogenous limited arbitrage).
  - Case with large firm vs small wind farm.

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  - Case with large firm vs small wind farm.
- Important aspects in common:
  - Declining price path (except full arbitrage).
  - Withholding by monopolist in the forward market (*even* with full arbitrage).
  - Prices above marginal cost of monopolist.

Summary of Predictions

- Institutional constraints on arbitrage and market power can give raise to declining prices,

$$p_1 > p_2 > \cdots > p_N.$$

- The price premium will be larger when:
  - Demand is large (A).
  - The residual demand in the first market is inelastic (b_1).
  - The residual demand in the second market is elastic (b_2).

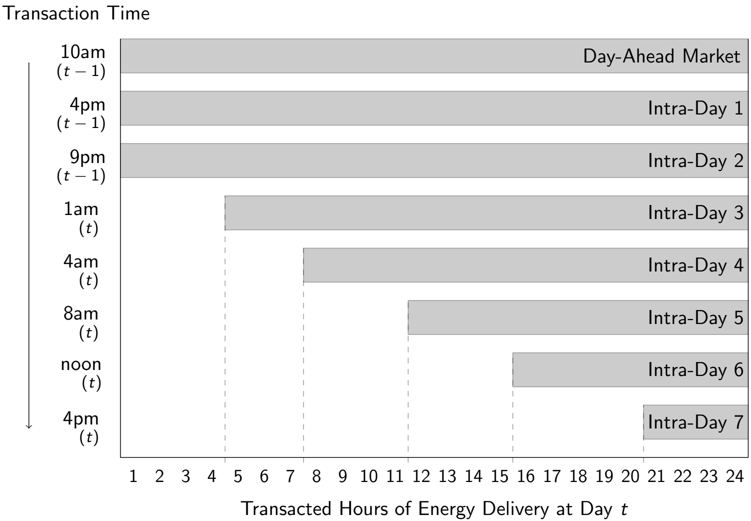
- Firms may arbitrage some of these price differences,
  - *incentives* only if they do not have market power.

Part 2: Empirical Application

The Iberian Wholesale Electricity Market

- Sample: 2010-2012.
- Day-ahead and up to seven intra-day markets.
- Unit level equilibrium outcomes for each market.
- Detailed bidding data at the unit level (strategies).
- An interesting mix of dominant firms and fringe firms
    1. Four dominant firms (roughly 70% of market share)
    2. Many competitive fringe firms

Sequential Markets in the Iberian Market



Summary Statistics

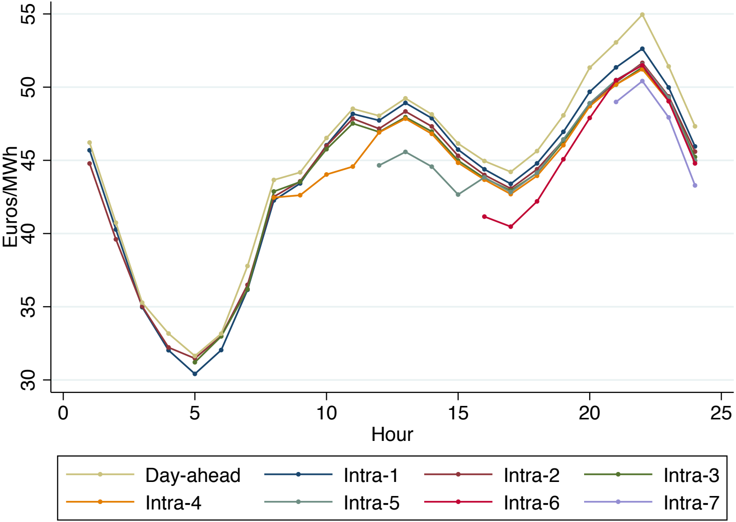
	Mean	SD	P25	P50	P75
Price Day-ahead (p_1)	44.7	14.1	38.6	48.0	53.5
Price Intra-day 1 (p_2)	43.8	13.9	38.0	46.2	52.5
Day-ahead premium ($p_1 - p_2$)	0.9	4.0	-0.4	0.5	2.6
Slope of DA Res. Demand (b_1)	343.2	102.9	281.9	316.4	369.9
Slope of I1 Res. Demand (b_2)	69.9	24.6	54.5	66.2	80.7
Demand Forecast (A)	29.3	5.2	24.8	29.4	33.3
Wind Forecast (q^w)	5.0	2.8	2.8	4.5	6.7

Notes: $N = 35,040$ hours. Prices in Euro/MWh. Slopes in MWh/Euro. Demand and wind forecasts in GWh.

Empirical exploration

1. Are there systematic price differences in the sequential markets?
2. Are they related to market power?
3. Do firms respond to price arbitrage opportunities?
   - Dominant firms
   - Competitive fringe firms

1. Are there systematic price differences?



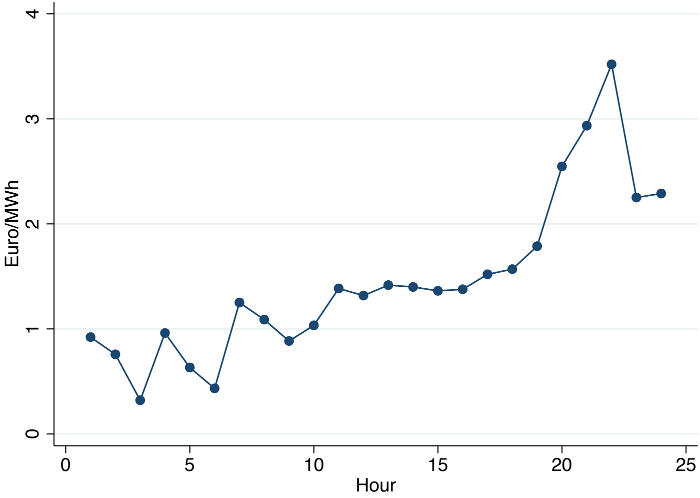
- Forward-market price premium ($P_{DA} > P_{I1} > ... > P_{I7}$)

2. Are they related to market power?

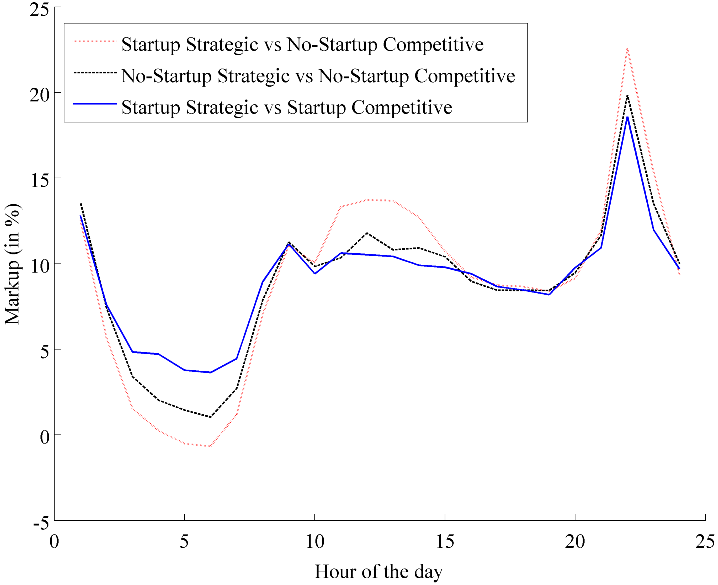
- Hours with more ability and incentives to exercise market power exhibit higher premia.
- Direction of premium in Spain consistent with market power on the sellers' side. What about the relative size across hours?

1. Compare $p_1 - p_2$ to traditional measures of market power.

Price Premium



Markups (Reguant, 2014)



2. Are they driven by market power?

- Hours with more ability and incentives to exercise market power exhibit higher premia.
- Direction of premium in Spain consistent with market power on the sellers' side. What about the relative size across hours?

1. Compare $p_1 - p_2$ to traditional measures of market power.
2. Regress $p_1 - p_2$ to predictors of market power.

Regress Price Premium on Predictors of Market Power

$$\Delta \ln p_{ht} = \alpha + \beta A_{ht} + \gamma_1 b_{1ht} + \gamma_2 b_{2ht} + \phi X_{ht} + u_{ht}$$

	(1)	(2)	(3)	(4)	(5)
Demand Forecast (GWh)	0.132	0.135	0.103	0.098	-0.002
	(0.025)	(0.025)	(0.025)	(0.024)	(0.039)
Slope of Residual Demand in Day-Ahead Market		-0.019	-0.024	-0.040	-0.090
		(0.003)	(0.003)	(0.003)	(0.014)
Slope of Residual Demand in Intra-Day Market			0.050	0.065	0.241
			(0.008)	(0.009)	(0.050)
Wind Forecast (GWh)				0.365	0.786
				(0.039)	(0.121)
Observations	26145	26145	26145	26145	26093
IV	No	No	No	No	Yes

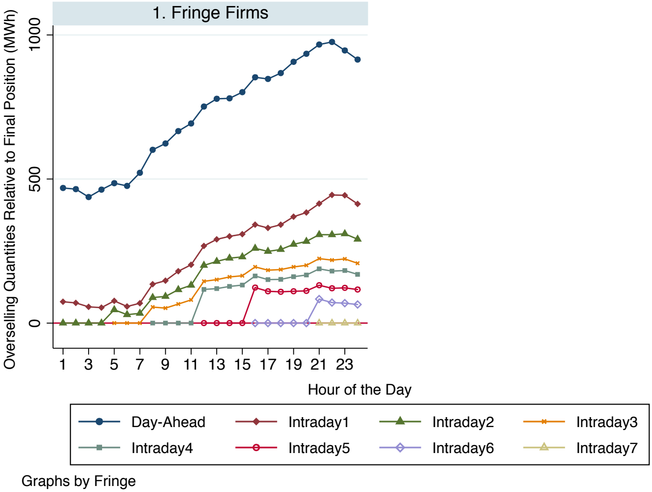
1. Higher demand correlates with higher premium.
2. More elastic DA res. demand correlates with lower premium.
3. Less elastic RT res. demand correlates with lower premium.

3. Do firms respond to price arbitrage opportunities?

- Two types of firms in the market:
  - Dominant firms that own wind and traditional power plants
  - Competitive fringe that own only wind

- Do firms oversell in forward markets relative to final position?
  1. Production from wind farms (q^w)
  2. Production from all power plants (Q)

Overselling in forward markets: Wind farms



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- Fringe wind farms arbitrage by overselling in forward markets

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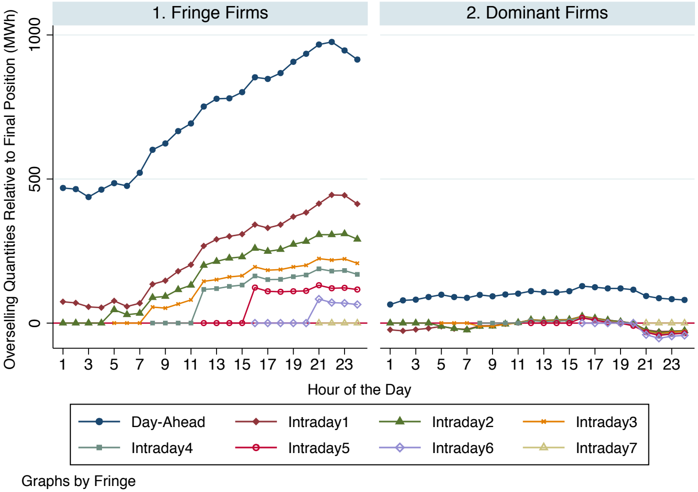

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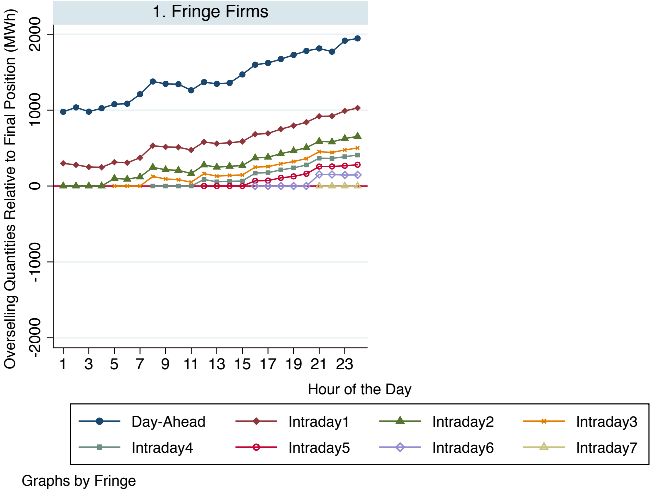

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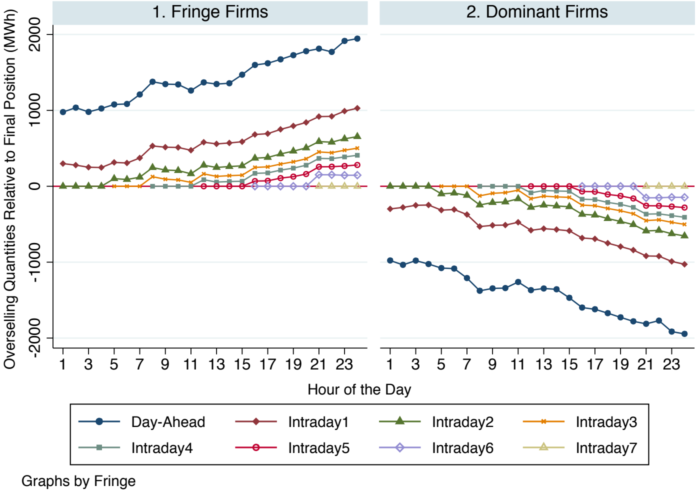

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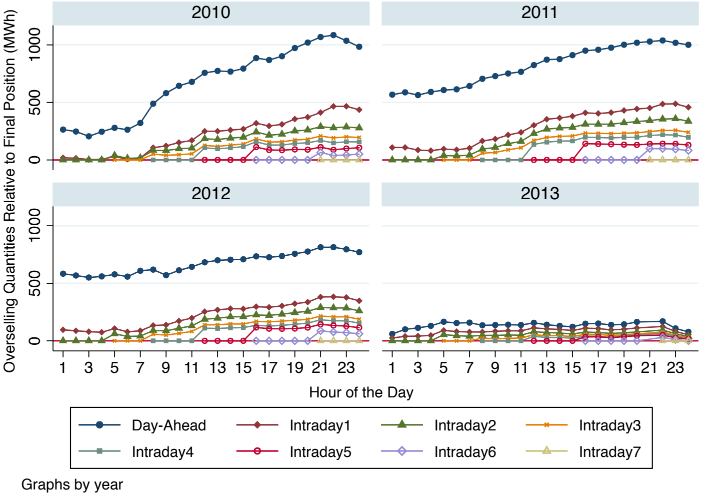
The Effect of Policy Change in 2013: Fringe wind farms



- After 2013, wind farms received a rate that is not linked to market price
- We exploit this quasi-experiment to test if they stopped arbitrage

Heterogeneity in Arbitrage by Fringe and Dominant Firms

$$\Delta \ln q_{jhtk} = \alpha + \beta \Delta \hat{p}_{htk} + \theta_j + \lambda_t + u_{htk}, \quad \text{with } k = \{\text{DA}, \text{I1}\}$$

By Power Plant Types

	Wind	Cogen	Demand	Thermal	Hydro	Solar	All Tech
Fringe Firms	0.098 (0.006)	0.027 (0.003)	0.026 (0.002)	-0.006 (0.003)	0.034 (0.009)	0.007 (0.007)	0.057 (0.003)
Dominant Firms	0.006 (0.005)	-0.000 (0.003)	0.000 (0.001)	-0.024 (0.004)	-0.003 (0.003)	0.006 (0.005)	-0.131 (0.010)

- Fringe firms use wind, cogent, demand, hydro for arbitrage
- Arbitrage by wind is the largest

Summary of empirical evidence

1. Are there systematic price differences in the sequential markets?
   - Systematic forward-market price premium
2. Are they related to market power?
   - Consistent evidence using several methods
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- What are the welfare effects of sequential markets from a market power point of view?
- Does arbitrage improve welfare?

Part 3: Welfare Counterfactual Analysis

Counterfactual Model

- Extends theoretical framework:
  - 4 strategic firms, 2 sequential markets.
  - Firms play Cournot, taking residual demand as given.
  - Marginal cost curve represented as a piece-wise linear function.
  - Uncertainty about exact demand A in period 2.

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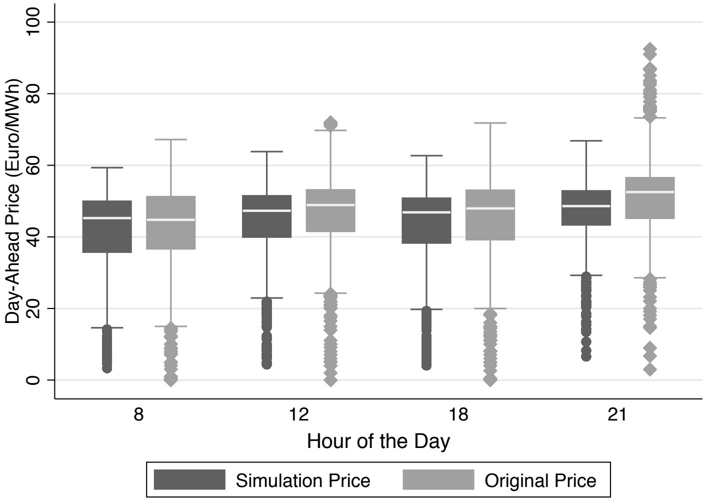
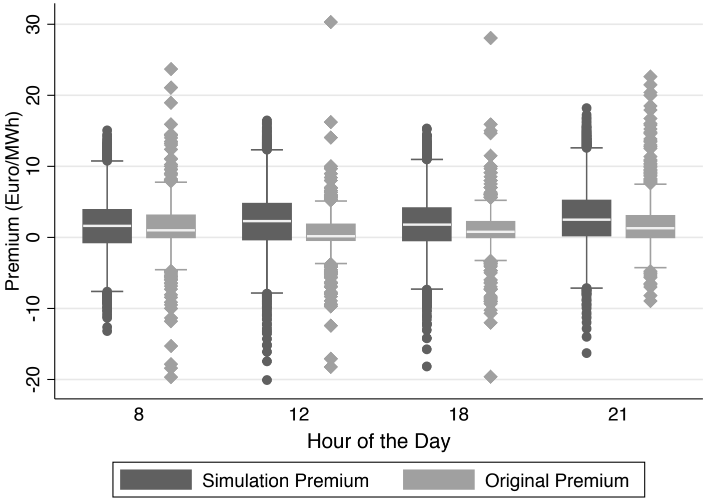
- Solved by backward induction.

Baseline Prices



Baseline Premium



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- Arbitrage by wind farms is potentially inefficient, as it makes wind planning harder.

- **Policy implication 1**: Better to decouple wind planning from arbitrage, with financial bidders (Jha and Wolak, 2014).

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- **Policy implication 2**: Arbitrage does *not* necessarily improve efficiency.

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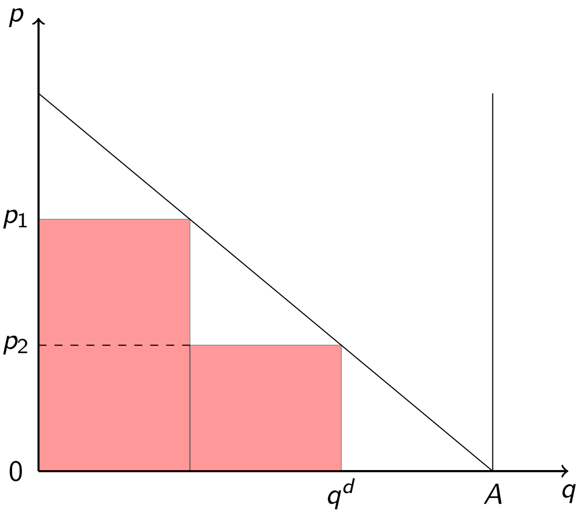

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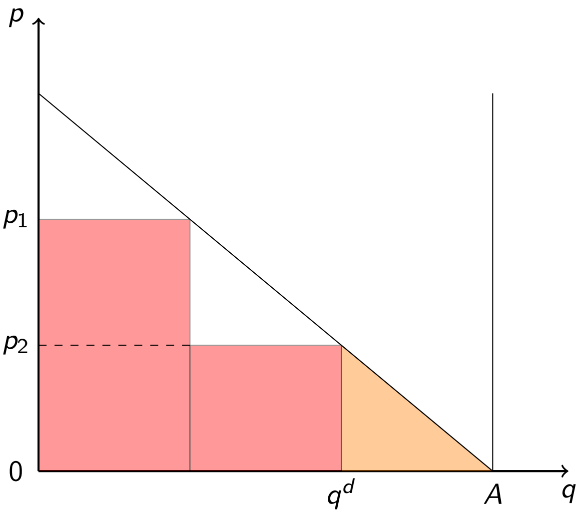

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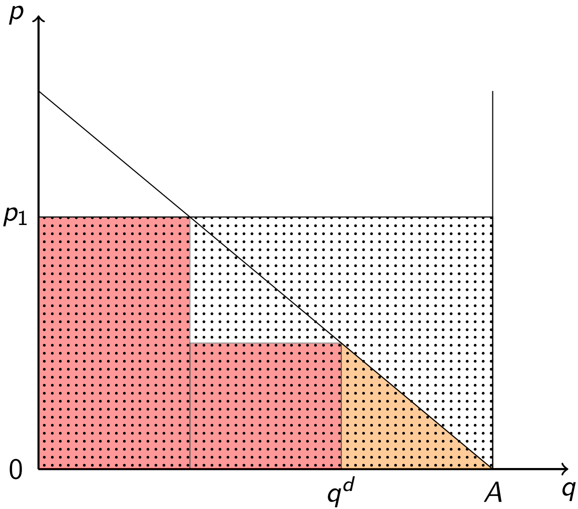

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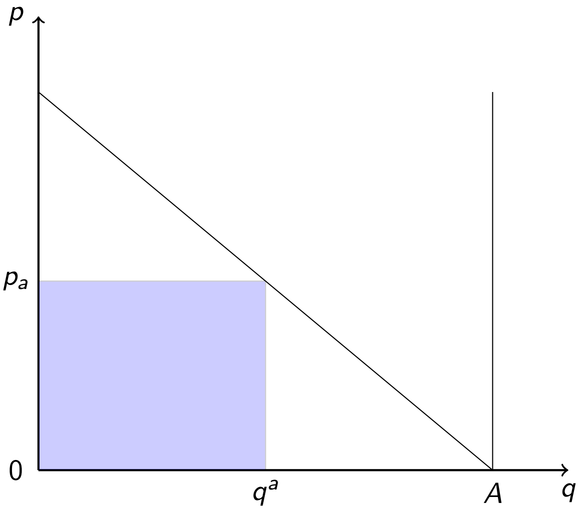

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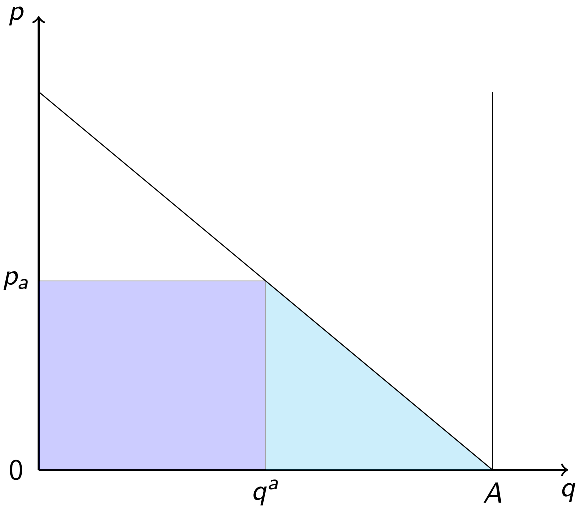

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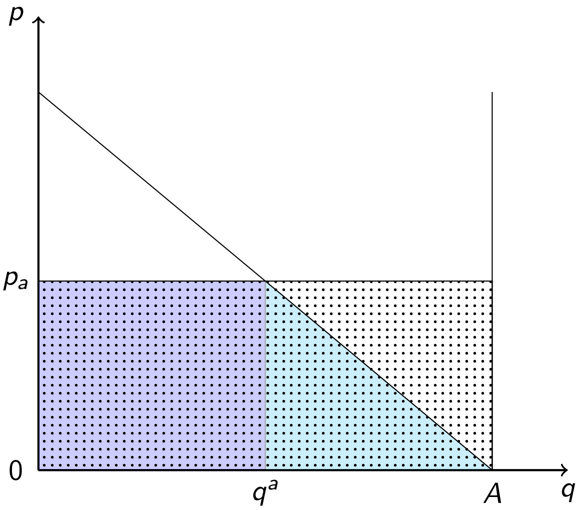

Counterfactual Experiments

- **Wind Arbitrage (Baseline):** Wind farms overbid by 20%.
- **Full Arbitrage (Single Market):** Perfect full arbitrage with no dynamic costs.
- **Sequential Market, No Arbitrage:** Zero arbitrage, maximal price discrimination.
- **Sequential Market, Strategic Arbitrage:** Profit-maximizing single arbitrageur.

Implied Arbitrage by Alternative Models

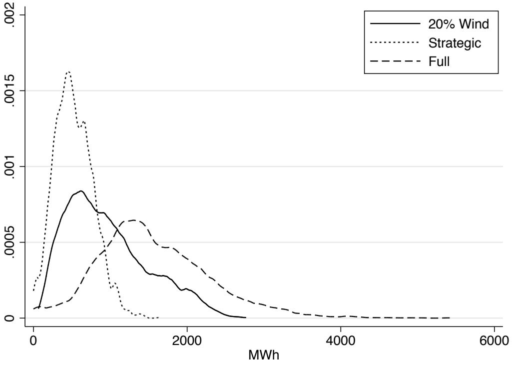

Figure: Strategic vs. Full Arbitrage for $b_2 < b_1$

Hourly Welfare Comparison Across Counterfactuals

	p_1	p_2	Premium (E/MWh)	Q_1 (GWh)	$Q_1 + Q_2$ (GWh)	Dominant Profit (000E)	Δ Ineff. from FB (000E)	Δ Cons. Cost from FB (000E)
First best (b_1)	-	38.2	-	-	15.3	60.5	-	-
Spot only (b_1)	-	46.5	-	-	12.8	123.2	17.2	265.5
Case $b_2 = b_1$								
No arbitrage	45.1	39.5	5.6	13.2	14.9	122.0	1.3	221.8
Str. arbitrage	44.6	40.2	4.4	12.0	14.7	119.0	1.7	204.3
Wind 20%	44.7	39.9	4.9	12.4	14.8	116.4	1.5	210.3
Full Arbitrage	42.5	42.5	0.0	7.7	14.0	100.7	4.8	138.0
Case $b_2 < b_1$								
No arbitrage	44.0	38.7	5.3	13.6	13.9	112.3	5.8	186.1
Str. arbitrage	43.8	40.3	3.5	13.1	13.8	111.4	6.2	180.8
Wind 20%	43.7	41.5	2.2	12.7	13.8	110.0	6.4	178.4
Full Arbitrage	43.5	43.5	0.0	12.2	13.7	108.3	7.1	170.3
Original Data	46.0	44.8	1.3	12.1	13.8	-	-	-

- Two sequential markets contribute to a better allocation. Allaz and Vila (1993) mechanism (requires at least two firms).

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- Sequential markets reduce costs by 1-2% exclusively due to reductions in market power.

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- Full arbitrage minimizes costs to consumers, but not production costs.

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- Price reductions can be substantially limited if the secondary market is not responsive.

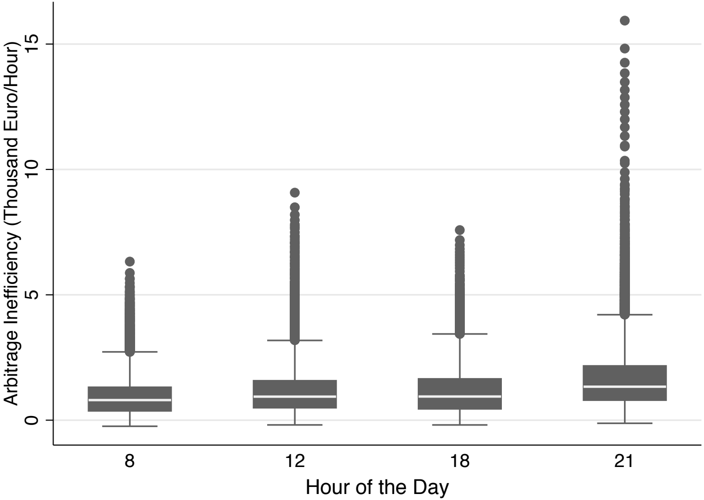
Implications

- Sequential markets improve allocation versus single market.
  - With several firms, it reduces their market power (Allaz and Vila, 1993).

- Institutional design allocates demand in the first market, and discourages arbitrage, preventing full arbitrage.

- Welfare effects of full arbitrage under imperfect competition:
  - Full arbitrage is not necessarily welfare improving in the presence of market power
  - Because it reduces productive efficiency.

Inefficiencies from Arbitrage (Full vs. No Arbitrage)



Conclusions

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- **Empirics**: Evidence from the Iberian electricity market
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- **A key policy implication**: Price equalization between forward and spot is not a sufficient indicator of an efficient market.

- Furthermore, full arbitrage is not necessarily welfare improving in the presence of market power.

Thank you!

Questions? Comments?

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